EXCEEDING THE VISION:
FOREST MECHANISATION OF THE FUTURE

Proceedings of the
52nd International Symposium
on Forestry Mechanization

6-9 October 2019 – Sopron, Hungary/Forchtenstein, Austria

Editor
Dr. Imre Czupy

Scientific Committee

Prof. Dr. Raffaele Cavalli
Prof. Woodam Chung
Prof. Dr. Hans Rudolf Heinimann
Prof. Dr. Tadeusz Moskalik
Prof. Dr. Tibor Pentek
Dr. Dominik Röser
Prof. Dr. Karl Stampfer
Prof. Dr. Rien Visser
Dr. Imre Czupy

Citation recommendation:
I. Czupy (2019): Exceeding the Vision: Forest Mechanisation of the Future. Proceedings of the 52nd International Symposium on Forestry Mechanization. Sopron, Hungary 2019. e-book 651p.

ISBN 978-963-334-343-2



Copyright © University of Sopron Press, Sopron, Hungary 2019.

Responsible publisher: Tibor Alpár vice-rector

K01 Keynote 01

OPPORTUNITIES IN REMOTE SENSING OF FORESTS RELATED TO THE ARRIVAL OF THE SENTINEL-2 SATELLITE
Clement Atzberger
BOKU

TRACTION VERSUS GROUND PROTECTION
Josef Primus
PEWAG Austria

CONDUCTING SUSTAINABLE FOREST OPERATIONS WHILE MINIMIZING ENVIRONMENTAL IMPACTS: A COMPILATION OF RESEARCH
Chad Bolding
Virginia Tech, USA

S01 Tech4Effect
Knowledge and technologies for effective wood procurement

ASSESSING CABLE TENSILE FORCES AND MACHINE TILT OF WINCH-ASSISTED FORWARDERS ON STEEP TERRAIN UNDER REAL WORKING CONDITIONS

Thomas Holzfeind, Christian Kanzian, Karl Stampfer, Franz Holzleitner
Institute of Forest Engineering, University of Natural Resources and Life Sciences, Vienna, Austria

PRODUCTIVITY AND FUEL CONSUMPTION OF HEAVY FORWARDERS UNDER DIFFERENT CONFIGURATIONS: BENCHMARKS FROM FLEET-LEVEL LONG-TERM RECORDS (ONE MILLION LOADS)

Raffaele Spinelli [1,2], Angelo Conrado de Arruda Moura [3]
[1] CNR IVALSA, Firenze, Italy; [2] University of the Sunshine Coast, Marochydoore, QLD, Australia; 3) Suzano, SP, Brazil

FACTORS AFFECTING PRODUCTIVITY AND UTILISATION OF WINCH-ASSIST MACHINES: SIX CASE STUDIES IN NEW ZEALAND AND CANADA

Cameron Leslie [1], Rien Visser [1], Dominik Roeser [2], Colin Koszman [3], James Hunt [3], Hunter Harrill [1]
[1] University of Canterbury, Christchurch, New Zeland; [2] University of British Columbia, Vancouver, Canada; [3] FPInnovations, Vancouver, Canada

PRODUCTIVITY AND ENVIRONMENTAL IMPACTS OF CABLE-ASSISTED LOGGING – A CASE STUDY IN SOUTHERN OREGON, USA

Woodam Chung, Brett Morrissette, Preston Green, Ben Leshchinsky, Kevin Bladon, Jeff Hatten, John Sessions
Oregon State University, Corvallis, USA

A MICRO-CATCHMENT APPROACH TO MONITORING SEDIMENT FLOWS AFTER CABLE LOGGING

Bruce Talbot [1], Omar Mologni [1,2], Rasmus Astrup [1], Stephanie Eisner
[1] Division for Forestry and Forest Resources, NIBIO. The Norwegian Institute for Bioeconomy Research, Ås, Norway; [2] Department of Forest Resources Management, The University of British Columbia, Vancouver Campus

FLAT AND WET: CABLE YARDING ON SENSITIVE SOILS IN EUROPE – MOTIVATIONS, CHALLENGES AND POTENTIAL

Gernot Erber [1], Raffaele Spinelli [2], Giovanna Ottaviani Aalmo [3], Dirk Jaeger [4], Marian Schönauer [4], Stephan Hoffmann [5], Bruce Talbot [6], Karl Stampfer [1], Christoph Pucher [7]
[1] University of Natural Resources and Life Sciences Vienna – Institute of Forest Engineering, Vienna, Austria; [2] Consiglio Nazionale delle Ricerche - Istituto per la Valorizzazione del Legno e delle Specie Arboree, Florence, Italy; [3] Norwegian Institute of Bioeconomy Research – Division of Food Production and Society, Ås, Norway; [4] Georg-August-Universität Göttingen - Department of Forest Work Science and Engineering, Göttingen, Germany; [5] University Freiburg, Chair of Forest Operations, Freiburg, Germany; [6] Norwegian Institute of Bioeconomy Research – Division of Forest and Forest Resources, Ås, Norway; [7] University of Natural Resources and Life Sciences Vienna – Institute of Silviculture, Vienna, Austria;

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

ASSESSING CABLE TENSILE FORCES AND MACHINE TILT OF WINCH-ASSISTED FORWARDERS ON STEEP TERRAIN UNDER REAL WORKING CONDITIONS

Thomas Holzfeind, Christian Kanzian, Karl Stampfer, Franz Holzleitner
Institute of Forest Engineering
Department of Forest- and Soil Sciences
University of Natural Resources and Life Sciences Vienna
Peter-Jordan-Strasse 82/3, A-1190 Vienna, Austria
thomas.holzfeind@boku.ac.at

Abstract: *Winch-assisted forwarders are now commonly accepted as an innovative alternative for extracting wood on challenging terrain. In order to assess safety risks, it is necessary to know the tensile forces in the steel wire rope and their interaction with the machine tilt under real working conditions. In this study, the tensile force and the machine tilt of two winch-assisted forwarders (John Deere 1210E and Komatsu 840TX) were observed for about 15 work hours without delays on two different stands in Austria. The tensile force data and the machine tilt data were separated by work elements. The mean tensile force ranged from 18.1 kN for unloading up to 56.8 kN for loading activities. During the measurements, the cable tensile force exceeded 50% of the minimum breaking strength (MBS) only twice. The maximum observed tensile force was 174.5 kN or 82.7% of the MBS, respectively, which led to a failure of the steel cable. For the machine tilt, a maximum of 80% was measured during loading and driving during loading. John Deere 1210E was operated 31% of the productive work time above the manufacturers tilt limit. For Komatsu 840TX, the manufacturers' maximum tilt limit was exceeded only twice. The study also showed that peaks with an amplitude of up to 50 kN can occur within a few centiseconds, which highlights the need of high measurement rates, when measuring cable tensile force of winch-assisted machinery. The detailed analysis of the peaks showed that 90% of the pit-to-peak amplitudes ≥20 kN occurred during driving activities. Only 10% of pit-to-peak amplitudes ≥20 kN were measured during loading activities, although loading took about 43.5% of the productive work time. As such, the study results confirm that amplitudes of peaks in tensile force, and hence safety risks, are significantly higher during driving than during loading.*

Keywords: steep terrain harvesting, winch-assisted forwarder, cut-to-length, tensile force

The study is already published and available under the following link:

http://www.crojfe.com/archive/volume-40-no.2/assessing-cable-tensile-forces-and-machine-tilt-of-winch-assisted-forwarders-on-steep-terrain-under-real-working-conditions/

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

PRODUCTIVITY AND FUEL CONSUMPTION OF HEAVY FORWARDERS UNDER DIFFERENT CONFIGURATIONS: BENCHMARKS FROM FLEET-LEVEL LONG-TERM RECORDS (ONE MILLION LOADS)

Raffaele Spinelli [1,2], Angelo Conrado de Arruda Moura [3]
[1] CNR IVALSA, Firenze, Italy; [2] University of the Sunshine Coast, Marochydoore, QLD, Australia; 3) Suzano, SP, Brazil
spinelli@ivalsa.cnr.it

Abstract: *Mechanized cut-to-length (CTL) harvesting is a Nordic design based on the harvester-forwarder team: the system is so effective and versatile that it has become a global best-seller and it is now widespread all over the World. Harvesters and forwarders are also popular in the eucalypt plantations of the Southern Hemisphere, where increasingly large and productive machines are being deployed. Both machines are quite successful there, too. in fact, the productivity levels achieved in dedicated industrial plantations are generally higher than those recorded in Europe, under the conditions offered by natural or semi-natural forests. That has been widely documented for harvesters, which are more glamorous than forwarders and have attracted much attention. Limited documentation is available for forwarders, often in the form of single case-studies. The goal of this study was to produce general benchmarks of the heavy forwarders used in the eucalypt plantations of the Southern Hemisphere, based on large amounts of productivity and fuel consumption data. To this purpose, the Authors tapped three whole years of production records for the forwarders used by Fibria in Brazil. The analysis focused on Valmet 930.3 model forwarders, because this is the model most represented in the company's fleet, where it is used under three main configurations: 6x6, 8x8 and Clambunk. Therefore, the study also allowed checking possible efficiency differences between different configuration. The dataset included over 2000 monthly record from 44 individual machines. The data represented over 1 million loads, or 18 million m3 under bark. Mean productivity exceeded 40 m3 ub per productive machine hour (PMH). Mean fuel consumption was moderate, for such large machines. Statistical analysis explored the significance of efficiency differences between alternative forwarder configurations.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

FACTORS THAT AFFECT PRODUCTIVITY AND UTILISATION OF WINCH-ASSIST MACHINES: SIX CASE STUDIES IN NEW ZEALAND AND CANADA

Cameron Leslie[1]*, Rien Visser[1], Dominik Roeser[2], Colin Koszman[3], Jim Hunt[3] and Hunter Harrill[4]
[1]School of Forestry, University of Canterbury, New Zealand
[2]Faculty of Forestry, University of British Columbia, Canada
[3]Fibre Supply, FPInnovations, Canada
[4]Humboldt State University, Arcadia, USA
*Corresponding author: cameron.leslie@pg.canterbury.ac.nz

Abstract: *Winch-assist technology is a well-established system used to extend the operating range of harvesting systems on steep slopes. However, these systems are expensive and little is known about their productivity and utilisation rates, or the factors that affect these. The aim of this project was to improve our knowledge of winch-assist in harvesting, its utilisation and productivity through six case studies in New Zealand and Canada. Winch-assist allows conventional excavators (falling machines) to be lowered down slopes with the security of a winch from an anchor machine. The anchor machine is generally located at the top of the slope.*

Three to five days of continuous utilisation and productivity were collected at each site. Utilisation was defined as the ratio of the time the machine was working on its primary tasks as a percentage of the total scheduled time. For winch-assist, working time was defined as; falling, bunching, moving between trees and brushing (cutting multiple stems). The time not included in productive time was time used for activities such as shovelling or delays being defined as operational, mechanical, or personal. The average utilisation recorded in these six case studies was 52%; ranging from 25% to 63%. In comparison, results from a five-month study in New Zealand showed where winch-assist was used utilisation were 57%.

Winch-assist productivity was recorded as volume harvested per productive machine hour (m^3/PMH). The volume per scheduled machine hour (m^3/SMH) was then calculated using the product of the utilisation rate and the volume harvested per PMH. It is important that machine productivity (m^3/PMH) is considered in relation to overall machine utilisation given the terrain and set up requirements for winch-assist systems. The average productivity recorded through the six case studies was 61m^3/PMH and 33m^3/SMH with it ranging from 34m^3/PMH to 102m3/PMH and 11m^3/SMH to 58m^3/SMH.

Keywords: Winch-assist, Productivity, Utilisation, Delay, Time study

1. Introduction

Forestry is a significant industry in New Zealand and Canada, contributing 3 percent of New Zealand's Gross Domestic Product (Ministry for Primary Industries, 2018) and 1.2 percent of Canada's (Government of Canada, 2016). In New Zealand, plantation forestry covers 1,7 million hectares or 6.4 percent of land area, excluding harvest area awaiting replanting. Currently, 49,900 hectares are harvested annually with a value of NZ$4.75 billion and are the third-largest export industry in the country (Forest Owners Association, 2016). Because of the scale, research is continually being carried out to optimize systems and create a more productive and safer environment.

Winch-assist allows conventional excavators (falling machines) to maneuver down slopes with the security of a winch from an anchor machine at the top of the slope. Winches can be integrated into the falling machine, although this is not common. New Zealand first introduced winch-assist machines in 2006. New Zealand manufacturers now have 120 spread throughout the country and have exported around 250 as of

July 2019. Of the 120 machines in NZ, 45 are EMS TractionLine; a dual winch excavator system. 35 are DC Equipment Falcon Forestry winch-assist; single winch excavator system. 18 are Remote Operated Bulldozers (ROB); which is a dual winch system with operating alarms. 7 are Waka Engineering winch-assist; a single winch excavator system. 3 are ClimbMAX steep slope harvesters, which is a single winch integrated into a feller-buncher track frame. The remaining 12 machines are NZ developed systems only operating within NZ.

In New Zealand, forests often occupy steep, remote and erosion-prone land that is not suitable for farming. A large area of forest is now becoming available to harvest as a result of sheep farm conversions in the late 1980s and early 1990s during a period of increased planting (Harril, Reriti, & Visser, 2018). Some of these forests may be economically unviable to harvest due to steep terrain, extensive infrastructure requirements, small tree size, and where harvest and transport costs exceed the market value of the trees (Ministry for Primary Industries, 2014). The increased availability of this wood source will see a trend toward steeper and more difficult forest areas suited to winch-assist harvesting.

Steep terrain harvesting is also projected to increase in Canada as timber on steep slopes becomes an increasingly crucial future fiber source as large scale disturbances caused by insects and wildfires have put pressure on traditional forest fibre sources and are forcing the industry to direct operations into previously unutilized and marginalized stands (Amishev & Dyson, 2018). This is a result of the Mountain Pine Beetle attack, which started in the 1990s and has resulted in the mortality of 50 percent of the total volume of commercial Lodgepole pine (Pinus contorta) in British Columbia. Currently, an outbreak covers over 16.3 million ha of British Columbia and Alberta in Western Canada (De la Giroday et al., 2011). Furthermore, the Government's initiative to slow the beetles' spread is harvesting affected stands before the economic value of the wood is lost or diminished (Government of Canada, 2018). A study carried out by De la Giroday and others (2011) found that Mountain Pine beetle (Dendroctonus ponderosae Hopkin) is primarily established in canyons and valleys, before moving into more open-sloped areas. Southwestern slopes of mid-slope ridges and small hills, southwest facing open slopes, and valleys that run in a northeast-southwest cardinal direction were positively associated with higher intensities of infestation. The need to increase harvesting on steep slopes has resulted in an increased interest into winch-assist harvesting systems in Western Canada over the past 7 years. Today more than 50 winch-assist machines by a range of different manufacturers are working in Western Canada.

Increasing mechanisation results in higher operational costs. With the already tight profit margin of harvesting on steep terrain, increased machinery costs and the likely fall of the NZ dollar (driving up already inflated machine costs), profitability on steep terrain becomes progressively more sensitive with increasing mechanisation (Raymond, 2012). Information on steep slope harvesting productivity and cost is limited. This research project will provide a basis for what winch-assist machines can achieve.

A review of the literature has been conducted looking at the background of winch-assist machines and identifying current winch-assist operations. A comparison has been undertaken to look at the productivity of these machines in both New Zealand and Canada. The contrast helped to explore any differences in operational environments and what the main differences are between the two countries — a third study was identified in Australia.

Previous studies on winch-assist productivity and utilisation studies provide widely differing outcomes. Amishev & Dyson; (2018) recorded a productivity of 42.8 m3/PMH while Malietoa (2016) from three different winch-assist operations, recorded productivities of; 79.6m3/PMH, 99.5m3/PMH, and 109m3/PMH. Results from a five-month utilisation study in New Zealand indicated a winch-assist utilisation at 57%. Another survey of 12 winch-assist machine owners found a low utilisation of 45% (Harrill, Reriti, & Visser, 2018). and one in Australia (Acuna, Skinnell, Mitchell, & Evanson, 2011). These three sources have provided a foundation for this study and further research.

Winch-assist machines require large amounts of time when shifting and relocating on the slope (Harrill, Reriti, & Visser, 2018). The utilisation rate is expected to differ depending on the ease of access on, off, and around the working area. The sampling procedures will be assessed and stage-gated after the first site visit to determine if adjustments to the methodology are required.

With an increasing demand for winch-assist systems throughout New Zealand and Canada, a preliminary assessment of six winch-assist operations has been conducted. The six case studies took place in New Zealand and Canada and were undertaken between August 2018 and May 2019. The purpose of this research was to improve our knowledge of winch-assist through six case studies. The research involved establishing the productivity and utilisation of six winch-assist systems, as well as identifying site and stand variables that could affect this.

The focus of this research project will aim to give forest engineers, forest managers, and contractors a guide to the productivity of winch-assist machines and the factors that affect it. Productivity and relating factors will be assessed through six different winch-assist operations, identifying effective work methods, and identifying suitable working conditions. Operations identified will be treated individually rather than creating comparisons between each operation. It is assumed that the best knowledge gain will be from assessing operations with different productivity and relating the various site factors such as: landing and setting difficulty and size of trees. In summary, carrying out this project will provide a gauge on what works well in a winch-assist operation.

2. Method

The method of work-study undertaken was a detailed time study taking into account several variables. Some of the critical variables included in the analysis are; slope, piece size, operator skill, machine size, working method/machine brand, terrain (rock outcrops, wet soils), stand condition (mortality, wind throw). For each operation, three to five days was required in the field to provide sufficient data for analysis. The stand characteristics of each case study harvest area were recorded from the harvest plan. The typical operating slope was measured by inclinometer. The crew characteristics of each case study were recorded from observation by the author.

The total amount of time of the study was recorded by stopwatch, as scheduled machine hours (SMH). Total study time was classified into productive tasks (such as tree falling, moving the feller buncher, and shovelling), and delays. Tree falling included bunching (collecting several felled stems into a bunch for extraction) and brushing (cutting multiple tree stems sequentially). Shovelling (sometimes called shovel logging) describes the task where the felling machine swings felled stems towards the landing or road edge.

Delays were further classified as either operational, mechanical or personal. Operational delays included moving the anchor machine, and setting up each line for the feller buncher, or where the winch machine was idle (waiting for work). Mechanical delays involved repairs and maintenance to the winch machine. Personal delays were recorded when the winch machine was available for work but the feller buncher operator was taking a break.

Productive time, measured as productive machine hours (PMH), was recorded as the time the winch machine was attached to the felling machine while the felling machine was working (falling and moving only). The utilisation of the winch machine was calculated as the ratio of productive time (total time excluding delays and shovelling) to scheduled time and expressed as a percentage.

Productivity was calculated by recording the total number of tree stems felled, and then multiplying this by the average tree size to calculate the total volume of wood produced (in cubic metres, or m3). The total volume of trees felled was divided by the total productive time, in PMH, to calculate the average productivity in cubic metres per productive machine hour (m3/PMH).

The average productivity in m^3/PMH was multiplied by the utilisation to calculate the average productivity in m^3/SMH.

Systems
The winch-assist machines assessed were those manufactured by Waka Welding Ltd of Waikouaiti, Otago; Remote Operated Bulldozer (ROB) manufactured by Rosewarne & May Ltd of Whangarei; Tractionline manufactured by Electrical and Machinery Services Ltd (EMS) of Rotorua; and Falcon Winch Assist manufactured by DC Equipment Ltd of Brightwater, Nelson.
The six case studies are:

- Button Logging Ltd, Okuku, North Canterbury, New Zealand
    - Waka winch assist on Hitachi Zaxis
- Gamble Forest Harvesting Ltd, Ferny Hill, Otago, New Zealand
    - Remote Operated Bulldozer (ROB) on John Deere 850J
- Mold Logging Ltd, Kaitaia, Northland, New Zealand
    - ROB on John Deere 850J
- Wadlegger Logging & Construction Ltd, Clearwater, British Columbia, Canada
    - Tractionline on Cat 330D L
- Lime Creek Logging Ltd, Carmi, British Columbia, Canada
    - Falcon Winch Assist on Volvo FC3329C
- Gorge Creek Logging Ltd, Armstrong, British Columbia, Canada
    - ROB on John Deere 850J3. Results

Case Study 1

The harvesting contractor was Button Logging Ltd, a local contractor in the region, and having two crews contracting to Rayonier Matariki Forests. The winch-assist was mounted on a Hitachi Zaxis excavator, and was one of six machines constructed by Waka Welding Ltd of Waikouaiti, Otago. The felling machine was a Tigercat LS855D tracked feller buncher with a Tigercat 5195 directional felling saw (Figure 1).



Figure 1. Waka Welding Ltd winch-assist and Tigercat LS855D: Case Study 1

The harvest setting was 5.8 hectares of douglas-fir (Pseudotsuga menziesii) with a stocking of 757 stems per hectare. The high stocking and relatively exposed site resulted in a relatively small piece size of 0.88m3. The average slope throughout the setting was 50% although in places where the study was carried out, slopes of up to 70% were recorded with an inclinometer.

The forest site was predominantly rocky and in some cases, time was required to shift rocks and boulders out of the way when falling and maneuvering between trees. Table 1 details the characteristics of the study site and crew.

Table 1. Stand and crew characteristics: Case Study 1

Crew	Button Logging Ltd.
Anchor machine	Waka Winch Assist on Hitachi Zaxis excavator
Felling machine	Tigercat LS855D
Felling head	Tigercat 5195 directional felling saw
Region	North Canterbury
Forest	Okuku
Harvest setting (ha)	5.8
Volume (m^3/ha)	662
Average stem volume (m^3)	0.88
Stocking (SPH)	757
Average slope (°)	29
Average slope (%)	50
Species	Douglas-fir

Case Study 2

The harvest setting was 16.2 hectares of radiata pine (Pinus radiata) and a tree stocking of 278 stems per hectare. The low stocking and longer rotation (32 years) allowed the trees to grow to a relatively large piece size of 2.23m3 in comparison to the other 5 studies. The average slope was 48% although it varied across the site with 22% of the area being less than 32% slope, 37% of the area was between 32 and 50% slope and 41% of the area was greater than 50% slope. The typical operating slope measured by inclinometer, during the study was 47%.

The ground was solid with strong and dry soil, providing good traction for ground-based machinery on days 1 2 and 3. On day 4, operations took place near the stream where soil was wet and soft. There was very little undergrowth throughout the study meaning limited brushing was required when falling trees and manoeuvring between trees.

The harvesting contractor was a resident in the area, with a long-term family relationship of at least 30 years with City Forests Ltd, the forest management company. The winch-assist machine was a Remote Operated Bulldozer (ROB) manufactured by Rosewarne & May Ltd in Whangarei, based on a John Deere 850 bulldozer. The felling machine was a John Deere 909MH feller buncher with a Woodsman Pro FH1350 directional felling saw (Figure 2).



Figure 2. ROB winch-assist and John Deere 909MH: Case Study 2

Table 2. Stand and crew characteristics: Case Study 2

Crew	Gamble Forest Harvesting Ltd
Anchor machine	Remote Operated Bulldozer (ROB)
Felling machine	John Deere 909MH
Felling head	Woodsman Pro FH1350 directional felling saw
Region	Otago
Forest	Ferny Hill
Harvest setting (ha)	16.2
Volume (m^3/ha)	621
Average stem volume (m^3)	2.23
Stocking (SPH)	278
Average slope (°)	26
Average slope (%)	48
Species	Radiata pine

Case Study 3

The harvest setting was 25.2 hectares of radiata pine (Pinus radiata) with a stocking of 320 stems per hectare. The relatively low stocking had enabled the trees to grow to a large piece size of 1,9m3. The average slope was 28 degrees and varied across the site with slopes of up to 46 degrees measured on site with an inclinometer. The soil was clay and shallow in places, large rocks were present in the soil. The soil was not favourable for winch-assist, causing traction issues on steeper slopes. The undergrowth was abundant at an average recorded height of 5 metres.

The harvesting contractor was Mold Logging Ltd and the forest management company was Summit Forests New Zealand Ltd. The winch-assist machine operating was a Remote Operated Bulldozer (ROB) manufactured by Rosewarne & May Ltd in Whangarei, based on a John Deere 850J bulldozer. The felling machine was a Tigercat LS855C with a Tigercat directional felling head (Figure 3).



Figure 3. Rob winch-assist and Tigercat LS855C: Case Study 3

Table 3. Stand and crew characteristics: Case Study 3

Crew	Mold Logging Ltd.
Anchor machine	Remote Operated Bulldozer (ROB)
Felling machine	Tigercat LS855C
Felling head	Tigercat Directional felling head
Region	Northland
Forest	Herekino
Harvest setting (ha)	25.2
Volume (m^3/ha)	608
Average stem volume (m^3)	1.9
Stocking (SPH)	320
Average slope (°)	28
Average slope (%)	53
Species	*Pinus radiata*

Case study 4

The harvesting contractor Wadlegger Logging & Construction Ltd was currently harvesting under contract for Canfor. The winch-assist machine was an EMS Tractionline on a Cat 330DL excavator base. The felling machine was a Tigercat L870C with a Tigercat 5702 continuous rotation bunching saw (Figure 4).

The harvest setting was 12.3 hectares with a stocking of 423 stems/ha; 78% spruce (Picea engelmannii), 14% balsam fir (Abies balsamea), 4% douglas-fir (Pseudotsuga menziesii) and 4% lodgepole pine (Pinus contorta).

The study site was located between 1210 and 1630 m elevation. During the study, the soil was frozen and firm. Large rocky outcrops were common in the forest and required blasting for road access. Dense undergrowth required brushing of small stems to gain access to the larger diameter commercial trees. The bunching saw is efficient at brushing, being able to grab multiple trees in a single cycle.



Figure 4. Tractionline winch-assist and Tigercat L870C feller buncher: Case Study 4

Table 4. Stand and crew characteristics: Case Study 4

Crew	Wadlegger Logging and Construction Ltd.
Anchor machine	EMS Tractionline on Cat 330DL
Felling machine	Tigercat L870C
Felling head	Tigercat 5702 bunching saw
Region	Clearwater, B.C, Canada
Forest	Block D219
Harvest setting (ha)	12.3
Volume (m^3/ha)	296
Average stem volume (m^3)	0.7
Stocking (SPH)	423
Average slope (°)	29
Average slope (%)	51
Species	Spruce, Balsam, Douglas-fir, Lodgepole pine

Case Study 5

The harvesting contractor was Lime Creek Logging Ltd. currently harvesting under contract for Interfor Corporation. The anchor machine was a Falcon Winch Assist mounted to a Volvo FC3329C. The felling machine was a Tigercat LX870D with a Tigercat 5702-26 continuous rotation bunching hot saw (Figure 5).



Figure 5. Falcon winch-assist and Tigercat LX870D: Case Study 5

Harvesting took place in three settings within the same forest. The first setting was 5.1 hectares with a stocking of 575 stems/ha. The second setting was 16.5 ha with a stocking of 368 stems/ha.The third setting was 23.7 ha with a stocking of 450 stems/ha. The species present were engelmann spruce (*Picea engelmannii*), balsam fir (*Abies balsamea*), douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), western larch *(Larix occidentalis*).

There was rock on the three sites but not enough to impede the operations. The terrain was broken within the areas viewed during the study (along with landscape in general). Therefore a mix of conventional untethered falling and winch-assist falling was needed. In areas of the forest, regeneration was thick, especially in areas where tracks and landings were located during first growth harvest. Throughout the stand, dense undergrowth required brushing of small stems to gain access to the larger diameter commercial trees.
Extraction was done by a method the operator referred to as “packing” given steep slopes observed didn’t exceed 100m in length. “Packing” was defined as walking the machine while carrying the cut tree stems. In this way stems are extracted to either the top or bottom of the slope where a skidder can reach them. This meant that extraction using a yarder or other machine was not required.

Case Study 6

The harvesting contractor was Gorge Creek Logging Ltd. currently harvesting under contract for Tolko Industries Ltd. The anchor machine was a Remote Operated Bulldozer (ROB) mounted on a John Deere 850J base machine. The felling machine was a levelling Cat 552 with a Satco feller director head and heel (Figure 6).



Figure 6. ROB winch-assist and Cat 552: Case Study 6

The forest setting was 36.3 hectares with a stocking of 890 SPH. The forest was second growth and the average piece size 0.41m^3. There were few rocks and soil did not impede productivity although snow was present at a depth of 1 – 1.5 m. The terrain was relatively easy-going throughout although very steep pitches occurred in some places. Throughout the stand, dense undergrowth required brushing of small stems to gain access to the larger diameter commercial trees. Extraction was carried out during the falling phase whereby the operator would hoe-chuck stems down the slope while falling (Table 5).

Table 5. Stand and crew characteristics: Case Study 6

Crew	Gorge Creek Logging Ltd.
Anchor machine	ROB on John Deere 850J
Felling machine	Self-levelling Cat 552
Felling head	Satco feller director
Region	Armstrong, B.C, Canada
Forest	Block 183
Harvest setting (ha)	36.3
Volume (m^3/ha)	361
Average stem volume (m^3)	0.41
Stocking (SPH)	890
Average slope (°)	24
Average slope (%)	45
Species	Douglas-fir, Western Red Cedar, Western Hemlock, Balsam, hybrid Spruce

5 Summary

Table 7 below displays the results of the six case studies, showing utilisation and productivity by productive machine hour (PMH) and scheduled machine hour (SMH).

Table 6. Case Study Results

	New Zealand			Canada			
Case Study	1	2	3	4	5	6	Average
Average Piece Size (m^3)	0.88	2.23	1.90	0.70	0.68	0.41	
Utilisation (%)	60	57	25	63	51	57	52
Productivity (m^3/PMH)	62	102	42	60	66	34	61
Productivity (m^3/SMH)	37	58	11	34	34	20	33

Winch assist falling and extraction operations differ considerably to traditional falling and yarding on steep slopes. It is important that harvest planners and forest managers understand winch-assist requirements to maximise the value from this new approach to falling and extraction. It should not be considered as the same operation, from a planning and layout perspective. Given costs of both field layout and winch-assist operations, it would be financially beneficial to all parties to ensure harvest planners are provided feedback from contractors as to how layout impacts logging. This will ensure the harvest plan meets the contractor's needs and maximises the benefit of winch-assist operations.

Installing aftermarket backup cameras to ensure that the operator has a clear view of the rear of the machine during moves is recommended. This would help reduce the time required to move the anchor machine, minimise the risk of damage to winches (and equipment) during moves in tight locations, and may improve safety.

When the falling machine is untethered to fall and extract flat areas, the anchor machine should be shutdown (remotely) during such times (provided the remote start is reliable). Not shutting down leads to unnecessary hours added to the machines operating time, impacting warranty hours and increased machine servicing (based on non-productive time). Reducing machine hours also promotes fuel efficiency and reduces carbon footprint.

To maximise winch-assist machine utilisation, the contractor should consider using standing trees or high stumps as catch trees. This technique could allow the anchor machine to face along the track while the falling machine can redirect the line by moving it to a stump suitable for the next corridor, refer to Figure 38. When this approach is used, it will; minimise machine moves, keep the anchor machine further away from falling operations, and can help when ridges or tracks are narrow. To take advantage of large high stumps on road right of ways, harvest planners and road construction crews should identify the need for high stumps and leave them to provide options for the winch-assist operation. Reducing anchor moves can increase productivity and improve overall utilisation.

Winch-assist felling machines are higher cost than a manual falling operation, although using a machine to fall and bunch trees increases the productivity of the extraction element of the harvest cycle.

10. Acknowledgements

The following people are acknowledged for their field assistance and cooperation leading up to and throughout each study; Nick Van-Handel and Ryan Drummond of Rayonier Matariki Forests, Kent Chalmers, Guy Bonner and Joseph Graham of City Forests Ltd., Riki Green of Summit Forests New Zealand, Matt Campbell and Kris Cooke of Canfor Corp., Bill Sperling of Interfor Corp., Ryan Potter and Bryan Halvorson of Tolko industries ltd. I would like to thank Colin Koszman, Jim Hunt and ken Byrne of FPInnovations for field assistance and guidance in Canada. Colin Koszman for photography. I would like to thank the harvesting crews and operators for their participation, making it possible to obtain the data. I would like to acknowledge the following for financial assistance; Northern Forest Products, the School of Forestry, Forest Growers Research, NZIF foundation for the John Dey Memorial Award and Mitacs, Canada for the Accelerate International Award.

11. References

Acuna, M., Skinnell, J., Mitchell, R., & Evanson, T. (2011). Bunching stems in steep slopes for efficient yarder extraction. CRC for Forestry, University of Tasmania

Amishev, D., & Dyson, P. (2018). Falcon Forestry Equipment (FFE) Winch-Assist Harvesting System. FPInnovations, Vancouver, B.C. Technical Note 39.

De la Giroday, H.-M., Carrol, A., Lindgren, S., & Aukema, B. (2011, July). Association of landscape features with dispersing mountain pine beetle populations during a range expansion event in western Canada. Landscape Ecology.

Forest Owners Association. (2016). Facts & Figures. New Zealand Plantation Forest Industry, 3-4. Retrieved from https://www.nzfoa.org.nz

Government of Canada. (2016). Natural Resources Canada. Indicator: Gross domestic product. Retrieved from http://www.nrcan.gc.ca/node/16556.

Government of Canada. (2018, June). Natural Resources Canada. Mountain pine beetle. Retrieved from https://www.nrcan.gc.ca/forests/fire-insects-disturbances/top-insects/13381.

Harrill, H., Reriti, B., & Visser, R. (2018). Measuring the utilisation of winch-assist machines – HTN10-03. Forest Growers Research. Rotorua, New Zealand

Malietoa, K. (2016). An Investigation into the System Production Balance Within Three Mechanised Harvesting Case Studies. University of Canterbury, Christchurch, New Zealand.

Ministry for Primary Industries. (2014). New Forest Management Approaches to Steep Hills.

Ministry for Primary Industries. (2018). News & Resources. Retrieved from http://www.mpi.govt.nz/news-and-resources/open-data-and-forecasting/forestry/.

Raymond, K. (2012). Innovation To Increase Profitability Of Steep Terrain Harvesting In New Zealand. New Zealand Journal of Forestry, 57, 19-23.

Visser, R., Raymond, K., & Harrill, H. (2014b). Mechanising steep terrain harvesting operations. NZ Journal of Forestry, 59(3).

Visser, R., & Stampfer, K. (2015). Expanding Ground-based Harvesting onto Steep Terrain: A Review. College of Engineering. University of Canterbury, Christchurch, New Zealand

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

PRODUCTIVITY AND ENVIRONMENTAL IMPACTS OF CABLE-ASSISTED LOGGING – A CASE STUDY IN SOUTHERN OREGON, USA

Woodam Chung, Brett Morrissette, Preston Green, Ben Leshchinsky, Kevin Bladon, Jeff Hatten, John Sessions
Oregon State University, Corvallis, USA
woodam.chung@oregonstate.edu

Abstract: *Cable-assisted, mechanized timber harvesting systems have recently been adopted by the forest industry in the Pacific Northwest, USA to replace conventional and dangerous manual tree felling on steep slopes. Despite its promise and rapid growth, the potential risk of damage to soil and water resources caused by heavy equipment on steep slopes remains uncertain, and has not yet been thoroughly examined. We conducted a comparative case study in southern Oregon to investigate the economic and environmental impacts of cable-assisted, mechanized timber felling in steep terrain by comparing mechanical felling with conventional manual felling followed by cable-logging. We performed detailed time studies on manual felling, mechanical felling, cable-logging after manual felling, and cable-logging after mechanical felling. Environmental impacts of these systems were measured through pre-felling, post-felling, and post-extraction samples of soil bulk density, penetration resistance, water infiltration rates, and sediment yield. The significance of this research is the development of data that can provide insights into potential economic and environmental impacts of cable-assisted timber harvesting relative to the conventional harvesting method in steep terrain.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

A MICRO-CATCHMENT APPROACH TO MONITORING SEDIMENT FLOWS AFTER CABLE LOGGING

Bruce Talbot[1*], Omar Mologni[1,2], Rasmus Astrup[1], Stephanie Eisner[1]
[1]Division of Forestry and Forest Resources
Norwegian Institute for Bio-Economy Research, NIBIO
Høgskoleveien 7, 1432 Ås, Norway
bta@nibio.no
[2] Department of Forest Resources Management
University of British Columbia, Vancouver Campus

Abstract: *This work presents some of the challenges and outcomes of a trial designed to quantify sediment flows on a steep slope after clearfell cable logging. The trial constituted 39 sediment traps placed on 11 successive contours down the slope and left in-situ for 2 years. Sediment samples were dried and categorized to fine and course mineral and organic components. Ultra-high resolution (1cm) digital elevation models (DEM) were generated from UAV image data, then downsized in 4 iterations. For each iteration, an evaluation of the effect of elevation model resolution on flow accumulation and catchment basin delineation was made in an attempt to model the soil erosion processes underlying the observed sediment flows.*

Keywords: UAV, drone, erosion, harvest, steep slope harvesting

1. Introduction

Site disturbance during timber harvesting can lead to increased surface run-off and soil erodibility, and consequently (increased) sediment export to streams and headwaters, as well as a loss of the soil and nutrients required in maintaining site productivity. Quantifying the amount of sediment in surface run-off is one method of assessing site disturbance, and has been used as a proxy measure of overall site impact. Numerous studies have been carried out in determining the effect of disturbances on forest soils, resulting either from semi-natural processes such as wildfires or directly from human activities, such as timber harvesting and the associated construction and maintenance of infrastructure like forest roads and trails.

Unmanned aerial vehicle (UAV) based photogrammetry has been shown to be provide detailed surface models and has found a wide range of applications in terrain modelling. This is especially true where there is little ground cover to obscure terrain, such as in quarrying or earthworks, or after major soil disturbance events such as landslides. More specific applications of UAV-based photogrammetry considering terrain in forest operations include quantifying volumes of soil displaced during the construction of temporary extraction trails (Pierzchała et al, 2014), measuring the depth of wheel rutting on the site after harvesting (Nevalainen et al, 2017), and in assessing the condition of the wearing course on forest roads (Hrůza, P, 2018).
The aim of the present study was to investigate whether a combination of high resolution digital elevation models, used in conjunction with a dense grid of sediment traps, could provide more accurate information on the amount of sediment mobilized by cable logging, as well as a more precise location of the origin of the sediment.

2. Materials and Methods

A harvesting site situated immediately east of the town of Voss in south-western Norway (60.617895 N, 6.460306 N), with a mean slope of 60% was used for the trial. The trees had been felled motor-manually

and the timber extracted uphill with a Konrad Mounty tower yarder. Thirty-nine sediment traps were installed on a portion of the site, including one of the cable corridors (fig.1). The centre of the feeding tray on each trap doubled as a ground control point (GCP). The trial was installed in the fall and terminated in the spring two years later.



Figure 1 Layout of the sediment traps on the 60% hillslope. The dashed lines show the position of the cable corridors while the arrow indicates the downhill direction (left). Close-up of sediment trap after 2 years, the orange marker indicating the position of ground control point used in processing UAV imagery

For data acquisition we used photo imagery from a Sony NEX 5N camera mounted on multi-rotor unmanned aerial vehicle (UAV), a Mikrokopter® Okto 2-26 that was flown manually up and down slope at a height over ground of roughly 35 m. This UAV has 8 rotors and can lift up to 1kg for flight duration of between 9 and 21 minutes depending on the type of LiPo battery. Agisoft Photoscan Professional®, which employs full structure-from-motion (SFM) and precisely estimates internal optical parameters and spatial positioning of the respective cameras, was used to generate the DEMs. All spatial modelling was done in ETRS89/UTM 32N (EPSG:25832). The high-resolution DEM output from the previous process was resampled to increasingly coarser resolutions as follows; 5 cm x 5 cm, 10 cm x 10 cm, 20 cm x 20 cm, and 40 cm x 40 cm. For each resolution, a flow accumulation analysis and micro-catchment calculation was done for each of the 39 sediment traps using an integration of different GIS and data analysis software (QGIS, WhiteboxGAT, and R).

3. Results and Conclusions

As DEM resolution was decreased stepwise from 5x5 cm, 10x10 cm, 20x20 cm to 40x40 cm pixels, the mean micro-catchment area for each sediment trap increased tenfold from 5 m^2 to 50 m^2, and corresponding mean slope length increased from 5.8 m to 17.3 m while mean slope decreased from 82% to 67%. This indicates that the anticipated more widespread use of drones in providing high-resolution DEMs for flow accumulation and erosion modelling in the future needs to take even relatively small differences in DEM resolution into account. Initial findings indicate that sediment export on the trial site was very low at roughly 0.85 Mg ha^{-1}.

4. Acknowledgements

We appreciate the assistance of PhD Daniel Kindernay during the installation of the trial. The UAV survey was carried out by Mr. Kåre Havås of Panorama Hardanger AS. Initial UAV image processing and analysis was done by PhD Marek Pierzhcała. We also extend our thanks to the cable logging contractor, Frivik Taubanedrift AS and the anonymous forest owner for making the site available for the trial.

5. References

Nevalainen, P. et al. "Estimating the rut depth by uav photogrammetry." *Remote Sensing* 9.12 (2017): 1279.
Pierzchała, M. et al. "Estimating soil displacement from timber extraction trails in steep terrain: Application of an unmanned aircraft for 3D modelling." *Forests* 5.6 (2014): 1212-1223.
Hrůza, P, et al. "Detecting Forest Road Wearing Course Damage Using Different Methods of Remote Sensing." *Remote Sensing* 10.4 (2018): 492.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

FLAT AND WET: CABLE YARDING ON SENSITIVE SOILS IN EUROPE – MOTIVATIONS, CHALLENGES AND POTENTIAL

Gernot Erber* (1), Raffaele Spinelli (2), Giovanna Ottaviani Aalmo (3), Dirk Jaeger (4), Marian Schönauer (4), Stephan Hoffmann (5), Bruce Talbot (6), Karl Stampfer (1), Christoph Pucher (7)

(1) University of Natural Resources and Life Sciences Vienna, Department of Forest- and Soil Sciences, Institute of Forest Engineering,
Peter-Jordan-Straße 82, 1190 Vienna, Austria
gernot.erber@boku.ac.at, karl.stampfer@boku.ac.at

(2) Consiglio Nazionale delle Ricerche - Istituto per la Valorizzazione del Legno e delle Specie Arboree
Via Madonna del Piano 10, 50019 Sesto Fiorentino, Italy
spinelli@ivalsa.cnr.it

(3) Norwegian Institute of Bioeconomy Research – Division of Food Production and Society,
Postboks 115, 1431, Ås, Norway
giovanna.ottaviani.aalmo@nibio.no

(4) Georg-August-Universität Göttingen - Department of Forest Work Science and Engineering,
Büsgenweg 4, 37077 Göttingen, Germany
dirk.jaeger@uni-goettingen.de, marian.schoenauer@uni-goettingen.de

(5) University of Freiburg, Chair of Forest Operations
Werthmannstraße 6, 79085 Freiburg, Germany
stephan.hoffmann@foresteng.uni-freiburg.de

(6) Norwegian Institute of Bioeconomy Research – Division of Forest and Forest Resources
Postboks 115, 1431 Ås, Norway
bruce.talbot@nibio.no

(7) University of Natural Resources and Life Sciences Vienna, Department of Forest- and Soil Sciences, Institute of Silviculture
Peter-Jordan-Straße 82, 1190 Vienna, Austria
christoph.pucher@boku.ac.at

Abstract: Soils are a finite natural resource and forests are among the best land uses to conserve them. Management of forests, and in particular timber extraction, can have large impacts due to the heaviness of equipment used. Soil compaction, displacement and rutting are major effects of these mechanised ground-based timber extraction operations, which are unavoidably resulting in erosion, reduced regeneration and growth. On flat and wet sites that are difficult or impossible to traverse with ground-based extraction systems, cable yarding has the potential to minimize site and stand impacts. Furthermore, an increase of the forest area associated with these conditions is likely due to the absence of frost periods or enhanced wet seasons. On these sites, cable yarding will in fact enable more environmentally sound extraction of timber compared to ground-based extraction systems, as the site will not be repeatedly trafficked by heavy machinery. Furthermore, cable yarding will allow for the management of sites that are not traversable at all or only traversable in winter when soils are frozen. However, these advantages are associated with higher extraction costs and higher hazard level for the crew. Therefore, to increase the use of this environmentally friendly extraction system on flat and wet terrain, improvements regarding overall costs and safety are necessary. This study's goal is to provide a deeper insight into cable yarding on flat and wet terrain. As the

literature body on this subject is fairly small, manufacturers of cable yarding equipment of cable yarding on flat and wet terrain across Europe were interviewed. Motivations for choosing this extraction system and specific challenges encountered under these conditions as well as actual and potential solutions to these are of major interest. Further, their views concerning the future potential and main hurdles for expansion of use of this system were collected. This study gives a valuable insight into a lesser known, but very relevant and potent application of cable yarding, which could enable more environmentally sound management of forests on sensitive terrain. A major output will be a list of suggested adaptations to allow more economic and safer operations.

Keywords: forest soils, sensitive soils, logging equipment, soil compaction, cable yarding

Acknowledgements: The research leading to these results was conducted as part of the TECH4EFFECT project. This project has received funding from the Bio Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 720757.

A manuscript has been submitted to Silva Fennica for publication.

S02 Soil Disturbances
Down and Dirty

ENHANCED SUSTAINABLE FOREST MANAGEMENT OF THE BRAZILIAN SECONDARY ATLANTIC FOREST BY INNOVATIVE AND ADAPTED TECHNOLOGIES

Pedro C. Britto [1], Dirk Jaeger [1], Stephan Hoffmann [2], Renato C. G. Robert [3], Alexander C. Vibrans [4], Alfredo C. Fantini [5]

[1] University of Göttingen, Göttingen, Germany; [2] University of Freiburg, Freiburg, Germany; [3] Federal University of Paraná, Curitiba, Brazil; [4] University of Blumenau, Blumenau, Brazil; [5] Federal University of Santa Catarina, Florianópolis, Brazil

WET AREA MAPPING USING REMOTE SENSING DATA IN LATVIA

Janis Ivanovs, Ainars Lupikis, Andis Lazdins

LSFRI Silava, Salaspils, Latvia

RESPONSE OF SOIL PHYSICAL PROPERTIES FOLLOWING THE APPLICATION OF SOIL RESTORATION TECHNIQUES ON MACHINE OPERATING TRAILS

Siegfried Waas [1,2], Eric R. Labelle [1], Herbert Borchert [2]

[1] Assistant Professorship of Forest Operations - Department of Ecology and Ecosystem Management - Technical University of Munich, Freising, Germany; [2] Bavarian State Institute of Forestry (LWF) - Department 4 – Forest Technology, Business Management and Timber, Freising, Germany

QUANTIFYING SOIL DISTURBANCE IN A WHOLE-TREE OPERATION METHOD

Alex. K George, Anil Raj Kizha

School of Forest Resources, University of Maine, Orono, ME-04469, USA

SOIL DISTURBANCE FROM TETHERED FORWARDING ON STEEP SLOPES IN BRAZIL

Austin M. Garren [1], M. Chad Bolding [1], W. Mike Aust [1], Angelo Moura [2], Scott M. Barrett [1]

[1] Department of Forest Resources and Environmental Conservation, College of Natural Resources and Environment, Virginia Tech, Blacksburg, Virginia USA; [2] Suzano Pulp and Paper, Jacareí, São Paulo, Brazil

SOIL DEGRADATION AND WOOD EXTRACTION OPERATIONS: COMPARING SKIDDING AND FORWARDING

Francesco Neri, Elena Marra, Giovanni Mastrolonardo, Andrea Laschi, Cristiano Foder, Enrico Marchi

DAGRI - Dipartimento di Scienze e Tecnologie Agrarie, Alimentari, Ambientali e Forestali, Università di Firenze, Firenze, Italy

FORMEC 2019 – Exceeding the Vision: Forest Mechanization of the Future
6-9 October, 2019 -Sopron, Hungary

ENHANCED SUSTAINABLE FOREST MANAGEMENT OF THE BRAZILIAN SECONDARY ATLANTIC FOREST BY INNOVATIVE AND ADAPTED TECHNOLOGIES

Pedro C. Britto*, Dirk Jaeger
Department of Forest Work Science and Engineering
University of Göttingen
Buesgenweg-4, 37077 Göttingen, Germany
pedro.britto@gmx.de, dirk.jaeger@uni-goettingen.de.

Stephan Hoffmann
Chair of Forest Operations,
University of Freiburg
Werthmannstraße 6, 79085, Freiburg, Germany
stephan.hoffmann@foresteng.uni-freiburg.de

Renato C. G. Robert
Forestry and Wood Science Center
Federal University of Paraná (UFPR)
Av. Prefeito LothárioMeissner 632, Curitiba, Brazil
renatorobert@ufpr.br.

Alexander C. Vibrans
Department of Forest Engineering
University of Blumenau
R. São Paulo 3250, Blumenau, Brazil
acv@furb.br.

Alfredo C. Fantini
Laboratory of Ecology and Management of Forest Ecosystems
Federal University of Santa Catarina (UFSC)
Rodovia Admar Gonzaga 1346, Florianópolis, Brazil
alfredo.fantini@ufsc.br.

Abstract: *Human activities intensively affected the Brazilian Atlantic Forest over the last decades. Yet, it is still of great importance for securing biodiversity, ecosystem services and for providing income opportunities for millions of inhabitants. Notwithstanding, in this biome, conservation and management are currently very conflicting goals as a result of the limited knowledge on sustainable management techniques and potential impacts caused by timber harvesting. Therefore, in order to contribute to fill this gap, our research assessed and compared a conventional harvesting method (CM), widely used by local forest owners, with an alternative and improved harvesting method (AM), performed by a professional chainsaw operator and supported by a snatch block and a skidding cone. Permanent sample plots were installed and a full pre-harvesting inventory was performed. A management plan was set in order to ensure the harvesting of commercial tree species and improvement cuts for enhancing future forest yield. The harvesting impact on the residual stand was classified and evaluated through a post harvesting inventory and the positioning of every tree was further georeferenced within ArcGIS software. The geoprocessing methodology "triangulated irregular network" (TIN) was used for generating damage maps based on damage intensity of residual trees for visual assessment of damage location. Felling*

direction and winching line bearings, measured with a field compass during the harvesting operation, were georeferenced and also plotted on the maps. Our results showed that the felling process caused most of the observed damages on residual stand for both methods (87% for CM and 88% for AM). Spatial analysis of the damaged areas and stand characteristics showed that the terrain slope, followed by the location of remnant trees and position of forest roads were the main variables affecting felling directions. Furthermore, CM damaged in average 1.6 trees per harvested tree, while AM damaged in average 1.4 trees per harvested tree and the spatial observation of winching lines did expose that the disturbed winching ground area under CM (23 % of the plot area) was higher compared to AM (10% of the plot area).

Keywords: timber harvesting, skidding cone, snatch block, impact assessment, ArcGIS.

1. Introduction

Due to its location along the Brazilian coast, the Atlantic Forest was an easy target for intensive exploitation and conversion to other land-uses. In the past century, the forest land base shrunk by the expansion of agriculture and urbanization to about 12 % of its original size (Ribeiro et al. 2009). Most of the remaining fragments of the Atlantic Forest are small and isolated patches of second growth vegetation in early to medium stages of typical succession fallow areas (Metzger 2009), preserved in locations where steep terrain made exploitation particularly difficult (Ribeiro et al. 2009).

Currently, conservation and management of the remaining forest are largely conflicting goals in the Atlantic Forest biome (Fantini et al., 2019). Irrespective of size of forest patches, commercial logging is banned by forest regulations aiming at protecting the remnant forests from deforestation and degradation (Fantini and Siminski, 2017). Moreover, environmental regulations for protecting remaining forests proved to be ineffective as landowners were not compensated and law enforcement was insufficient (Alarcon et al. 2011). This situation is partly induced by the lack of knowledge on potentially suitable forest management practices for sustainable resource utilization. Various researchers argued that sustainable management of secondary forests providing income opportunities would be more effective in increasing the willingness of land owners to conserve and possibly even expand the forest. (Alarcon et al., 2011; Britto et al., 2017; Fantini et al., 2019; Fantini and Siminski, 2017; Silva et al., 2018; Trevisan et al., 2016).

Alarcon et al. (2011) pointed out the necessity for a policy to promote sustainable forest management of native species from secondary forests. Nonetheless, studies to support effective policy-making for allowing and regulating potential utilization of native trees from the Atlantic Forest and associated harvesting operations are scarce. Fantini & Siminski (2017) estimated the mature harvestable timber volume of the secondary Atlantic Forest at 36 million cubic meters in Santa Catarina state, only. The authors also pointed out that wood from secondary forests has a good market and may reach revenues of 260 € m^{-3} to 340 € m^{-3} while wood from regional pine and eucalyptus plantations may reach comparatively lower revenues of 130 € m^{-3} to 210 € m^{-3}.

An appropriate timber harvesting system is fundamental for the success of the sustainable forest management and it should addresses the economically viable and environmentally sound forest management plans as well as the specifics of the local forest (Britto et al., 2017). However, despite its relevance, only few studies on timber harvesting systems and related impacts on forest stands have been done in the Atlantic Forest biome (Britto et al., 2017; Bulfe et al., 2009; Silva et al., 2018).Our goal is, therefore, to contribute the current knowledge gaps on potentially suitable forest management practices by assessing timber harvesting impact of a conventional harvesting method (CM), widely used by local forest owners, with an alternative and improved harvesting method (AM), performed by a professional chainsaw operator and supported by a snatch block and a skidding cone.

2. Methodology

2.1 Research area

The research site was located in the municipality of Guaramirin in Santa Catarina State, southern Brazil (26º32´10´´ S and 49º02´38´´ W) (Figure 1a). The research was carried out in a fragment of the evergreen rainforests (ERF) (Oliveira-Filho et al., 2015). The forest cover consisted of 35 year old second growth forest, regenerating after swidden agricultural farming plots were abandoned (Britto et al., 2017; Silva et al., 2018). The Institute for the Environment of Santa Catarina (IMA) is one of the partners in this study and had provided the exceptional permit for timber harvesting, as part of long-term research. This case study site is, therefore, a unique area in the Atlantic Forest to test and evaluate alternative forest management regimes for sustainable utilization concepts.

Three stands (A, B and C) were selected within the study area. Two square plots of 40 m x 40 m were set in each stand, in order to compare the harvesting methods. In every plot, a pre-harvesting inventory of all trees with diameter at breast height (DBH) above 7 cm over bark (o.b.), was conducted, recording tree species, DBH, tree height and location (Cartesian X and Y coordinates) (Figure 1b). Measured trees were permanently marked with an aluminum tag, allowing for tree identification during the intended multi-year post-harvesting monitoring of the plots.



(a) (b)

Figure 1. a) Map of the research area; b) Research plot design and trees positioning inside plot.

2.2 Timber Harvesting

A thinning plan was developed and implemented considering species composition, ecological groups, tree age and tree growth. A basal area reduction of 40 % was target in all research plots. The felling operation focused on both commercial trees and noncommercial trees. Commercial trees felling focused on rather mature trees of species of economic value for generating revenues for the landowner. The landowner possesses and ran a small sawmill, where the timber produced during this study was further processed. Noncommercial trees felling included harvesting small trees of low quality or low economic value felled to improve the quality of the remnant stand (Britto et al., 2017). While all commercial felling included extraction of logs, most of the stems resulting from improvement felling remained in the stands except for those at close distance to a forest road, which were extracted and used as firewood.

In this study, two different harvesting methods were assessed and evaluated: a) the “Conventional Method” (CM), which was formerly widely used by landowners in the region for timber harvesting operations in the Atlantic Forest; and b) the “Alternative Method” (AM), with a trained operator combined with improvements in technology application as an integral part to implement sustainable forest management. In both methods, trees were felled, delimbed and bucked inside the stand using a chainsaw. The timber extraction was done by using a winch fitted tractor. The tractor was always positioned outside the stand, on the forest road and, therefore, did not enter the forest stand. A coworker assisted the tractor operator in both methods, pulling out the cable from the winch to the log location inside the stand.

CM tree felling and delimbing was carried out using a chainsaw (model Stihl 251). The chainsaw operator had no specific training, but he had more than 20 years of experience at the wood yard of his small sawmill. Stem length logs were extracted by a Valmet tractor model 85 (2x4, 63 kW) operated by the chainsaw operator himself. The tractor was equipped with a forestry winch TMO model Caçador 33T and a steel cable with 15 mm of diameter and 100 m length (Figure 2a). In contrast, AM was conducted by a contracted professional chainsaw operator, experienced in reduced impact logging techniques in the Amazon region. He executed the tree felling with a Stihl chainsaw (model 661 - which is the common model used in Amazon forest and which is therefore the model that the professional operator uses routinely). The consecutive log extraction was conducted with a state of the art TAJFUN winch (model EGV 85 AHK), fitted to a 4x4 tractor (Figure 2b) and supplemented with a Portable Winch® skidding cone (Figure 2c) and a TAJFUN snatch block (Figure 2d) (Britto et al., 2017). Although the operator was skilled in directional and reduced impact felling techniques, he had no experience working in local conditions of secondary Atlantic Forest.



(a) (b) (c) (d)

Figure 2. a) Tractor winch in the conventional method; b) Tractor winch in the alternative method; c) Skidding cone; d) Snatch block (Britto et al, 2017).

2.3 Impact assessment

The harvesting impact on the residual stand was determined by visual inspection of all standing trees in a post harvesting inventory and recorded as undamaged, damaged or dead tree. Categorization and rating of damaged trees according to damage severity classes (minor, moderate and severe) followed the methodology of Silva et al. (2018) (Table 1). The damage intensity on remnant trees was assigned a rating value ranging from zero (0) to nine (9) resulting from the sum of rating values of the damage severity classes (minor, moderate and severe) on the three evaluated tree´s regions (crown, bole and leaning). Moreover, undamaged trees were assigned with the lowest damage rating values (0) while not found and dead trees were assigned the highest scores (9).

Table 1. Classification criteria for harvesting damage to residual trees in a secondary Atlantic Forest according to Silva et al. (2018).

Category of damage	Intensity of damage					
	Minor	*Rating value*	Moderate	*Rating value*	Severe	*Rating value*
Crown damage	X <1/3 of crown	*1*	1/3 < X < 2/3 of crown	*2*	X >2/3 of crown	*3*
Bole damage	Bark damage	*1*	Superficial wood damage (cambial tissue)	*2*	Deep wood damage (sub cambial tissue)	*3*
Tree leaning	Slight leaning	*1*	Partially uprooted	*2*	Fully uprooted	*3*

Causes of damage on standing remnant trees were further classified as a) felling or b) winching. The damages caused by felling were usually evidenced by damages that were caused by the felling of neighboring trees and characterized by damages to the crown and vertical scratches at the bole at any

height (Figure 2a). Damages caused by winching were characterized by horizontal scratches at the bole and observed, usually, up to one meter from the ground surface (Figure 2b).



(a) (b)

Figure 3. Examples of: a) damaging of the bole caused by the felling of neighboring trees; and b) by winching, during log extraction.

2.4 Analytical methods

Statistical analyses were conducted using SPSS software version 22.0 (IBM Corp. Armonk/NY, USA). All data were checked for normality before applying suitable testing methods (non-parametric Whitney U Test; $p < 0.05$). We compared different stand for structural characteristics: stand density (number of trees per area), tree DBH, tree height, basal area (of trees ≥ 7 cm o. b.) and stocking volume. Additionally, we verified the harvesting impact on the remnant stand, based on the number of damaged trees per hectare, damaged basal area and damaged volume.

Based on the post-harvesting inventory every tagged tree was georeferenced with the transformation of its Cartesian coordinates (X, Y) into UTM coordinates (WGS 1984, Zone 22 South). Felling direction and winching line bearings, obtained with a field compass during the harvesting operation, were georeferenced, analyzed in ArcGIS software version 10.5.1 (ESRI Inc., Redlands/USA) and plotted on the maps according to the measured azimuth and position of trees within the stand. The geoprocessing methodology "triangulated irregular network" (TIN) (Fowler and Little, 1979) within ArcGIS was used for generating damage maps based on damage intensity of remnant trees for visual assessments of damage locations. For TIN generation, the damage intensity scores (obtained from the post-harvesting damage assessment - table 1) replaced the height values (z-axis) generated on the map. Therefore, the highest values of height (score 9) represented the most damaged areas in every plot and, thereafter, the lowest values of height (score 0) represented the lowest damaged area per plot. Furthermore, within TIN analysis, lines of equal damage intensity were generated around the most damaged areas and further transformed into polygons to outline the size of most damaged areas into every research plot. These maps allowed analyzing the location of most damaged trees with respect to tree felling direction, length of winching line and size of disturbed ground area due to the winching operation, and terrain slope.

3. Results and Discussions

3.1 Forest Structure

Within the research plots, 110 different tree species were identified, representing nearly 20% of the 577 different species occurring in the Atlantic evergreen rainforest (ERF) as described by Lingner et al. (2015). Furthermore, there is a statistical different among stands for most of the observed forest structure and site characteristics (tree density, mean DBH, basal area, standing volume) (Table 2). These results evidenced the high heterogeneity of the forest, which associated with the small number of replications and also limited by the available resources, represented an extra effort for the experimental layout and challenged the statistical comparison between harvesting methods. Yet, the characteristics of the studied forest are typical of the region (Fantini and Siminski, 2017) and therefore, representative for the Atlantic Forest biome.

In general, stand A was characterized by a steep terrain (≈ 50% slope) and bigger commercial trees while stand C was located in more flat terrain (≈ 5 / 10% slope), with high density of smaller trees. On the other side, stand B presented some intermediary conditions between A and C, with more flat terrain (≈ 10 / 25% slope) but also with some bigger commercial trees.

Table 2. Main stand characteristics among plots.

	Stand A		Stand B		Stand C	
	CM	AM	CM	AM	CM	AM
Tree density (N ha^{-1})	1600.0 ^{aA}	1331.3 ^{aA}	1456.3 ^{aA}	1393.8 ^{aA}	1625.0 ^{aB}	1887.5 ^{aB}
Mean DBH (cm)	14.8 ^{aA}	15.1 ^{aA}	12.7 ^{aB}	14.4 ^{aB}	13.0 ^{aC}	11.8 ^{aC}
Mean tree height (m)	9.7 ^{aA}	9.6 ^{aA}	10.0 ^{aA}	10.3 ^{aA}	10.1 ^{aA}	9.9 ^{aA}
Basal area (m² ha^{-1})	39.5 ^{aA}	37.6 ^{aA}	24.7 ^{aB}	30.1 ^{aB}	28.2 ^{aB}	29.2 ^{aB}
Volume (m³ ha^{-1})	313.0 ^{aA}	259.3 ^{aA}	187.0 ^{aB}	211.5 ^{aB}	191.5 ^{aB}	195.2 ^{aB}
Terrain slope (%)	≈ 40-50		≈10-25		≈ 5-10	

Different lowercase letters in the same line indicate significant differences between harvesting methods. Different capital letters in the same line indicate significant differences among stands.

3.2 Timber harvesting damage

Despite the challenging situation in stand A (steep terrain), no effect on the rates of damaged remnant trees became obvious with respect to terrain slope or stand characteristics. Surprisingly, stand A, with the highest terrain slope (40-50%), showed the lowest degree (29.2%) of damaged basal area (including damaged and dead trees) and the lowest degree (28.0%) of damaged tree volume compared to stands B and C. In the moderately sloped stand B (10-25% slope); both the highest degree of damaged basal area and of damaged volume (35.6% and 35.1%, respectively) was recorded. Stand C, with the lowest terrain slope (5-10%), showed slightly lower degrees of damaged basal area and damaged volume (34.2% and 33.2%, respectively) (Table 3).

Table 3. Harvesting damage for the conventional (CM) and the alternative (AM) harvesting methods across stands considering all trees with DBH ≥ 7 cm o.b, including commercial tree species.

	Stand A		Stand B		Stand C	
	CM	AM	CM	AM	CM	AM
Remnant trees(N ha^{-1})						
Remnant trees	1425.0 ^{aA}	1225.0 ^{aA}	1356.3 ^{aA}	1256.3 ^{aA}	1268.8 ^{aA}	1487.5 ^{aA}
Undamaged trees	762.5 ^{aA}	618.8 ^{aA}	643.8 ^{aA}	668.8 ^{aA}	525.0 ^{aA}	618.8 ^{aA}
Damaged trees	387.5 ^{aA}	425.0 ^{aA}	450.0 ^{aA}	368.8 ^{aA}	462.5 ^{aA}	506.3 ^{aA}
Dead trees	275.0 ^{aA}	181.3 ^{aA}	262.5 ^{aA}	218.8 ^{aA}	281.3 ^{aA}	362.5 ^{aA}
Basal area (m² ha^{-1})						
Undamaged trees	14.3 ^{aA}	13.3 ^{aA}	8.8 ^{aA}	12.2 ^{aA}	7.0 ^{aA}	8.5 ^{aA}
Damaged trees	9.4 ^{aA}	7.4 ^{aA}	7.3 ^{aA}	7.4 ^{aA}	6.4 ^{aA}	7.0 ^{aA}
Dead trees	2.8 ^{aA}	1.7 ^{aA}	2.5 ^{aA}	2.2 ^{aA}	2.6 ^{aA}	3.5 ^{aA}
Volume (m³ ha^{-1})						
Undamaged trees	102.5 ^{aA}	98.5 ^{aA}	61.8 ^{aA}	87.4 ^{aA}	49.8 ^{aA}	58.4 ^{aA}
Damaged trees	70.7 ^{aA}	51.5 ^{aA}	55.8 ^{aA}	53.6 ^{aA}	44.3 ^{aA}	46.3 ^{aA}
Dead trees	16.2 ^{aA}	9.5 ^{aA}	15.8 ^{aA}	13.3 ^{aA}	15.4 ^{aA}	21.7 ^{aA}

Different lowercase letters in the same line indicate significant differences between harvesting methods. Different capital letters in the same line indicate significant differences among stands.

It is important to mention that statistical analysis showed no significant difference between harvesting methods nor among stands regarding the number of residual, undamaged, damaged and dead trees and the corresponding basal area and volume of damaged trees. Despite the lack of statistical proof, we observed slightly higher rates of damaged basal area and damaged volume for CM in stand A and stand B compared to AM. Differently, in stand C, small dimensional trees at high density did not allow any improved felling technique for a reduced impact harvesting. Additionally, it is important to mention that

AM operator was unfamiliar with the characteristics of the Atlantic Forest, particularly composition and structure of a regional secondary forest. This indicated that AM technique with more practice and knowledge in local conditions might achieve better results and, most likely, lower harvesting impact.

Damages caused by the felling were significantly higher than those caused during the winching, in both harvesting methods and in all three stands (Figure 4). The lower impact caused by winching, compared to tree felling, resulted from the planning of individual winching lines in both methods, which included extraction of logs at many different angles in relation to the road. Furthermore, the tractor did not enter the forest stand which also contributed to the lower rates of winching damages.

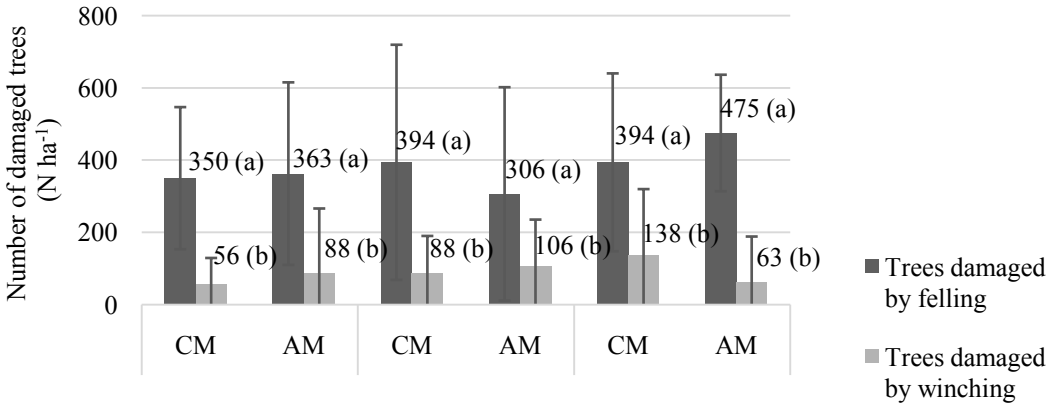


Figure 4. Harvesting damage caused by felling and winching for conventional (CM) and the alternative (AM) harvesting method across stands, considering all trees with DBH ≥ 7 cm o.b. The values represent the mean values (± standard deviation). Different letters indicate significant differences between felling and winching damage.

Regardless of DBH class, the proportion of remnant trees damaged during the harvesting was similar for the two harvesting methods (Figure 5). Yet, most of the damaged or dead trees (65%) belong to the lower DBH class (from 7.0 cm to 11.9 cm). However, despite the ecological importance that smaller trees and tree regeneration may have to the forest recovery, it is expected that any forest intervention may cause some damage to the remnant trees (Picchio et al., 2012). Furthermore, the high grow rates typical for the secondary Atlantic Forest (Fantini and Siminski, 2017) might promote a faster recovery of the forest, mainly in this lower DBH classes.

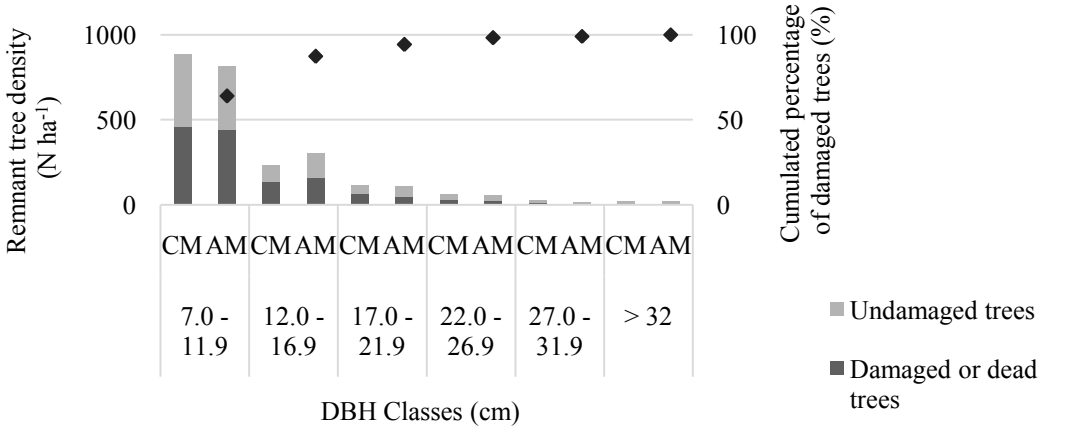


Figure 5. Harvesting damage for the conventional (CM) and the alternative (AM) harvesting methods, considering DBH classes for all tree species. Black dots represented the cumulated percentage of damaged trees related to the total number of remnant trees.

Several studies evaluating the harvesting impact in tropical forests considered only trees above 12.0 cm DBH (Bulfe et al., 2009; Jackson et al., 2002; Johns et al., 1996; Verissimo et al., 1992). Our research, therefore, gave special focus to harvesting damage to intermediary and higher DBH classes (above 11.9 cm DBH) and we recommend them as a guideline for further researches. For every harvested tree CM damaged between 0.8 tree ha^{-1} (stand C) and 2.5 trees ha^{-1} (stand B), while the use of AM resulted in a damage rate between 0.6 tree ha^{-1} (stand C) and 2.2 trees ha^{-1} (stand A) of remnant trees (above 11.9 cm DBH). Stand C showed the lowest degree of damaged tree per harvested tree mostly likely due the high harvesting intensity of improvement felling applied in this stand.

3.4 Geo Analysis

Most of the damaged trees were concentrated in small areas within the plots. Stand A showed a slightly larger "high damaged area" (13.8%) compared to stand B (11.1%) and yet, lower than the dense stand C (15.9%) (Figure 6). Although the map does not show the canopy opening resulting from the felling, intensively affected areas may indicate the creation of big gaps, important to support the development of natural regeneration. However, these gaps are not homogenous and well distributed over the entire plot. Opening a large gap can promote the growth of undesired pioneer species with no commercial interest.

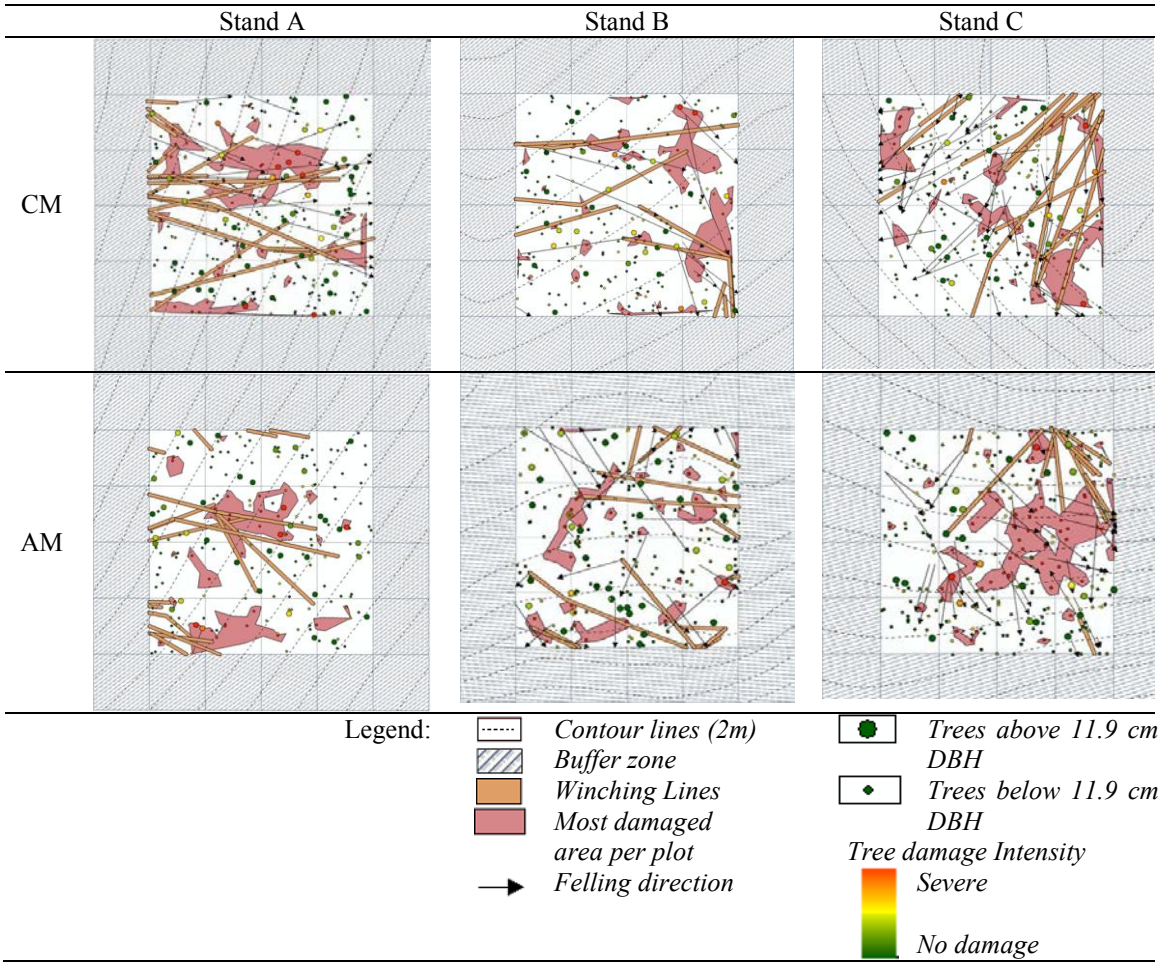


Figure 6. Damage maps with the contour lines, felling direction, winching lines and the most damaged area (red damage zones on the map) per plot.

It is notable in stand A and B, the CM harvesting damaged a larger "most damaged area per plot" (234.3 m² and 194.5 m²) compared to AM harvesting with respectively 206.0 m² and 160.0 m² (Table 4).

Table 4. Winching distance and disturbed ground area per plot.

	Stand A		Stand B		Stand C	
	CM	AM	CM	AM	CM	AM
TIN Most damaged plot area (m²)	234.3	206.0	194.5	160.5	218.5	290.8
Shortest distance from the tree location to the road (m)	32.7	29.7	26.1	23.5	21.1	12.0
Performed winching distance (m)	34.8	30.6	21.5	19.1	33.7	13.1
Estimated winching disturbed ground plot area (m^2)	200.6	140.5	105.9	113.4	184.2	72.0
Estimated winching disturbed ground area per winched tree (m^2)	100.0	54.9	60.1	47.2	60.6	18.0

Note: each research plot has 1600 m². No statistical test was performed for these figures given the lower number of observed winched trees, which resulted in insufficient number of repetitions.

Furthermore, the disturbed ground area by winching under CM in stand A (12.5% of the plot area) and C (11.5%) was also higher than under AM (8.8% and 4.5%, respectively). We attribute the reduced damaged area to the use of a skidding cone and a snatch block during AM harvesting system. These tools enabled improved winching in AM, allowing accommodating the extraction of logs directed to the common extraction direction, for increasing variety of usable extraction corridors and most advantageous, for using extraction corridors for several logs and consequently reducing the total stand area impacted by extraction. Furthermore, spatial analysis of winching lines indicated that the winching lines did not follow the shortest extraction distance from the tree location to the road.

4. Conclusions

Our results suggest that small improvements, like the use of extraction tools and increasing the chainsaw operator's skill, can significantly reduce damage to residual trees. Moreover, the high stand heterogeneity characterized an extra effort and challenged the assurance of comparability between harvesting methods or stands. The high stand density of these forests may also limit the effectiveness of the efforts to reduce harvesting damage. However, this result is important in itself as it reinforces the statement that the secondary forest of the region forms a mosaic of small patches with particular site conditions as well as forest composition and structure.

5. Acknowledgments

The authors would like to express their sincere thanks for the financial support from Barbara und Elisabeth Grammel Studien stiftung; and in addition for further financial support by Eva Mayr-Stihl Stiftung; Georg Ludwig-Hartig Stiftung; Wissenschaftliche Gesellschaft Freiburg. Foundation of Support to the Research and Innovation of the State of Santa Catarina (FAPESC). The authors very much appreciated the support from Mr. Clemente Bizewisky and Mr. Cristiano Bizewisky; Mr. Marlos Schmidt from TAJFUN Brazil; Tropical Forest Institute (IFT); Mr. Sarunas Jomatas; Mr. Heitor Felipe Uller; Mrs. Aline Klitzke; Mr. Gabriel Bollmann, Mrs. Erica Pereira and Mr. Gefferson Elias Piazza. A. C. Fantini and A. C. Vibrans received research scholarships from CNPq.

6. References

Alarcon, G.G., Caporal, D.S., Beltrame, A.D.V., Karam, K.F. (2011). "Transformação da paisagem e o uso dos recursos florestais na agricultura familiar: um estudo de caso em área de Mata Atlântica". Ciência Florestal 21. https://doi.org/10.5902/198050983242

Britto, P.C., Jaeger, D., Hoffmann, S., Robert, R.C.G., Fantini, A.C., Vibrans, A.C. (2017). "Productivity assessment of timber harvesting techniques for supporting sustainable forest management of secondary Atlantic Forests in southern Brazil". Annals of Forest Research 0. https://doi.org/10.15287/afr.2017.898

Bulfe, N.M.L., Galvão, F., Filho, A.F., Donagh, P.M. (2009). “Efeitos da exploração convencional e de impacto reduzido em uma floresta estacional semidecidual na província de misiones, nordeste da argentina”. FLORESTA 39.

Fantini, A.C., Schuch, C., Siminski, A., Siddique, I., (2019). “Small-scale Management of Secondary Forests in the Brazilian Atlantic Forest”. Floresta e Ambiente 26.

Fantini, A.C., Siminski, A. (2017). “Manejo de florestas secundárias da Mata Atlântica para produção de madeira: possível e desejável”. Revista Brasileira de Pós-Graduação 13.

Fowler, R.J., Little, J.J. (1979). “Automatic Extraction of Irregular Network Digital Terrain Models, in: Proceedings of the 6th Annual Conference on Computer Graphics and Interactive Techniques, SIGGRAPH ’79”. ACM, New York, NY, USA, pp. 199–207. https://doi.org/10.1145/800249.807444

Jackson, S.M., Fredericksen, T.S., Malcolm, J.R.(2002). “Area disturbed and residual stand damage following logging in a Bolivian tropical forest”. Forest Ecology and Management 166, 271–283.

Johns, J.S., Barreto, P., Uhl, C. (1996). “Logging damage during planned and unplanned logging operations in the eastern Amazon”. Forest Ecology and Management 89, 59–77.

Lingner, D.V., Schorn, L.A., Sevegnani, L., Gasper, A.L. de, Meyer, L., Vibrans, A.C. (2015). “Floresta ombrófila densa de Santa Catarina - Brasil: agrupamento e ordenação baseados em amostragem sistemática”. Ciência Florestal 25. https://doi.org/10.5902/1980509820595

Metzger, J.P. (2009). “Conservation issues in the Brazilian Atlantic forest”. Biological Conservation, Conservation Issues in the Brazilian Atlantic Forest 142, 1138–1140.

Oliveira-Filho, A.T., Budke, J.C., Jarenkow, J.A., Eisenlohr, P.V., Neves, D.R.M. (2015). “Delving into the variations in tree species composition and richness across South American subtropical Atlantic and Pampean forests”. J Plant Ecol 8, 242–260. https://doi.org/10.1093/jpe/rtt058

Picchio, R., Magagnotti, N., Sirna, A., Spinelli, R. (2012). “Improved winching technique to reduce logging damage”. Ecological Engineering 47, 83–86. https://doi.org/10.1016/j.ecoleng.2012.06.037

Ribeiro, M.C., Metzger, J.P., Martensen, A.C., Ponzoni, F.J., Hirota, M.M. (2009). “The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation”. Biological Conservation, Conservation Issues in the Brazilian Atlantic Forest 142, 1141–1153.

Silva, D.A. da, Piazza, G., Fantini, A.C., Vibrans, A.C.(2018). “Forest management in a secondary Atlantic Rainforest: assessing the harvest damage”. Advances in Forestry Science 4, 187–193.

Trevisan, A.C.D., Schmitt-Filho, A.L., Farley, J. Fantini, A.C., Longo, C., (2016). “Farmer perceptions, policy and reforestation in Santa Catarina, Brazil”. Ecological Economics 130, 53–63.

Verissimo, A., Barreto, P., Mattos, M., Tarifa, R., Uhl, C.(1992). “Logging impacts and prospects for sustainable forest management in an old Amazonian frontier: The case of Paragominas”. Forest Ecology and Management 55, 169–199. https://doi.org/10.1016/0378-1127(92)90099-U

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

WET AREA MAPPING USING REMOTE SENSING DATA IN LATVIA

Janis Ivanovs, Ainars Lupikis, Andis Lazdins
LSFRI Silava, Salaspils, Latvia
janis.ivanovs@silava.lv

Abstract: *Aim of this study is to evaluate possibilities of using LiDAR data and multispectral satellite imagery in detecting spatial distribution of wet mineral soils in forest. Area of this study consists of 20 sites, each covering 1 km2 and are located on different types of Quaternary sediments. Up to 10 study plots are in each study site. Data about forest and soil characteristics are collected during field works, but various spatial indices are acquired from*
remote sensing data. One-way ANOVA test are used to compare obtained data for different soil wetness classes, while binary logistic regression analysis is used to obtain indices for predicting soil wetness in wider area. The results of this research show that different remote sensing indices and their combinations should be used to predict soil moisture regime on various Quaternary deposit types. The accuracy of soil wetness classification is tested on training data and on different Quaternary sediment types it is between 83 – 97%.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

RESPONSE OF SOIL PHYSICAL PROPERTIES FOLLOWING THE APPLICATION OF SOIL RESTORATION TECHNIQUES ON MACHINE OPERATING TRAILS

Siegfried Waas [1,2], Eric R. Labelle [1], Herbert Borchert [2]
[1] Assistant Professorship of Forest Operations - Department of Ecology and Ecosystem Management - Technical University of Munich, Freising, Germany; [2] Bavarian State Institute of Forestry (LWF) - Department 4 – Forest Technology, Business Management and Timber, Freising, Germany
siegfried.waas@lwf.bayern.de

Abstract: *In recent decades, the use of heavy machinery in mechanized timber harvesting has increased exponentially in central Europe. Heavy axle loads of machines required to harvest and transport wood within the forest stand result in serious soil structure damage such as compaction, rutting and soil displacement. Compacted machine operating trails commonly exhibit higher soil bulk density as well as lower water infiltration and hydraulic conductivity. To facilitate the long-term use and maintain technical trafficability of machine operating trails, restoration strategies for the management of affected areas have to be developed. To gain additional knowledge, the aim of this study was to analyze and compare the effects of two soil restoration techniques performed in triplicates on three machine operating trails in Freising (Germany, Bavaria). All machine operating trails had been exposed to forwarder traffic during a recent mechanized cut-to-length operation. In treatment 1, the damaged trails were levelled and packed with a light tracked excavator (15,000 kg). In treatment 2, the trails were additionally aerated with a tractor-mounted attachment equipped with 35 cm long spades (total mass of 14,100 kg). Several soil physical parameters (penetration resistance, bulk density, infiltration rate, hydraulic conductivity, air permeability, pore size distribution) were examined before and after the restoration procedures. Productivity and the costs of the considered techniques were also monitored and assessed. In the field, intact soil cores of 100 cm³ (total of 192 samples) were sampled at pre-defined transects on the machine operating trails at 10, 20 and 30 cm depths and used for measurements of soil dry bulk density, hydraulic conductivity and air permeability. Penetration resistance (864 measurement points) and infiltration rate (120 measurement points) were measured pre and post impact on transects located perpendicular to the main axis of the trails to assess the performance of the treatments. First results suggest that the restoration and aeration of compacted machine operating trails lead to a significant decrease in soil dry bulk density and penetration resistance, thus potentially indicating their usefulness in the restoration of compacted forest soils.*
Keywords: Forest soil; Soil compaction; Soil disturbance; Soil health; Mechanized harvesting

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

QUANTIFYING SOIL DISTURBANCE IN A WHOLE-TREE OPERATION METHOD

Alex. K George, Anil Raj Kizha
School of Forest Resources, University of Maine, Orono, ME-04469, USA
alex.george@maine.edu

Abstract: *Soil disturbance, in the form of compaction and rutting, induced by skidding in timber harvest stands is proved to have adverse long term effects on forest productivity and sustainable management. Laying harvest residues (slash) along sensitive areas on the skid trails is one common strategy used to mitigate disturbance caused to soil profile. The primary objective of the study was to understand the impacts of frequency of machine pass, soil moisture content, slope of skid trail, and machine turnings on soil disturbance during timber extraction phase. The next objective was to analyze the impacts of the depth of slash mats on soil compaction and rutting. The field study was conducted on a whole tree harvesting operation in Central Maine, USA. Penetrometer depth (at 1.7 mpa), rut depth, and soil disturbance classes were measured for the first 15 machine passes of the skidding phase from designated monitoring station. Other variables measured included soil moisture conditions, skid trail slope, and slash depth on skid trail. Standardized models are being developed to determine the impact of the above-mentioned variables on soil compaction and rutting. The expected results of the study are to find a correlation between, i) penetrometer depth and machine frequency; ii) slash depth and rut depth; iii) slash depth and penetrometer depth; iv) soil disturbance and slash depth; v) soil disturbance and soil moisture; and vi) soil moisture and machine frequency. The study aspires to come up with an optimal slash depth model which can achieve minimal soil disturbance. We anticipate the study will provide crucial information to the timberland managers and operational foresters in better understanding the effects of skid trail, choosing sustainable and cost-efficient extraction methods.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

SOIL DISTURBANCE FROM TETHERED FORWARDING ON STEEP SLOPES IN BRAZIL

Austin M. Garren [1], M. Chad Bolding [1],
W. Mike Aust [1], Angelo Moura [2], Scott M. Barrett [1]
[1] Department of Forest Resources and Environmental Conservation,
College of Natural Resources and Environment,
Virginia Tech, Blacksburg, Virginia USA;
[2] Suzano Pulp and Paper, Jacareí, São Paulo, Brazil
bolding@vt.edu

Abstract: *Timber harvesting on slopes too steep for safe machine travel has typically been accomplished by using labor-intensive and often environmentally impactful methods such as manual felling with chainsaws and extraction using bladed skid trails, winching, or cable yarding. On gentle terrain, ground-based mechanized harvesting systems are common throughout the world and have been adapted and refined to achieve high levels of productivity. In some regions of the world, cut-to-length harvesters and forwarders are used and are typically low-impact, safe, and efficient alternatives. However, when this equipment is operated on steep slopes, numerous problems are encountered such as poor stability, loss of traction, and increased soil disturbance. Tethered or cable-assisted logging practices are being used around the world to overcome some of the issues associated with operating equipment on steep slopes. This technology has been implemented in Brazilian Eucalyptus plantations for some time; however, questions remain in relation to operational feasibility and environmental impacts. There is especially a lack of information regarding how ground-based equipment affects the soil when tethered on steep slopes. The objectives of this project were to quantify changes in soil bulk density, rutting depth, and predicted erosion resulting from varying numbers of passes and payload levels by forwarders. The machines were equipped with two different track-band configurations for improved traction and tethered by either a machine-mounted (HAAS) or self-contained winch (Twinch), on slopes ranging from 50-87%. This study will provide baseline information on how impactful tethered forwarders are on soil properties and how the impacts vary based on slope steepness, traffic level, and winch assist mechanism.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

SOIL DEGRADATION AND WOOD EXTRACTION OPERATIONS: COMPARING SKIDDING AND FORWARDING

Francesco Neri, Elena Marra, Giovanni Mastrolonardo, Andrea Laschi, Cristiano Foder, Enrico Marchi
DAGRI - Dipartimento di Scienze e Tecnologie Agrarie, Alimentari, Ambientali e Forestali, Università di Firenze, Firenze, Italy
francesco.neri@unifi.it

Abstract: *Forest harvesting operations may have a significant impact on soil physical properties. The soil disturbance extent and severity, during wood extraction operations, are related to the condition of the soil, harvesting system. Impacts mainly consists of soil compaction, displacement, and rut formation. Several papers investigate, on the short term period, the soil damages caused by logging operations, but information on the effects of logging on the medium and long term period are still missing, thus highlighting the needs of further investigations on this topic.*
This study investigates the effects of wood skidding and forwarding on soil degradation on three sites located in Central Italy. Results are related to the medium and to the long term period after logging operations and in details were considered six months, 1 year and 3 years after forest operations.
Changes in porosity, bulk density, shear and penetration resistances were investigated on two plots for each wood extraction system adopted (skidding and forwarding). The analysis was conducted using traditional methods (cone penetrometer, steel cylinder and vane test) for evaluating soil damages caused by a loaded forwarder and skidder. The lack or the presence of forest regeneration was also highlighted. After different period from logging operations it was possible to assess that the restoring time of extraction tracks it is related to the previous soil compaction level. Natural regeneration was often observed where the skidder operated and on sandy soils compacted by forwarder machines.
In conclusion the effects on soil of forest machines are still present after long term period, thus suggesting that the use of previous tracks must be encouraged to avoid the extension of soil disturbance.

S03 Human factors
It's still hard work out there

ACQUIRE AND MANAGEMENT OF CHAINSAW TREE FELLING AND BUCKING WORK BY ICT - SMART CHAINSAW AND UTILIZATION
Toshio Nitami [1], Sooil Suk [2], Yasufumi Maruyama [1], Tetsuya Matsumura [1]
[1] University of Tokyo, Tokyo, Japan; [2] Co-Lab., Daegu, Korea

AGEING WORKFORCE – A CHALLENGE FOR WORK SCIENCE, JOB DESIGN AND HUMAN RESOURCES DEVELOPMENT
Edgar Kastenholz, Andrea Teutenberg, Ute Seeling
Kuratorium für Waldarbeit und Forsttechnik (KWF) e.V.

COMPARISONS BETWEEN BATTERY AND GASOLINE CHAINSAWS IN TERMS OF NOISE EXPOSURE, ENERGY EFFICIENCY, AND CUTTING PERFORMANCE
Christoph Huber, Nikolaus Nemestóthy
Austrian Research Center for Forests - Forest Training Center Traunkirchen, Austria

FORESTRY EDU TRAINER - COOPERATION FOR INNOVATION IN EDUCATION AND TRAINING
Andrea Teutenberg, Joachim Morat, Ute Seeling
KWF e.V. - Kuratorium für Waldarbeit und Forsttechnik e.V., Groß-Umstadt, Germany

MOVEMENT ANALYSIS OF A WORKER IN THE FOREST CLEANING ACTIVITIES
Marin Bačić, Matija Landekić, Marijan Šušnjar, Mario Šporčić, Zdravko Pandur
Faculty of Forestry, University of Zagreb, Croatia

ANALYSIS OF RISKS CAUSED BY VIBRATIONS AND NOISES IN SMALL-SCALE FIREWOOD PRODUCTION
Andrea R. Proto [1], Stefano Grigolato [2], Salvatore Papandrea [1], Maria Francesca Cataldo [1],Raffaele Cavalli [2], Giuseppe Zimbalatti [1]
[1] Department of AGRARIA - University Mediterranea of Reggio Calabria, Italy [2] Department of Land Environment Agriculture and Forestry - University of Padova, Italy

FORMEC 2019 – Exceeding the Vision: Forest Mechanization of the Future
6-9 October, 2019 - Sopron, Hungary

Acquire and management of Chainsaw tree felling and bucking work by ICT - Smart Chainsaw and utilization

Toshio Nitami*[1], Sooil Suk[2]
Yasufumi Maruyama[1], Tetzya Matsumura[1]

1: Laboratory of Forest Utilization, Department of Forest Sciences
Graduate School of Agricultural and Life Sciences, The University of Tokyo
1-1-1 Yayoi, Bunkyo-ku, Tokyo, Japan
2: Co-Lab., 4th Floor, 14. Dongdeok-ro-6-gll, Jung-gu
Daegu, 41953, Republic of Korea

1: nitami@fr.a.u-tokyo.ac.jp, batoncookiemonster@gmail.com, tetzmat@gmail.com
2: hl5fca@me.com

Abstract: *Chainsaw tree felling is an inevitable forestry work which suffer from frequent manual work accidents. Even if we are delight with advanced machineries in the forestry fields, the most important work processes were carried out by chainsaw manual work especially on the steep hillsides. Our Smart Chainsaw was developed based on a general engine chainsaw and attaching sensors, such as 3 axis acceleration, 3 axis gyro and so on, on it and provided with information connect function through Bluetooth. It aims at lesser these accidents, better work environments and more efficiency. A work process and posture were acquired by sensors on the chainsaw and were showed in 3D moving scenario. Tree felling works were digitalized and the processes were compared to show the difference of process. Understanding through acceleration signals was focused on at initial stage.*

Keywords: chainsaw, manual work, vibration, posture

1.Introduction

Chainsaw is essential machine for manual forestry work not only for tree felling and for versatile work in the forests. And chainsaw today is very sophisticated to have well design for manual handing, safety function, high power and less vibration and son on. But we still suffer from

trouble/accidents through the operation. ICT offers us to make it useful by reading the condition and put management on it. The operation situation, cutting accuracy, felling productivity could obtain through the system.

2.Material

A chainsaw with sensors and data processing/transmitting function was developed and the functions are having been evaluating and the data process system has been developing.

Through attending an WLC for chainsaw workers operation data were obtained for an operation under designed manner. In the trial of the Novice class at HLC held in Tottori Prefecture in July in 2019, it participated with a smart chainsaw, and the operation situation at that time was recorded as digital data. The trial was done by cutting down, cross cutting, and delimbing. In particular, it was analyzed using a vibration acceleration, figure 1.



Felling , Short log version for Novice.



Crosscutting



Delimbing

Figure 1. Operation trial at Chainsaw technique competition HLC (Husqvarna Logging Championship).

3.Method

The chainsaw was equipped with sensors based on the HusqvarnaGP4350EZH, figure 2. The ICT part embedded a board with sensors embedded in the handle grip. The data was stored in a built-in SD card and also sent to the smartphone via Bluetooth.

The chainsaw was extensively equipped with several sensors to know location, acceleration, rotation, throttle and engine revolution. The chainsaw has scarcely room and handle grip inside and bottom were utilized to install devices. Data were sampled at 100Hz.



Figure 2. Sensors and the PCB was installed inside the handle grip.

4.Result

A series of collected data is of the above three trials performed during about three and a half hours. I show the acceleration in the x-axis direction in the figure 3.

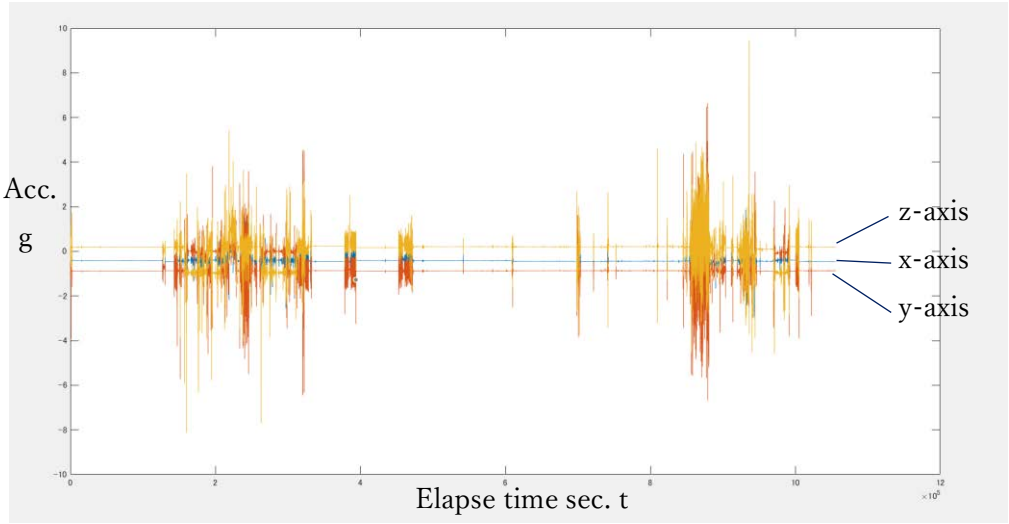


Figure 3. Record of chainsaw operation.

t: 1.5-3.0*10^5: felling, 3.5-5.0*10^5: cross cutting, 8.2-9.0*10^5: delimbing

blue: x-axis, red: y-axis, yellow: z-axis

It was divided into three sections trial of felling, cross cutting, and delimbing.

Since the raw data is a synthesis of gravitational acceleration and vibration acceleration, we tried to grasp the chainsaw posture by moving average. It was determined that the tendency of the posture can be read when the moving window size was 10 seconds as shown in the figure 4,5,6.

In the felling trial, initial tree trunk preparation by v smoothing left and right vertical sides of the trunk (a) as shown in the figure 1. Also, it was possible to read the sawing was advanced to make felling hinge last (b) and cut off. The vibration by the cutting acceleration of about 0.4 - 0.8g.

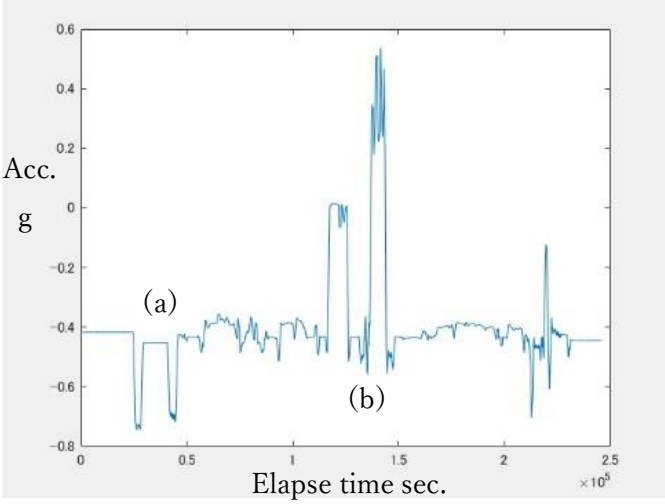


Figure 4. Acceleration-x axis
Felling, 10 sec smoothed.

In the delimbing trial, it was understood that the branches were cut off while moving chainsaw along on the trunk while changing the chainsaw posture as shown in the figure 5.

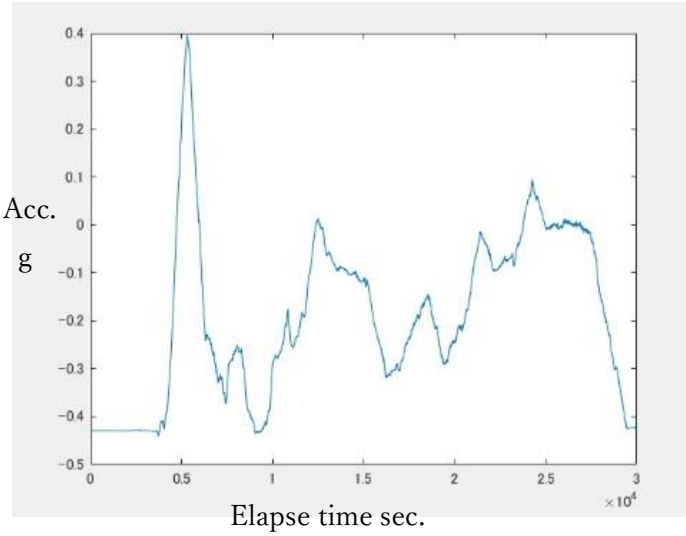


Figure 5. Acceleration-x axis
Delimbing, 10 sec smoothed.

In cross cutting trial, it was possible to grasp two works of cutting off of the log ends were carried out by moving one to another as shown in figure 6.

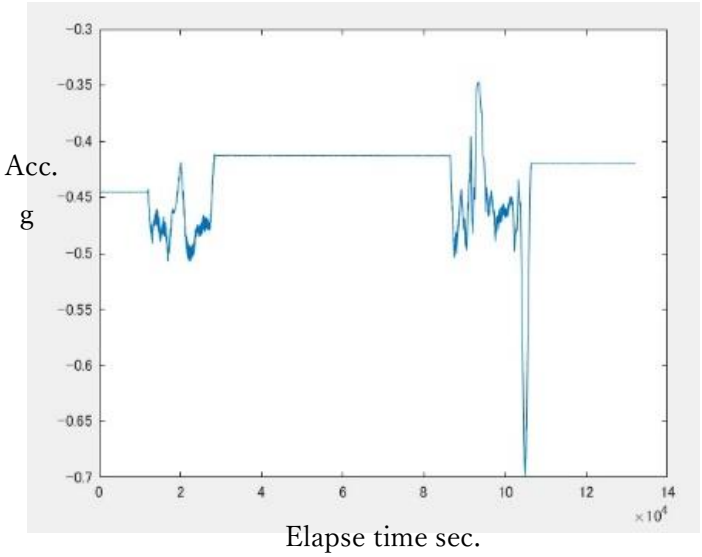


Figure 6. Acceleration-x axis Crosscutting, 10 sec smoothed.

The machine vibration magnitude during sawing work was evaluated by three-axis synthetic acceleration, AC3.

AC3 is defined by,

$$AC3 = \sqrt{acx^2 + acy^2 + acz^2} \quad (1)$$

here, acx is acceleration in x axis,

acy is acceleration in y axis,

acz is acceleration in z axis.

So, we have AC3 for felling operation, AC3 for delimbing operation and AC3 for cross cutting operation, as shown figure 7, 8, 9.

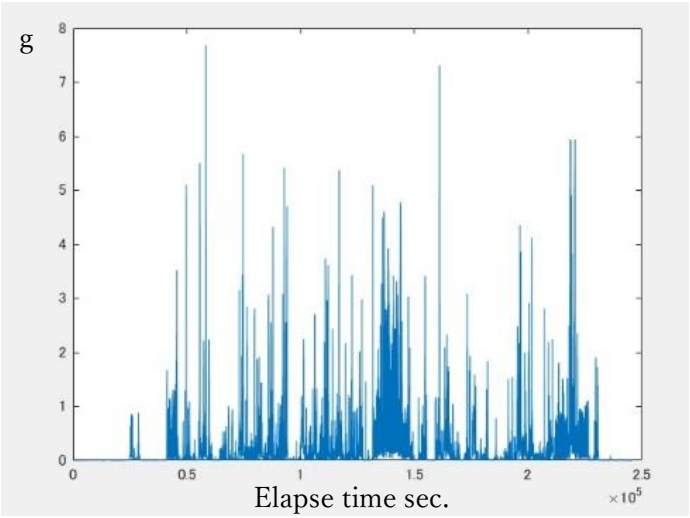


Figure 7. AC3 at Felling.

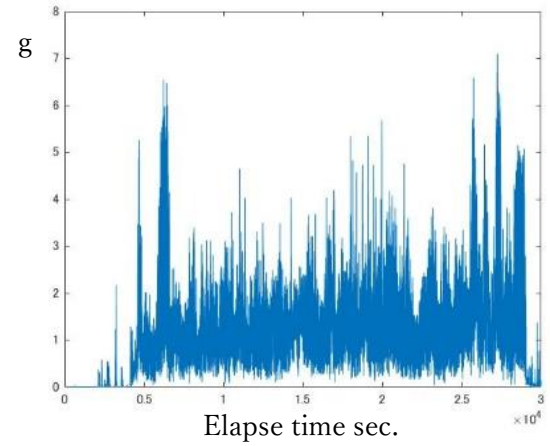


Figure8. AC3 at Delimbing

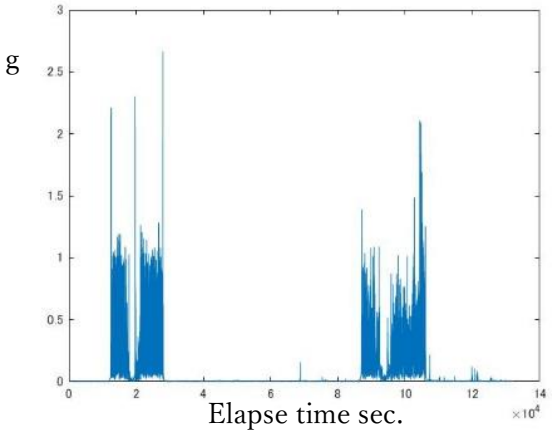


Figure 9. AC3 at Crosscutting

5.Discussion

Vibration acceleration in the actual chainsaw sawing work is large, about 5g was frequent. Since the three-axis synthetic acceleration representing the chainsaw body vibration characteristics are many things are 4 to 5m/ s^2, i.e. 0.5 g, it was about 10 times larger than them.

Posture action of the chainsaw manual work was shown by magnitude of acceleration move mean with the wind size of 10 seconds. Each axis acceleration was processed by this way and combination of x, y and z acceleration visualize the movement of the chainsaw (video).

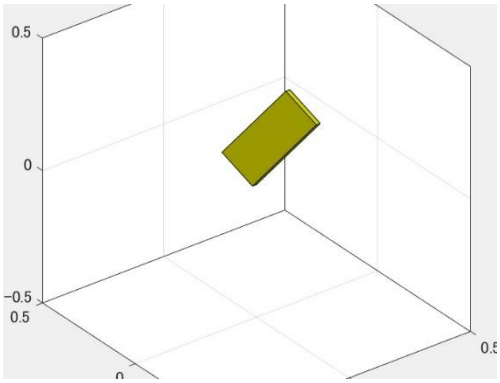


Figure 10. Chainsaw posture in action (movie).

6.Conclusion

We were able to attach sensors to any chainsaw to understand the situation at work numerically. The acceleration data allows us to understand the working posture. From the size of the work contents and vibration, cutting mode cut to wood is the main, vibration was large at cross cutting operation. It was about 10 times larger than that of idle racing. Although it is presumed that the appropriateness sharpening of the saw chain to be cut tree/log affects the vibration, it is necessary to consider in quantity about the appropriateness and vibration that stand out in the future.

Further development is needed to configure operation model in introducing extra measurements such as the throttle opening, engine speed, saw chain speed, and attitude angle speed.

Sensor devices can be standardized to accommodate a wide variety of models. We would like to promote the development and development of application software and improve the functionality and convenience.

A function for less experienced worker to advice the operation and also a function for experienced worker to keep the safety and productivity will be installed. For the business management requirement, Bluetooth connection to smartphone can be useful to have electrical daily operation report function.

7.Acknowledgements

We thank so much Husqvarna Zenoah Japan for providing chainsaw machines/parts for the research/development and operation field assistance.

8.References

Nitami T., Suk S. and Amerika-ya (2018) “Smart Chainsaw - ICT and IOT on manual chainsaw operation for safety and productivity at forestry operation –,” FORMEC2018, Madrid, Spain.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

AGEING WORKFORCE – A CHALLENGE FOR WORK SCIENCE, JOB DESIGN AND HUMAN RESOURCES DEVELOPMENT

Edgar Kastenholz, Andrea Teutenberg, Ute Seeling
Kuratorium für Waldarbeit und Forsttechnik (KWF) e.V.
Spremberger Straße 1, D-64823 Groß-Umstadt, Germany
edgar.kastenholz@kwf-online.de

Abstract: The anticipated shortage of keen and motivated forest workers is a severe thread for forest operations in the future. Due to high competition for young entrants in all sectors the recruitment of forestry workers becomes more and more difficult. While it is of crucial importance to increase the training and recruitment of young workers, it is evenly important to ensure that forest workers will stay in their jobs. The forestry workforce on average is ageing and many forestry workers have constraints to carry out specific demanding tasks well before reaching the statutory retirement age. For many reasons, not at least to sustain a competent workforce, it is important to take initiatives to maintain the employability of forest workers as long as possible. Actual research aims at concepts for age-friendly working conditions in forest operations and personnel development policies to achieve a holistic life-course approach of early intervention, general risk prevention, and job design.

Keywords: workforce, demographic change, employability

1. Introduction – demographic change and ageing workforce

1.1 Demographic change

Demographic change has a deep impact on societies and economies. Demographic change has achieved high awareness as a future challenge in industrialised countries and has achieved a high priority on the political agenda. In a nutshell demographic change means that the social fabric changes due to decreasing birth rates and increasing longevity. With improved medical treatment and better living conditions people not only have the chance to get older but also to have higher number of healthy live years, which is the timespan until severe health complaints occur which limit their well-being and activity (EU-OSHA, 2017). As a general effect people will be able to stay considerably longer in employment than their parent generation. And they will also have to work longer since the statutory retirement age has been risen gradually over the past years.

Therefore, maintaining the employability of the workforce therefore is an enormous challenge for enterprises in all economic sectors since an ageing workforce is of course not only a problem in forestry. Consequently, the European Commission (2014) identifies in its “Strategic Framework on Health and Safety at Work 2014-2020” that taking account of the ageing of the EU's workforce is one major key challenge of today.

To keep workers in their jobs as long as possible is not only a political and social need, it is also more and more important for maintaining a keen and competent workforce, since the availability of young entrants is limited. Forestry competes on a very tight market with other professions which may be more attractive in various terms. Forestry work seems to have a rather low attractiveness compared to other jobs, not at least since it is a physically demanding profession.

1.2 Work ability and employability

Before the impact on forestry and forest operations is addressed, it is worthwhile to outline the problem area in more general terms not at least to provide some definitions and clarity on social and political frame conditions. Physical and mental capacities change with time. Unfortunately, physical capacities of most people decrease during their life time and the probability of suffering from chronic diseases increases. What may sound like a platitude is the rationale for looking into the concepts of work ability and employability.

In the age group 55 years and older the proportion of workers suffering from a chronic disease or having an illness that has lasted more than 6 month is higher than among younger workers. Chronological age is not the only factor. It is obvious that there are older workers who are fit and healthy and face no constraints at all to carry out physically strenuous work, while there are young workers who have a limited working ability due to health issues (Eurofound, 2014). Also workers in the middle age group may suffer from chronic diseases or accident related handicaps and have to quit their jobs before the age of 55 (Eurofound, 2014). It very much depends on individual physical and mental dispositions at what time in life health problems arise.

Many people do not stay in employment until the statutory retirement age. "The average age at which workers exit from the labour market in the EU is 61 years" (EU-OSHA et al., 2017). And for many people it is not really desirable or manageable to work as long. "In Europe 28% of the workers think that they are not going to be able to work until they are 60. In workers older than 55 27% feel that they will not continue working throughout the next 5 years"(EU-OSHA et al., 2017). There are many reasons for early retirement. In many cases poor health is a driving or contributing factor.

In the context of this paper the focus is on workers suffering from health problems which limit their ability to work in their own job. The most prominent and obviously most frequent case in forestry is that chainsaw operators are no longer able to cope with the physical strain of their tasks throughout a working day. A typical reason is low back problems. In this case a worker faces health related limitations to continue carrying out the tasks which are substantial to their job. This is a loss or limitation of work ability and has led in the past to the medical certificate of an early disablement with subsequent early retirement. But the political and social frame conditions have changed. Today, it is a highly ranked political goal to increase the employment participation of the older population as long as possible, among others as a means for integration and contribution of people in social life, but of course also from the utilitarian perspective to maintain a competent workforce under the premise of demographic change. And last but not least, pension and insurance schemes can simply not afford any more extended expenses for pensions when the life expectancy is still increasing. And, speaking for the actual German situation, in times of high unemployment the justification for retiring before the statutory retirement age was much easier than today, when in Germany one can speak of full employment.

The EU Lisbon Strategy (2000) sets the goal of promoting employment by creating more jobs and longer working lives with better quality. The key objective on society and enterprise levels therefore is to maintain the employability of workers. In simple terms this means that a person may have lost their ability to carry out tasks which are substantial to the own job, e.g. working with a chainsaw. But this worker is still able to be employed either with alternative or additional tasks in the scope of the own enterprise or in a different job. This is in line with the policy of rehabilitation instead of pension which has become a principle in German social legislation.

As a result, enterprises are challenged to facilitate the employability of their workforce by individual and enterprise policies and strategies consisting of health and safety concepts, human resources development concepts, in line with improving working conditions and adapting working conditions to the needs and capabilities of older workers.

In this context the term "altered performance" plays a role. At first sight the term may be seen as a political correct wording for "disablement" what would provide a rather weak conceptual value for dealing with the problem that a high number of forest workers face limitations of their work ability due to

health problems. In fact these workers suffer from a partial disablement which should not be covered by a verbal adulteration. It should be clearly named that forest workers are exposed to health risks and are at risk to suffer from work related health problems and disablement. Coherently, “altered performance” has not yet entered juridical terminology in Germany, where the legal basis for compensation, rehabilitation and retirement still clearly is whether a person has limitation to its work ability. But when it comes to human resources management and development the exclusive focus on disablement or degree of work ability does not offer solutions. Since the challenge is to maintain the employability of a person it is necessary to look at the overall set of capabilities this person owns. The most commonly used formula is: with age a worker will get reduced physical capacities but wins experience and knowledge. This is more and more identified as a highly valuable asset of enterprises. And it can be assumed that particularly in forest operations the value of these “soft skills” is still dramatically undervalued.

1.3 Aim of this paper

This paper reflects on the relevance of the impact of demographic change on forest operations in the future. It tackles an issue which so far has been announced on a political level. It has not yet been followed up by substantial scientific analysis. This presentation therefore intends to raise awareness for the need to take a closer look into the issue and it invites the forest work science community to joint research activities for coping with the arising challenges.

1.4 Material, empirical basis and scope

The empirical basis on demographic factors in forestry is still rather weak. The last inquiry in Germany was undertaken in 2011 and covered the age distribution of the overall workforce in German state forest enterprises. Already this study showed clearly that the amount of employees in the age group 50 years and older was over- proportional to a balanced age distribution (Brand et al., 2011). Unfortunately, this statistical assessment could not be updated until the presentation of this paper.

The actual findings on the state of art in German state forests which form the empirical basis of this paper are based on exploratory interviews with experts and a group discussion with safety and health experts from all German state forest enterprises which was held in spring 2019.

Therefore, this paper presents an explorative study with a specific scope. It focuses mainly on the situation in Germany, but there is a considered guess, that the core findings match the experience in other countries. Further, this study can only reflect the situation of the core workforce in state enterprises. A contribution to the evenly exciting question how forest service enterprises deal with age-related changes of workers´ performance cannot be derived from these considerations.

2. Ageing work force - a challenge for forestry

2.1 Ageing work force on the political agenda

The availability of a keen and competent forest workforce has been identified on many occasions as a critical bottleneck for sustainable forest management. This is namely the fact on the European political arena. Among other data sources the analysis of the data for the State of Europe´s Forest report 2011 showed that the sustainability of the forestry work force is at risk due to ageing workers, declining numbers of employees in forestry, and a persisting alarming accident frequency (Forest Europe, 2011). The on-going ageing of the forestry workforce was confirmed again by updated statistics (Forest Europe, 2015).

On the other hand it is a clear political statement that

> "[a] sustainable, trained and safe workforce is one of the pillars of a more competitive forest sector. Well-managed forests with qualified forest managers, workers and entrepreneurs pave the way for a sustainable and competitive forest sector that plays an important role in rural development and in the whole economy while providing societal benefits" (European Commission, 2013).

Concerns related to ageing and demographic change were also risen by the ILO which in its recent report on forestry the ILO observed that "… in view of demographic transitions and the shortage of young people working in forests, challenges such as the capacity to cope with strain are a matter of concern for the older forestry workforce" (ILO, 2019).

While the problem of demographic change and its impact on forest management and forest operations have achieved some political awareness, it has not yet been taken up by the scientific community as a topic for research and development. Therefore, the empirical evidence on the subject is rather limited and the search for knowledge based solutions has not yet been started. However, the observations and the evidence provided from practice justifies that the problems and challenges need to be taken serious.

2.2 From early retirement to rehabilitation and maintaining employability

Already at a workshop held in 2011 the concern about demographic change and its impact on the future forestry workforce was discussed (Brand et al., 2011). One major conclusion was that forest enterprises should search for task within the forestry management processes to allow forest workers with altered capabilities to stay employed in the enterprise. This was a considerable shift of focus since in the past it was quite common that a forest worker who suffered e.g. from musculoskeletal disorders – commonly: low back problems, which of course related to a high physical work-load over his working life, received the medical certificate of an early disablement. This workers were not able to carry out their own jobs any more due to poor health and – based on the medical certificate – they was allowed for early retirement. Matter of fact a high number of forest workers retired around the age of 60 (e.g. Lewark and Härle, 1991). The number of workers staying in forestry work older than 60 was rather rare since most of the workers suffered from some kind of work related health complaints.

However since times are changing the opportunity for older workers to stop working and retire with a disability pension has been reduced considerably for many reasons. This again calls for activities on enterprise level to maintain the employability by individual support, decent work organisation and human resources development strategies on enterprise level. The following chapter provides some impressions of the situation in German forestry.

3. State of the art in German state forest enterprises

3.1 German state forest enterprises face the challenge of an ageing workforce

While there are structural and organizational differences between German state forest enterprises, they all have in common that they face the challenge that the forest workforce is ageing. The average age of the forest workers in German state forests enterprises gets closer to 50 years. This is partially due to the fact that over the last decades forest operations have been gradually outsourced to contractors, and that vacant posts of retired forest workers were not replaced with young entrants. Secondly, workers stay longer in employment than in the past, since early retirement based on a medical certification of work-related disablement is less common than in the past.

First inquiries show that there are considerable differences between the German state enterprises, particularly with regard to the human resources management and development strategies applied at enterprise level. For the scope of this paper it is not intended to dig into the management structures and

their differences and commonalities. The focus will be on strategies and measures which are applied or planned at different levels across Germany. An assumption on how the effectiveness of age management is related to the form and extend of human resources management and the awareness for health and safety on top management level must be subject to future considerations. Just in brief: In discussions about experiences in enterprises it was addressed that the effectiveness of employing workers with altered capabilities with meaningful jobs is very much related to the level of awareness from managers.

3.2 Ageing and altered performance of forest workers

The common denominator is that ageing of the workforce is a severe concern in all German state forest enterprises. And it is nothing coming out of the blue, but it has been forecasted for many years (Brand et al. 2011). However, most German state forest do not yet have a clear strategy or concept to cope with the problem that a considerable amount of workers is not capable any more to carry out specific physically demanding tasks. It needs to be stated again, that at first hand limited capabilities and loss of work ability are individual phenomena which are subject to a medical diagnosis and need a medical certificate. On the other hand it has become a collective organisational problem since the number of workers with health related limited capabilities increases.

Forestry work, particularly motor-manual work is carried out in teams, preferably teams of 3 or more workers who have their operation area in a specific district. In the best case these workers form are a well-rehearsed team with a considerable amount of autonomy. When one team member is no longer able to carry out the assigned task, e.g. to work full time on the chainsaw, the team is not operational any more. For the district management and the team it is an enormous organisational challenge to replace a team member for example by shifting workers from one district to another. Higher commuting distances, adaptation to changing group structures are factors which are not well appreciated by most workers and need to be compensated with various incentives.

The matter of concern in most state forest enterprises is that the amount of tasks which can be carried out by workers with limited work ability does not seem to match the work capacities. Therefore, the question arises, whether alternative tasks are productive and effective enough to justify employing a professional forest worker.

In the recent explorative study industrial physicians and managers raised a very important point: It is of utmost importance to respect that forest workers draw a considerable amount of their self-esteem from their professionalism which includes of course the physical and mental capacities to cope with strenuous and dangerous tasks. An experienced industrial physician considers that the diagnosis of a limitation to the work ability in the own job is one of the major reasons for psychological health problems of forest workers. And it is worth mentioning that today psychological issues are more frequently identified among forest workers than in the past.

3.3. Strategies

Some state forest enterprises have embarked on coping with the challenge. In some cases positions for human resources development have been established, and these enterprises work on strategies to maintain the employability of the ageing workforce. From these enterprises good practice cases can be presented.

> Good practice 1: Based on a longer term strategy starting about a decade ago specialised teams have been formed. They consist of workers with health related limitations for heavy physical work These teams carry out a number of tasks, such as silviculture work, planting, road maintenance and maintaining of hunting infrastructure. They work on inter-district level, which means that they offer their capacities for a full regional management unit. These teams are well appreciated by colleagues and managers and their services are well in demand. The team members do not consider themselves as a fifth wheel in the company but have the feeling that they do a valued job.

Good practice 2: Forest workers are offered opportunities for further education or re-training to change to administrative positions. This has been proven successful in some cases. The caveat is that the candidate needs to be willing to change from his chosen outdoor job to an office position. Experts report that this is a real individual solution for a few workers. It is by no means a solution to offer employment for a larger number of workers with altered capabilities. But it is one effective element of a wider strategy towards age-friendly work.

Good practice 3: In some enterprises forest workers facing the problem of limited physical capacities are assigned with assistant tasks to the district manager, which seems to be rather sensible in cases where organisational changes have led to increasing management areas and work load. There, experienced forest workers can provide an enormous support e.g. by organising and controlling contractor operations. It is another look at capacities of workers which approves the concept of "altered performance" and acknowledges the competences and experiences of the individual.

While good practices can be found, the most common approach seems to be that the enterprise management does not have a strategy to manage age-friendly forestry work. Generally, district management rather looks for individual solutions to keep workers with altered performance employed, e.g. with workshop or simple assistance tasks. This works as long the quantity of workers with limited work ability for physical work is manageable. But the numbers are rising. One forester stated that in his district one third of the workforce is already faced with limited work capabilities, and he could present no actual solution.

A general conclusion of the collected expert opinions is that – with few exceptions – forest enterprises are still very much at the beginning of a search for solutions to cope with the challenge to maintain employability of their workforce and to facilitate more age-friendly working conditions in their enterprises.

4. Conclusions and Out look

4.1 Research Needs

Generally, there is not yet sufficient knowledge about the impact of demographic change on the future labour capacities for forest operations. The alert of a future lack of a competent workforce is mainly based on experts´ assumptions and industry representatives´ expressions with limited empirical evidence. The need for statistical baselines for policy and sector development has been addressed before (Kastenholz, 2014). Particularly with regard to the diversity of the workforce more research activities are needed to focus on targeted development strategies. There is also the need to look into the diversity of the workforce in small service enterprises which carry out more the majority of forest operations. Here, statistical data are not available. Qualitative studies will have to be carried out to assess whether and to what extend demographic change will affect the capacities and the performance of this important part of the workforce.

Research on the impact of demographic change has to take a two-tier approach. On the one hand we need to understand the development of the collective forestry workforce, based on the volume and quality of the future task and the need for work capacities. On the other hand a focus on individual worker´s careers is necessary to better cope with the challenges of ageing and altering performances and to design age-friendly working conditions in forestry.

On enterprise levels there is the crucial demand to identify alternative tasks to offer employment opportunities which meet the capacities of workers with altered performances. It is not only about finding tasks from a quantitative perspective. To follow the goal of creating "better jobs" tasks must be identified and allocated which are both value-adding for the enterprise and facilite the self-esteem of the individual.

4.2 Focus on "sustainable work"

The authors are well aware that stressing "sustainability" again in this context may cause a bit resentment among some readers. However, it is worthwhile to reflect on the concept of "sustainable work" as a guide bar for human resources development in forestry.

> "Eurofound's working definition of 'sustainable work over the life course' means that working and living conditions are such that they support people in engaging and remaining in work throughout an extended working life. These conditions enable a fit between work and the characteristics or circumstances of the individual throughout their changing life, and must be developed through policies and practices at work and outside of work" (Eurofound, 2015).

"Sustainable work" covers quite well the idea of creating better jobs and focussing on the demand for age-friendly work design and organisation.

Keeping workers healthy by preventing accidents and designing work places with lesser health risks is still one order of the day. It is of utmost importance to continuously strive for a prevention culture in the forest sector (Kastenholz et al., 2018) which not only looks into the causes and symptoms of injuries and diseases but gives health and safety a top priority in work organisation and human resources management. This is one cornerstone of "sustainable work". This must be accompanied by continuous skills development to enable workers to shift to other jobs or tasks when they face health problems and altered capabilities. The job opportunities outside forestry are encouraging since there is an emerging unsatisfied demand for motivated workers in other sectors .

Finally, the scope of developing age-friendly work needs to be opened beyond the forestry borders. In many cases the chances to maintain the employability will be in finding new jobs in a different sector. The earlier in the working live these opportunities and the required skills will be developed the better the chances for a worker to adapt to new tasks and conditions. For human resources development in forest enterprises this implies that developing age-friendly work does not start when people are getting old and face health problems. Age-friendly work starts from the beginning of the career and is a continuous development task.

References

Brand, H., Gerding, V., Helms, A., Morat, J. (2011) KWF-Workshop „Demografischer Wandel in der in der Forstwirtschaft Forstwirtschaft" 19. und 20. 05. 2011 Groß-Umstadt. Forsttechnische Informationen, Heft 5+6, 2011, S.4-7.

Eurofound (2014) Employment opportunities for people with chronic diseases. Eurofound, Dublin.

Eurofound (2015) Sustainable work over the life course: Concept paper. Publications Office of the European Union, Luxembourg.

Eurofound (2017) Working conditions of workers of different ages: European Working Conditions Survey 2015. Publications Office of the European Union, Luxembourg.

European Commission (2014) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU Strategic Framework on Health and Safety at Work 2014-2020. COM(2014) 332 final, Brussels, 6.6.2014.

EU-OSHA, Cedefop, Eurofound and EIGE (2017) Joint report on: Towards age-friendly work in Europe: a life-course perspective on work and ageing from EU Agencies, Publications Office of the European Union, Luxembourg.

Forest Europe, UNECE and FAO (2011) State of Europe's Forests, 2011. Forest Europe Liaison Unit Oslo.

Forest Europe, UNECE and FAO (2015) State of Europe's Forests, 2015. MCPFE Liaison Unit, Madrid.

ILO (2019) Promoting decent work and safety and health in forestry. Report for discussion at the Sectoral Meeting on Promoting Decent Work and Safety and Health in Forestry (Geneva, 6–10 May 2019) International Labour Office, Sectoral Policies Department, Geneva, ILO, 2019.

Kastenholz, E. (2014) How to assess if jobs in Europe´s forests are decent and green. https://www.unece.org/fileadmin/DAM/timber/Forest_Policy/ToS_Green_Jobs/Kastenholz_Study_assess_decent_and_green_work.pdf

Kastenholz, E., Habenicht, H., Kampe, J., Klöber, K., Kreil, C., Morat, J., Niemeyer M., Teutenberg, A., Seeling, U. (2018) Fitting Health and Safety Measures to Needs and Conditions of Enterprises. In: Proceedings of the 51st International Symposium of Forest Mechanisation. 24-28 September 2018, Madrid. Ed. Fundación Conde del Balle de Salazar, pp. 183-193.

Lewark, S., Härle, P.-R. (1991) Das Ausscheiden von Waldarbeitern der Staatsforstverwaltung 1983 bis 1990. Frühinvalidität und Berufswechsel am Beispiel des Bezirks Darmstadt. Allgemeine Forstzeitschrift 46, 470-474.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

COMPARISONS BETWEEN BATTERY AND GASOLINE CHAINSAWS IN TERMS OF NOISE EXPOSURE, ENERGY EFFICIENCY, AND CUTTING PERFORMANCE

Christoph Huber, Nikolaus Nemestóthy
Austrian Research Center for Forests - Forest Training Center Traunkirchen, Austria
christoph.huber@bfw.gv.at

Abstract: *In forestry, chainsaws are widely used for felling and processing trees all over the world. During working, the operators are exposed to the risk of injuries and several other health hazards such as noise, vibration, and exhaust gases.*
Today, battery chainsaws are already seen as an alternative to combustion driven saws in many industrial sectors like urban gardening or construction engineering. The fast development of light and powerful batteries within the last few years made them also interesting for the forestry sector.
The present research aims to evaluate and compare the cutting performance, energy consumption and noise exposure of two battery and three gasoline chainsaws during cross-cutting and delimbing. Results showed that battery chainsaws emit significantly less noise than gasoline chainsaws. Nevertheless, the battery chainsaws exceeded the upper exposure action value for noise set by the European Union, both during cross-cutting and delimbing. The tested battery chainsaws showed similar cutting-speed values to compact gasoline chainsaws with a power output of approximately 1.7 kW. Professional chainsaws with a higher power output showed much higher cutting speeds.
In conclusion, battery chainsaws are more favorable than gasoline chainsaws in terms of noise emission and energy efficiency, but cannot keep up with professional gasoline chainsaws in terms of cutting speed.

FORMEC 2019 – Exceeding the Vision: Forest Mechanization of the Future
6-9 October, 2019 - Sopron, Hungary

FORESTRY EDU TRAINER - COOPERATION FOR INNOVATION IN EDUCATION AND TRAINING

Andrea Teutenberg, Ute Seeling, Joachim Morat
Kuratorium für Waldarbeit & Forsttechnik (KWF) e.V.
German Center for Forestry Work & Forest Technologie
Spremberger Straße 1, D-64823 Groß-Umstadt, Germany
andrea.teutenberg@kwf-online.de; ute.seeling@kwf-online.de

Abstract: *Forestry EDUTrainer is an ERASMUS+project that deals with the pedagogical-methodological skills of trainers in the field of education and training of learning adults in forestry in Europe. The background to this is that precisely this methodological-pedagogical qualification of trainers in forestry is rather the exception in most European countries. In view of the important key role that trainers play - also with regard to the requirements of occupational safety and health protection - the project aims to develop a training standard including a multi-module qualification concept based on an e-learning platform for trainers in the forestry sector. The project is funded by the EU under the ERASMUS + program.*

Keywords: Forestry EDU Trainer, qualification, methodological skills, social skills, occupational safety, health protection, VET training, occupational training, e-learning, blended learning,

1. Introduction

The main objective of the Forestry Edu Trainer Project is to conceive, issue and disseminate a Training Course in order to improve and foster general teaching and pedagogical skills for forestry trainers in Europe, i.e. VET trainers in both school and work-based system, who train future forest operators, both adults and young people. Why is this necessary? In general the technical and factual skills of trainers in forestry are goo but there is an enormous lack of methodological-pedagogical and social-personal skills.
In order to build the training course, the partnership has worked on a Competence and a Training Standard common to all European countries, i.e. key teaching and pedagogical competencies and skills for technical trainers in the forest sector to improve their qualification and training capacities. The training course will finally lead to a European Certificate for Forestry Trainers (ECFT).
After the elaboration of the Competence and the Training standards, the partnership has therefore developed the training course that is available on Moodle platform through blended learning to become a certified Forestry Trainer.
In order to test the course and also the Moodle platform, the partnership has developed a one week training course for experienced forestry trainers. Those trainers tested the resources of the Module 1 of the Training course 'Communication basics for forestry trainers'. They also have been prepared to understand the issues at stake behind the topics of this course, in order to train in the future other less experienced forestry trainers. The trainers, who have participated to this 1st Experimental Training, are the 1st "EduTrainers" who will initiate the process of "train of trainer (ToT)" of this project.
Within this output, KWF e.V., in collaboration with the forestry training centre Waldarbeitsschule Kunsterspring, has designed and issued the TRAINING COURSE 'Communication basics for trainers in forestry' FOR THE FIRST EXPERIMENTAL TRAINING OF "EDU TRAINERS" that successfully took place in Ludwigsfelde, Germany, 1st – 5th of July 2019.
This paper describes the path from the idea of an EDU Trainer to the e-learning training course on a platform that is open to all forestry trainers in Europe to sharpen their competencies and qualification for being an excellent trainer besides the (important) factual skills.

2. The Competence Standard – Definitions and Proceeding

2.1 Trainer and Competence

In European countries education and training are regulated differently – either it is professional/vocational training or further education. In Germany for e.g. forest worker is an officially recognized vocational discipline. The vocational training for forest workers is incumbent upon so called forestry-masters, who have to take an exam (Ausbildereignungsprüfung) that proves their general ability to teach and train. The 'Ausbildungseignungsverordnung' – a special regulation for trainers giving vocational trainings – gives an overview of the competencies, a vocational trainer ought to have. For e.g. at the Forestry School in Hachenburg – the courses for future forestry-masters include extra-curricular skills besides the professional skills. It is getting more and more into consciousness that to the same extent methodical, technical and personal skills as well as psychological and pedagogical competencies have a huge and sustainable impact on the achievement of objectives in trainings.

Professional competence is the ability to link, deepen, critically examine and apply interdisciplinary knowledge in a professional and multidisciplinary capacity. These are purely professional skills and knowledge, which are usually acquired within the framework of an apprenticeship and extended by further training. Based on the question in the project, these are all the skills that an instructor in the forestry field should have in relation to the three different training domains manual logging, mechanized logging and skidding.

When we speak of technical competence, methodological competence, social and personal competence, we are talking about the competencies that a good instructor in the forestry sector has in regard to their own teaching and pedagogical skills.

Technical competence encompasses the knowledge, control and application of the technical means necessary for the training and teaching process and the technical use of the methods.

Method competence is the ability as an instructor to obtain information, structure it, prepare it for the learning process and present it in an appropriate form. This includes learning and teaching skills, planning and organizational skills, media literacy, teaching and learning methods, moderation methods, methods of learning transfer and evaluation, as well as decision-making skills and general thinking.

The willingness and ability to grasp and understand social relationships and interests, and to engage and communicate responsibly with others, includes social competence. Social competence includes features as empathy, communication skills, teamwork and cooperation ability, conflict ability, helpfulness, ability to contact, tolerance, etc.

Personal competence refers to the willingness and ability to reflect on one's own behavior and development and to further develop it in connection with individual and social values. This includes, for example, independence, critique, self-confidence, reliability, sovereignty and personal authority, responsibility and obligation awareness, etc.

In addition to these competencies, foreign language competence is becoming increasingly important in the course of internationalization and in the context of migration.

Across countries are the ideas about what makes a good trainer professionally and pedagogically human – at least on the part of the trainees – in huge parts in line with the idea of an European certificate for Forestry Trainers.

2.2 How to get an idea of the Competence Standard - Proceeding

At the beginning of 2018 the KWF e. V. carried out about 45 pre-surveys with apprentices to the forestry profession at two forestry education centers, in Weilburg and in Hachenburg. After the evaluation of the personal surveys in the context of the pre-surveys, a questionnaire was developed, translated and published to the project partners in France, Belgium, Spain, Italy, Finland and Germany. The returning questionnaires of trainees and instructors in the partner countries confirmed in an impressive way the pre-results of KWF e.V., that the extra-professional competencies of the trainers are significantly more important to the learners than generally expected. Based on these results, a competency questionnaire was developed and sent to the project partners for evaluation, which included an extensive list of individual technical, social and personal competencies as well as methodological competencies. The results of these competency assessments were presented at the KWF in the context of the 2nd transnational meeting at the end of February 2018 and discussed extensively. The result of the discussion ultimately flowed into a

competency questionnaire on self-assessment for trainers in the forestry industry of the project partners. A total of almost 60 questionnaires came back, on the basis of which the Forestry Edu Trainer Competence Standard had to be formulated, including the pre-results.

2.3 Results of the surveys for the Comeptence Standard for Trainers in Forestry

2.3.1 Talent – Trainers‘ Check

A real strength, i.e. real mastery, is achieved by a person whenever three factors come together: talent, practical experience and knowledge/methods/tools. In the trainers' check the aspects of professional competence (How good is someone professionally? How current is the skill?), positive attitude towards working (including prevention and security skills), willingness to self-responsible further education and personal development (lifelong learning, personal growth), enthusiasm for the activity as instructor/trainer (fun at work) and work with trainers and trainees (human friend), self-reflection and self-confidence. Some more talents that are helpful to deal with difficult groups or situations may also be: self-assurance, courage, contact and communication skills, sensitivity in perception, flexibility and humor.
The aim of the instructor's check could, for example, be a common agreement on a common training mission statement for trainers. At the same time, this common agreement can be used as a control and evaluation tool for trainers and for the latter also as a reflection tool in the course of training and further career.

2.3.2 Standard for Technical Competencies in Trainings and VET (Vocational Educational Training)

Being technical competent as a Trainer in Forestry Trainings and VET means, to know all the relevant technical methods and tools, to be able and willing to use them without any questions in training contexts properly and without hesitation.
The technical standard comprises - based on an excellent vocational knowledge - the ability to define objectives and to identify all the necessary training contents to reach the goals, writing scripts and curricula for the trainings, controlling the process to ensure the outcome, including time management. Methods for defining goals and for structuring important training contents and developing scripts have to be part of the curriculum.
As far as Digital Competence, IT-Skills and Social Media Skills are getting more and more important in forestry business (just think about digitalization in Forestry 4.0), for presentation, sharing knowledge, distance learning and for communication and information with groups, they should also be part of the Train of Trainers (ToT). Finally, it is an important prerequisite for blended learning to be able to use appropriate IT features.

2.3.3 Standard for Methodical Competencies in Trainings and VET

The standard referring methodical competences should cover four main aspects that include comprehensive knowledge about methods and tools to be used professionally in trainings on the two levels of training: factual level and relationship/emotional level.
Flexibility as competence means to know different training methods and tools and to be able to use them adequately. It is the ability to switch between them and to adapt them to the needs and requirements of the situation and/or the group if necessary. Acting flexible is more than knowing methods and tools. Flexibility is the result of constant exercising and their daily application and use.
What do we expect from an excellent trainer and what should be the standard?
He or she has to know how to create an activating learning environment. This is especially interesting when learning takes place indoor and outdoor. What are the characteristics and features of an inspiring learning environment? What has to be considered? What different presentation methods exist? When do we use them? What are the advantages and disadvantages of different presentation methods? How to use PowerPoint, flipcharts, pin boards for input and presentation? What about the classrooms? Are they suitable?
Secondly it is important to create a group atmosphere where learning is possible and the participants feel comfortable. A modern, participant orientated planning and leading of the courses ensures the transfer and that participants and trainees stay motivated. The difference between the factual level and the

relationship level is well known as well as how to handle those two levels at the same time. The standard for the factual level comprises different methods of individual work and group work, modern and proven seminar components and sequences. The trainers' toolbox is filled with exercises such as role games, tower of power and others, energizers, storytelling, visualization tools, evaluation and creativity methods and also some coaching tools to enable and support self-regulated learning. The exact methods and tools have to be specified in the next step of the project. This also includes the professional use of evaluation methods and assessments.
Guiding both levels, but especially the relationship level requires some psychological knowledge about motivation and motivation to learn, learning itself, 4+1 stages of learning and learning curves, group dynamics, leadership, needs and behavior, perception and interpretation as well as different types of personality, conflicts and the connection between the use of methods on the factual level and the impact on the emotional level. Of course the psychological knowledge is very much tight to social and personal competence.
The link between all is the ability to communicate professionally. The competence is to be able to react in an adequate manner in all situations: self-leading and with the group. This means that a trainer has to use communication tools such as constructive feedback, questions, active listening and also methods (in line with NLP e.g.) to handle critical situations and cope with conflicts.

2.3.4 Standard for Social Competencies in Trainings and VET

Social and personal competencies can't be divided by 100%. There are many overlappings. Both need a fundamental willingness for lifelong learning to develop ones personality and for personal growth.
As mentioned before, social competence includes interest in human beings, empathy, skills in communication, cooperation, solving conflicts and teambuilding/teamwork as well as helpfulness, acceptance/tolerance, contact ability and group dynamics. It is also helpful to train how to deal with different personality types. Models like DISC Profile, Herrmann Brain Dominance Instrument® (HBDI), Meyrs-Briggs Type Indicator (MBTI), Theme-Centered Interaction (TCI), Neuro Linguistic Programming (NLP) or Transactional Analysis (TA) are very helpful and useful. In short all characteristics that support us when we work together with others to reach a specific goal and help us to understand each other better.
The development or let us say evolution of social competences is based on the psychological knowledge evolving from the methodical competencies. Besides the theoretical input, methods have to be used, that support to incorporate the theoretical knowledge by the way that it becomes social behavior. Those methods can be study cases, role games and psychological exercises, exercises to train conversation skills but also self-reflecting exercises (which will lead to personal competencies) and feedback for e.g. by evaluating video takes.

2.3.5 Standard for Personal Competencies in Trainings and VET

Coming to the personal competencies we now talk about excellent and high end EDU Trainers. Modern neuroscience proves that we learn at our best when our teachers are good trainers and facilitators. The most important aspect to influence the motivation of participants to learn and to transfer the new knowledge into practical work is covered by the personality of the trainer and his or her ability to go into the needs of the group or the individual participant. At least it is not a question of methods and technics. Training success is a question of how trainers and trainees fit to each other: Does the trainer 'love' what he or she does and does he or she 'love' the participants.
The following aspects should be standard when we talk about trainers' competencies in the forestry business: Depending on the situation trainers should either be problem orientated or solution focused. The way to success and the wheel of success, the comfort zone model, self-responsibility for e.g. should be discussed. A non-judging and non-dominating inner attitude that ensures to interact appreciatively and respectfully on eye level have a much bigger influence on the success of trainings than the tools that are used. Concepts like the 'house of being' or the 'triangle of disempowerment' are part of the basics for trainers. They should be aware that the content never should dominate the process of the training (process orientated). And finally, the capacity to act should include the ability to reflect his or her part in the success or failure as well a healthy manner of self-assurance, composure and natural authority (what does not mean authoritarian or bossy).

2.3.6 Resumee of the Competence Standard

Training and further education in forestry business is more than teaching. The professional trainers' capacity to act is composed of high expertise in forestry skills, technical and methodical competencies, social competencies and personal competencies that are overlapping in several aspects. To be capable of acting trainers in forestry businesses have to combine all competencies. This requires a change in the mindset of the former educational practice by the way that so called soft skills are becoming more important than they used to be. Regarding the further curricula we now had to choose the matching methods and tools for the trainers' trainings and we had to make a decision which learning contents and methods are suitable for the e-learning platform und which contents are more likely to be taught in classroom trainings or workshops.

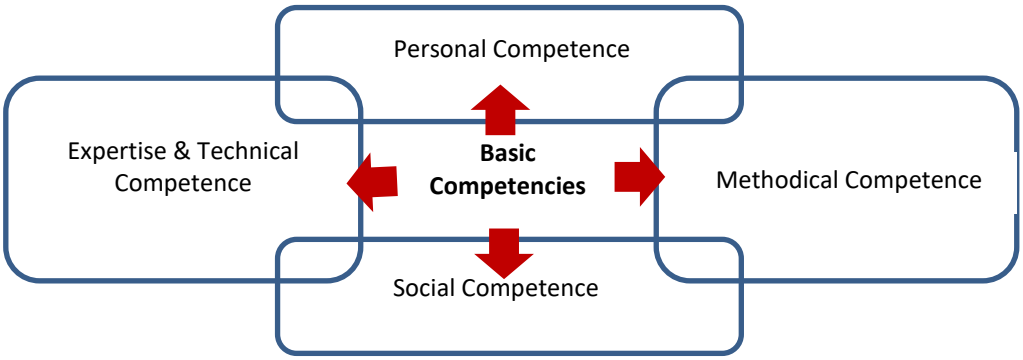


Figure 1: Competencies for Trainers in Forestry

3. The Training Standard

3.1 Choosing the Modules and Contents

The training standard as a cluster was built out of the Competence Standard and describes the individual modules by a template following the 4Mat.[1] The training material was later derived out of the training standard and was presented as an Online Blended Learning Course for trainers in forestry in the first experimental training.

As a result of the 3rd Transnational Meeting of the Forestry Edu Trainer Partners in Jyväskylä and Jämsä, Finland, the following modules for a basic training course were highlighted:

- Module 1 'Communication Basics for Trainers in Forestry'
- Module 2 'Safety Culture in Forestry Work'
- Module 3 'Methods & Tools for Trainings'
- Module 4 'Attitude & personality of a successful trainer'
- Module 5 'Psychological Basics & Group Dynamics'
- Module 6 'Facilitation & Presentation in training'
- Module 7 'Digital Competence & Networking'
- Module 8 'Evaluation, Monitoring & Feedback'

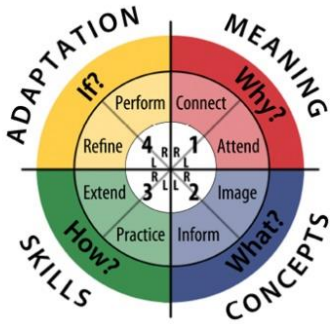


Figure 2: The 4MAT Model to describe the modules and their contents

[1] Bildquelle: https://4mat4learning.com.au/what-is-4mat/

3.1 Description of a Module with 4MAT – Module 2 as an Example

Name of the Module	Module 2 - ‚Safety Culture in Forestry Work'
Symbols (Examples)	 
Learning objectives (Why)	Over 90% of occupational accidents are behavioral. Much has been done in the past, especially in technical and organizational terms, to reduce the number and severity of accidents at work.[2] But safety in forestry is at a point, where the numbers of accidents will not be reduced any further by still focusing on the technical and organizational aspects of forestry work. We have to realize that psychological factors are the determining factors to increase a culture of prevention. Therefore, an important starting point today is to deal with (changes in) attitude and behavior towards risk acceptance and insecure behavior among trainers and trainees in order to achieve further improvements in the culture of prevention. Having finished Module 2 the trainer knows what differs a culture of prevention from technical work safety. He is given an overview of the main fields of action of work security and health in forestry work. The trainer knows what a culture of prevention is about and what he/she can actively do to increase his/hers and the trainees' awareness of the importance of a safe behavior in forestry work and to improve their motivation to work safely as well as using the right tools properly. Module 2 refers to manual logging, mechanized logging and skidding.
Sub objectives and Contents (What)	1. Culture of prevention: What is it about? 2. Self-assessment on culture of prevention 3. The proSILWA-process to analyze and increase a culture of prevention 4. Recap of contents in Modules 1 to 8 that are important for Module 2 5. Developing personality – Authentic behavior as a trainer 6. How to use DISC in practical work: Analyzing the trainees' risk acceptance, their strengths and weaknesses 7. Salutogenetic approach vs. Deficit orientation 8. The logic levels of Change by DILTS
Methods used (How)	Theoretical input, Examples, Exercises, Test, Face to Face workshop, Video, Skype Coaching
Transfer and practical work (What else/What if)	Trainers are important role models. Their authenticity and attitude towards a culture of prevention in vocational training and further education in forestry have the most significant impact on trainees' future behavior. Increasing the trainers' competencies on prevention and safety at work as far as their ability to teach this to their trainees will decrease the number of accidents in forestry work.
Related to	Module 1, Module 3, Module 4

Figure 3: Description of a Module with 4MAT

[2] This means that not only the technical skills and the manner how work processes and procedures are carried out have an influence on the number of accidents. It is mainly the inner attitude and motivation towards a safe behavior. The technical skills and their training are not part of this course for trainers.

3.2 Description of Sub Objective 3 in Module 2 - Example

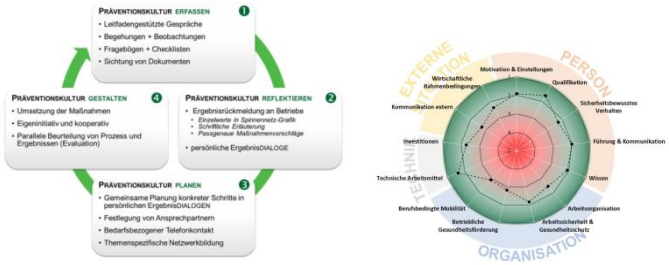
Name of the Sub Objective	**M2 S03 - BASIC** The proSILWA process: analyze and increase a culture of prevention
Symbol	
Learning objectives (Why)	Coaches have a great impact on the safe behavior of their trainees through their roles as a role model. In order to be able to influence the prevention culture around their trainees, they need background knowledge that they pass on to their trainees. For example, which factors influence culture, how they are analyzed and how change processes can be initiated at all. With the proSILWA process, trainers will learn about a new process for implementing individual and demand-oriented measures for health prevention in forestry operations and forestry companies in accordance with work and situation requirements. The goal is the development of an effective prevention culture.
Contents (What)	• M2SO1 as Recap • Capture prevention culture • Reflect prevention culture • Plan prevention culture • Design a prevention culture
Methods used (How)	Theoretical input, Examples, Exercises, Video, Skype Coaching
Transfer and practical work (What else/What if)	Safety at work, health in forestry work, culture of prevention
Related to	M1, M2SO1

Figure 4: Description of a Sub Objective based on 4MAT

4. Deriving the Training Material from the Description on the Content

The next step towards a blended learning course on the Moodle Platform was to create the detailed training material based on the descriptions of the modules in the training standard. Training material means: How to formulate in a participant orientated manner the ideas written down in the training standard in a way that it was understandable for the target group. This training material was later then transformed onto the Moodle Platform. The following figures will give an idea how the training material was created.

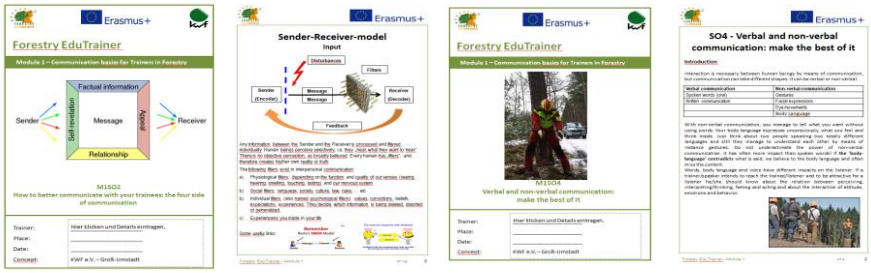


Figure 5: Training material – Examples (Picture left based on Schulz von Thun)

5. The Online Course on Moodle Platform and the first Experimental Pilot Training in Germany

After the elaboration of the Competence and the Training standards, the partnership has therefore developed the training course that is available on Moodle platform through blended learning to become a certified Forestry Trainer.

In order to test the course and the Moodle platform, the partnership has developed a short training course for experienced forestry trainers, who have tested the resources of the first Module of the training course (Communication Basics for Trainers in Forestry) and who have been prepared to understand the issues at stake behind the topics of this course, in order to train in the future other less experienced forestry trainers. Why did we choose Module 1? It was because communication is the link between all the Modules of the course and is the most important tool you have as a trainer to guide trainings successfully. The 11 trainers, who have participated to this 1st experimental training, are the 1st "Edu Trainers" who will initiate the process of "train the trainer" of this project and came from five different European countries.

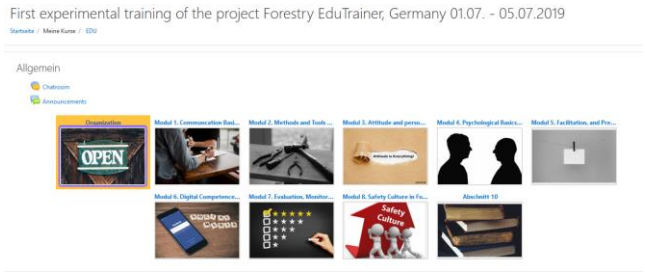


Figure 6: Starting page of the Moodle Course

In the following you will find some impressions of the training. It was a so called Blended Learning Training which means that the online resp. e-learning course available on Moodle was completed by additional and specifically chosen face to face exercises and practical input on communication given by experienced communication trainers. The feedback of the participants was absolutely positive.

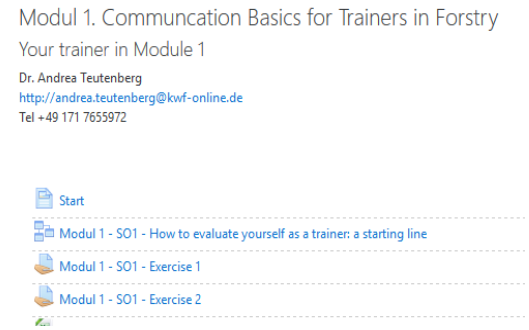


Figure 7: Entrance to the Course – with typo



Figure 8: Training group in a presentation



Figure 9: Visualization



Figure 10: Exercise 'Asking questions'

What comes next? Now the Modules 2 to 8 will also be transfered onto the e-learning platform. First in English and additionally in the languages of the project partners: Dutch, German, French, Finish, Italian and Spanish. The Edu Trainers who took part in the Experimental Training will have to finish the whole course until the end of March 2020. And they themselves will then give the course to other, less experienced trainers in forestry in their country until summer 2020. The goal is to have well trained and qualified trainers in Forestry in many European countries with very good knowledge in methods and technics and with high social and personal competence.

6. Resumee

The feedback from the participants in the first Experimental Training on Module 1 'Communication basics for trainers in forestry' confirmed the project team at all levels in the selection of competences, modules and content. A survey was first used to formulate the Competence Standard, from which the specific training standard was derived. An essential step followed with the design of the detailed training content and training methods. A challenge was and still is the transfer of the training material to the Moodle Platform. Reason is the fact that with this transfer additional e-learning tools are used and these in turn require a specific adaptation of the training content. This becomes clear, e.g. in module 1 in the video sequences produced especially for this module by the Italian project partners.
The combination of e-learning shares and presence elements has also proved its worth, especially with regard to content that relates to personal and social skills and should therefore be conveyed in an experience-oriented way. A great hope, which lies in the conception of this blended learning course, is to influence the willingness of the trainees to behave safely while working in the forest and thereby reduce the number of accidents through a stronger awareness of being role model as a trainer.

7. References

Arnold, R.; Krämer-Stürzl, A.; Siebert, H. (2011) Dozentenleitfaden, Cornelsen Verlag, Berlin

Kreil, C.; Kampe, J.; Kastenholz, E. (2018) “Herausforderungen für die Prävention in Kleinstunternehmen am Beispiel der Forstwirtschaft” praeview 1/2018, 26-27

Kreil, C.; Kampe, J.; Kastenholz, E. (2018) “Präventionskultur in Klein- und Kleinstbetrieben” praeview 1/2018, 28-29

Kreil, C.; Kampe, J.; Kastenholz, E. (2018) “Von der ERfassung bis zur kontinuierlichen Gestaltung: Präventionskultur im Dialog” praeview 1/2018, 30-31

Schulz von Thun, F. (1981) Miteinander reden 1: Störungen und Klärungen: Allgemeine Psychologie der Kommunikation, rororo

Seiwert, L.; Gay, F. (2013) The behavioral Blueprint: 4 kinds of people you need to know, persolog GmbH

Sobanski, H. (2012) Der Problemlöser für Trainings und Workshops, Cornelsen Verlag, Berlin

Teutenberg, A. (2018) Trainingsmaterial von at kommunikation, Neu Anspach

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

MOVEMENT ANALYSIS OF A WORKER IN THE FOREST CLEANING ACTIVITIES

Marin Bačić*, Matija Landekić, Marijan Šušnjar, Mario Šporčić, Zdravko Pandur
Faculty of Forestry, University of Zagreb
Department of Forest Engineering
Svetošimunska cesta 25, 10000 Zagreb, Hrvatska
mbacic1@sumfak.hr, mlandekic@sumfak.hr, msusnjar@sumfak.hr, msporcic@sumfak.hr, zpandur@sumfak.hr

Abstract: *The main tool used in a forest cleaning is a billhook, a hand tool consisting of a hold and a hooked blade sharpened on both sides. Forest cleaning is physically very tiring and takes place under difficult working conditions (high temperature and humidity, dense vegetation, insects). Moreover, working with billhook is exclusively manual work and its effects on health are mostly unknown. A novelty in Croatia, regarding motor - manual forest cleaning, are battery shears, a more ergonomic and humane approach to forest cleaning. For the purpose of the ergonomic comparison of the two types of forest cleaning methods, a top technology was used – Xsens MVN. Xsens technology consists of sophisticated hardware and software for human movement analysis. It is a full-body human measurement system based on inertial sensors, biomechanical models, and sensor fusion algorithms. The aim of this paper is to present a new and modern method of movement analysis in ongoing research of two mentioned forest cleaning methods, to show challenges of field measurements, and to assume possible application in forestry regarding ergonomic measurements.*

Keywords: movement analysis, forest cleaning, billhook, battery shears

1. Introduction

Forest cleaning is a silvicultural procedure within forest tending in which a negative silvicultural selection is made. In traditional and modern forest management it is a necessary step to ensure healthy and high-quality stands. Being a pre harvesting procedure with virtually no direct financial benefits it didn't get the same "progression treatment" as other harvesting procedures. While the harvesting methods used in thinning, regenerative, and selection felling benefited from technological advancement, methods and tools used in forest cleaning, besides gasoline-powered chainsaws, haven't changed at all. Tools like billhook, machete, and sickle that were used centuries ago are still in use today. Forest cleaning is carried out with a manual method of work, with the exception of a motor-manual method using a gasoline-powered chainsaw in older stands. This kind of work is mostly carried out in the vegetation period and that means extremely hard working conditions regarding high temperatures and humidity, dense vegetation, insects, etc. The combination of hard-working conditions and sharp manual tools result in a very high risk of physical injuries. Moreover, the facts point to the significant strains on the worker's body when working with a billhook. The observed movement is very repetitive, and our preliminary studies record over 6000 billhook swings per working day, within 4 hours of effective working time. As an alternative to hand tools in forest cleaning activities, intensive research had been done in Croatian forestry on the application of battery shears. It is assumed that substituting manual method with the motor-manual method can have a positive impact on worker's health. Nutto et al. (2013) researched the effect of different types of tools, including a hand saw, pruning shears and battery shears, in eucalyptus pruning on the physical workload of the worker and concluded that working with battery shears result with the least physical workload. Bačić et al. (2018) also recorded lower average and maximum heart rates during forest cleaning with battery shears in

comparison to manual method with a billhook. Regarding ergonomic studies. aside from measuring physical workload, postural load and recording number and type of injuries, kinetic and motion capture measurements in forestry are not very common. Nowadays, with the help of the new technologies, it is possible to capture, record and analyze every movement. Every movement, especially the repetitive one can have a negative impact on worker's wellbeing and that is a great "unexplored territory" with a lot of pending questions. The focus of this paper is to present a new method of movement analysis in forest cleaning when using manual (billhook) and motor-manual (battery shears) method. For that purpose, a special suit with integrated IMU sensors was used. This kind of technology was used in sports (Lintmeijer et al., 2018,) and medicine (Held et al., 2018, Longo et al., 2018, Karatsidis et al. 2019). It is assumed that observed values for upper limb angles and kinematics, trunk torsion and body center of mass will significantly differ between two forest cleaning methods.

2. Materials and methods

2.1 Research area

The research was conducted in 10 years old state forest managed by Forest Administration Zagreb, Forest Office Popovača, management unit Popovačke prigorske šume, section 16a (Figure 1). Main tree species were sessile oak (*Quercus petraea* (Matt.) Liebl.), common hornbeam (*Carpinus betulus* L.) and common beech (*Fagus sylvatica* L.). Due to technical limitations, all measurements were conducted on the edge part of the stand, in close vicinity of the road.



Figure 1. Section 16a – measuring site

2.2 Research objects

The worker was a 50 years old male with a body mass of 105 kg and height of 186 cm (Figure 2). At the time of research, the worker had 20 years of working experience in forestry. The worker was dressed in Xsens lycra suit with integrated IMU sensors and standard issued protective clothes.



Figure 2. Worker wearing measuring suit

For manual forest cleaning method worker was using standard issued billhook with a mass of 1,5 kg and a length of 1,15 m. For motor-manual method, Stihl ASA 85 battery shears with a mass of 0,98 kg and AP 300 backpack battery with a mass of 1,7 kg was used (Figure 3).



Figure 3. Tools used in forest cleaning

2.3 Research instruments and methods

Kinematic data were recorded using Xsens full-body motion capture suit with 17 IMU sensors (Figure 4). It is a full-body human measurement system based on inertial sensors, biomechanical models and sensor fusion algorithms. Each IMU consists of a 3D accelerometer, a 3D magnetometer, and 3D gyroscope (Xsens Technologies, Enschede, Netherlands).

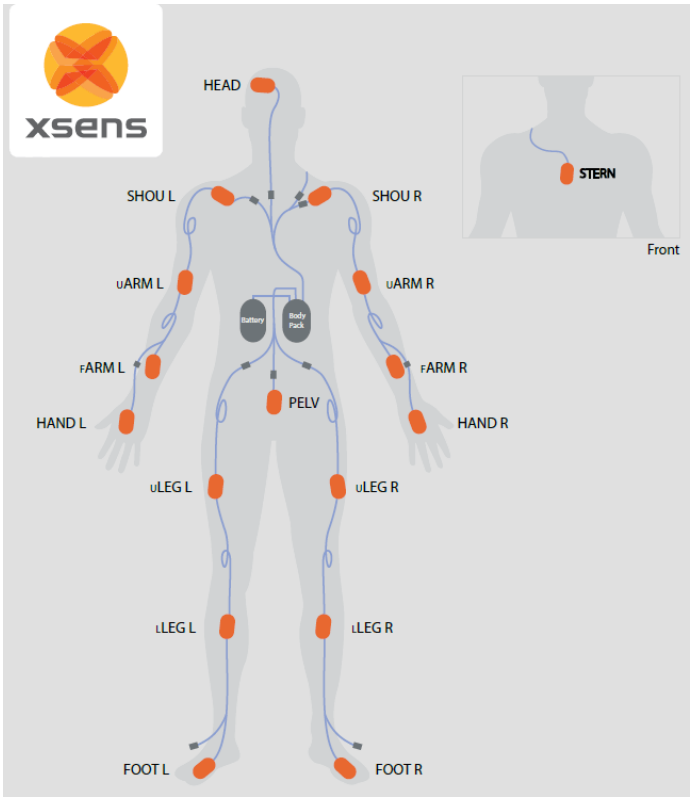


Figure 4. Positions of IMU sensors on human body

Measured data is to be analyzed in MVN Analyze software capable of real-time 3D animations, graphs and data streaming. Possible 3D data outputs are joint angles, segment kinematics, segment global positions, the body center of mass and sensor data. Since measuring setup required a steady 220 V power supply, a 1 kW generator was used to power laptop and receiver (Figure 5).



Figure 5. Equipment setup and power source

Before measuring procedure, an obligatory calibration was conducted to "pair" the suit and the worker. The selected worker was instructed to perform forest cleaning using two mentioned methods, around 15 min of each method. Selected trees were marked beforehand. Since the IMU sensors are constantly sending data via the receiver to the laptop, a model of a worker model could be observed in real-time (Figure 6). Because of the dense vegetation which was interfering the communication between the receiver and IMU sensors (worker/suit), the measurement was limited to the edge part of the stand which was closer to receiver and power supply.

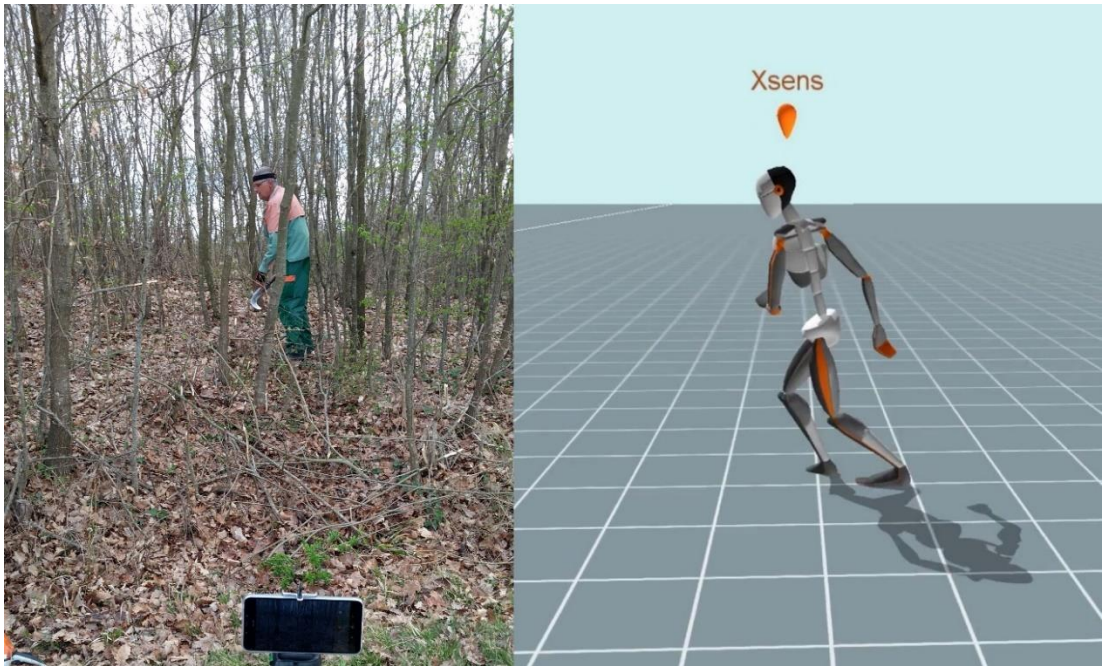


Figure 6. Worker and his model

It was also observed that the electric power supplied by gasoline generator was not steady enough to properly power laptop and receiver. A 12 V battery with a power inverter would be a better solution.

3. The potential of new technology

Since the data of this research is still in the processing phase, this chapter will be focused on elaborating the potential and validity of the use of the new technology. The essence of the problem is repetitive movement (over 6000 a day) and their effect on the human body. To analyze and valorize a movement of the whole body or a specific body segment, a motion capture technology is needed. In forest cleaning, characteristic movement patterns can be observed. When using a manual method (billhook), a worker is mostly using his upper body. The billhook is an almost exclusively single-handed tool with the exception of two-handed wielding when facing bigger trees. An example of characteristic movements is given on right-handed worker. After approaching the subject tree (or trees), the worker is using his left arm to bend the tree for easier cutting and removal of cut down material. During the movement, his left arm is sometimes fully extended and at an angle of more or less 90° to his trunk (Figure 7).



Figure 7. Position of the left arm (billhook)

His right arm is simultaneously used to swing a billhook toward the base of the tree. During the swing, his right arm is extending until billhook hits the tree (rarely fully extended). The worker is in a slightly bent position (Figure 8). The kinematics of the body segments used in the swinging motion is the core of the problem since that motion is the repetitive one.



Figure 8. Position of the right arm (billhook)

When using battery shears, worker's left arm is basically doing the same work as with using billhook. The difference is in the right arm where there are no more big swings but only "lock and squeeze" action as with any shears, with exception of these being powered by an electric motor and require minimal force to operate the switch. Since the cutting part of the shears is close to the hand, unlike the billhook blade which is extended with a wooden handle, the worker is in a more bent position (Figure 9).



Figure 9. Position of both arms (battery shears)

Joint angles (shoulder, elbow, and wrist), upper body angle and right arm kinematics such as velocity and acceleration obtained through motion capture technology would be very beneficial in describing and valorizing the effects of each forest cleaning method on the human body. Since the observed movement is very repetitive and motion capturing logging frequency is high, by using this new technology in real working conditions a great quantity of usable data can be obtained for a very short period of time. Furthermore, previous motion capture technologies were developed for indoor use which is not appropriate for outdoor forestry application, but this technology, with a few limitations like weak reception in dense vegetation, can deliver on that task.

4. Conclusion

Because of its practicality, different data outputs, precision, and the possibility of outdoor use, this technology has a great potential in forestry-related ergonomic measurements. Basically, any type of outdoor forestry work can be recorded, analyzed and improved. Especially the part of forestry works that haven't changed in terms of tools and methods. As a result, guidelines can be given for new work methods or even tool designs in order to preserve the health and safety of forestry workers. Noticed limitations like weak reception can be avoided if the data is logged directly on-site (memory integrated into the suit itself) and the only real limitation of this technology is the financial cost of the measuring equipment.

5. References

Bačić, M., Šušnjar, M., Pandur, Z., Šporčić, M., Landekić, M. (2018), "Physical workload while working with hedging bill and battery cutter in tending of pedunculate oak," Proceedings of the International Symposium Ergonomics 2018 – Emphasis on Wellbeing, Zadar, 59-64.

Held, J. P. O., Klaassen, B., Eenhoorn, A., van Beijnum, B. F., Buurke, J. H., Veltink, P. H., Luft, A. R. (2018), "Inertial sensor measurements of upper-limb kinematics in stroke patients in clinic and home environment," Frontiers in Bioengineering and Biotechnology, 6:27, doi: 10.3389/fbioe.2018.00027.

https://bmslab.utwente.nl/knowledgebase/xsens/

Karatsidis, A., Jung, M., Schepers, M., Bellusci, G., de Zee, M., Veltink, P. H., Andersen, M. S. (2019), "Musculoskeletal model-based inverse dynamic analysis under ambulatory conditions using inertial motion capture," Medical Engineering & Physics, 1-50.

Lintmeijer, L. L., Faber, G. S., Kruk H. R., van Soest, A. J., Hofmijster, M. J. (2018), "An accurate estimation of the horizontal acceleration of a rower's centre of mass using inertial sensors: a validation," European Journal of Sport Science, 18:7, 940-946.

Longo, A., Meulenbroek, R., Haid, T., Federolf P. (2018), “Postural reconfiguration and cycle-to-cycle variability in patients with work-related musculoskeletal disorders compared to healthy controls and in relation to pain emerging during a repetitive movement task,” Clinical Biomechanics, 54, 103-110.

Nutto, L., Malinovski, R. A., Brunsmeier, M., Schumacher Sant’Anna, F. (2013), “Ergonomic aspects and productivity of different pruning tools for a first pruning lift of *Eucalyptus grandis* Hill ex Maiden,” Silva Fennica, 47, 1-14.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

ANALYSIS OF RISKS CAUSED BY VIBRATIONS AND NOISES IN SMALL-SCALE FIREWOOD PRODUCTION

Andrea R. Proto [1], Stefano Grigolato [2], Salvatore Papandrea [1], Maria Francesca Cataldo [1],Raffaele Cavalli [2], Giuseppe Zimbalatti [1]
[1] Department of AGRARIA - University Mediterranea of Reggio Calabria, Italy [2] Department of Land Environment Agriculture and Forestry - University of Padova, Italy
andrea.proto@unirc.it

Abstract: *In Italy, as in many European countries, coppice forests is widely distributed among small-scale forest ownership and farm forestry from hill to the mountain. In rural areas, farm forestry are widely recognized for increasing and diversifying farm productivity while releasing pressure on existing forests. As a consequence, agroforestry or farm forestry represents an important resource that offers alternative and more sustainable modes of land exploitation in area not completely forestry but is tipically poorly developed with a low mechanization level. Most of these coppice stands are normally managed by the same self-employed owners and the motor manual felling wood harvesting is the unique process used in the area. Felling is done by chainsaw to guarantee that the stump is cut near the ground level and that no fibers are pulled out. Use of chainsaws presents a risk to workers safety and health. In addition to the highest accident rate in professional and non-professional work, the main problems are exposure to environmental hazards, wood dust and in particular noise and hand-arm vibration. The activity of these operators is irregular and not constant over the years. Consequently, the used chainsaws are aged with the following larger exposure to vibration and noise. As a consequence, the present work collected a set of nine chainsaws currently used by a sample of self-employed forest owners in the Sila area in Calabria (Southern Italy). The aims of the work were to analyse by a controlled test (same wood type, moisture content and diameter, the same operator) the hand-arm vibrations and the noise to which self-employed forest owners are subjected with the use of these chainsaws.*

S04 CTL harvesting optimization
Bit-and-Pieces

CHARACTERISTICS ANALYSIS OF DEFORMATION ABOUT V-HONEYCOMB WITH WING FOR FEEDING ROLLERS OF FOREST HARVESTER

Wang Dong [1,2], Wang Dian [1,2], Liu Jinghao [1,2], Huang Qingqing [1,2]
[1] School of Technology, Beijing Forestry University, China; [2] Key Laboratory of Forestry Equipment and Automation of State Forestry and Grassland Bureau, China

MULTI-STEM CTL HARVESTING OF SHORT ROTATION POPLAR PLANTATIONS

Natascia Magagnotti [1], Piotr Mederski [2], Raffaele Spinelli [1]
[1] CNR Ivalsa, Sesto Fiorentino (FI) - Italy; [2] Poznań University of Life Sciences, Faculty of Forestry, Department of Forest Utilisation, Poznań - Poland

IMPACT OF TREE MARKING AND SILVICULTURAL TREATMENT ON HARVESTER PERFORMANCE IN EARLY THINNING OPERATIONS – AN EXPERIMENT

Franz Holzleitner [1], Magdalena Langmaier [2,3], Bernhardt Obermayer [1], Eduard Hochbichler [2], Christian Kanzian [1]
[1] Institute of Forest Engineering, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences Vienna, Austria [2] Institute of Silviculture, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences Vienna, Austria [3] Austrian Research Centre for Forests, Department of Forest Growth and Silviculture, Seckendorff Gudent Weg 8, A-1130 Vienna, Austria

WORLDWIDE SHARE OF CUT-TO-LENGTH HARVESTING METHOD AND EXPLAINING FACTORS

Mikael Lundbäck, Carola Häggström, Tomas Nordfjell
Swedish University of Agricultural Sciences, Umeå, Sweden

INFLUENCE OF ALTERNATIVE MACHINE RELOCATION OPTIONS ON CUT TO LENGTH LOGGINGS IN EASTERN-FINLAND

Kari Väätäinen, Juha Laitila, Tuula Packalen, Pekka Hyvönen, Hannu Hirvelä
Natural Resources Institute Finland (Luke)

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

CHARACTERISTIC ANALYSIS OF DEFORMATION ABOUT FEEDING ROLLERS STRUCTURED WITH V-WINGED NPR HONEYCOMB

Wang Dong[1,2], Wang Dian[1,2,*], Liu Jinghao[1,2], Huang Qingqing[1,2]
1.School of Technology , Beijing Forestry University, Beijing, 100083，China
2.Key Laboratory of Forestry Equipment and Automation of State Forestry and Grassland Bureau, Beijing, 100083 ， China

Abstract: *The spikes of feeding rollers of harvesting head causes damage to the logs on the lateral surface of the processed assortment. The severity of the damage may be mostly influenced by the friction between rollers and logs and the effective contact area between feeding rollers and logs is too small. The objective of the study was to investigate a kind of variable stiffness feeding rollers to enlarge the contact area, which may reduce the damage depth. The feeding rollers is structured with multiple V-winged Negative Poisson's ratio (NPR) honeycomb. For analyzing the characteristics of honeycomb in the Y-direction, the plane elastic constants model and the solid models with different structural parameters were established. Then, the results show that Ey, the equivalent modulus of elasticity about the honeycomb of feeding rollers, increases with the thickness of honeycomb walls, and decreases with the upper angle and half width of honeycomb. While, the Poisson ratio vxy, decreases with the lower angle and upper angle of honeycomb. A test was made according to the density of spikes about the roller of LAKO 43HD harvesting head, which shows a 2-layer NPR honeycomb structured feeding roller, under an average pressure like the weight of an Eucalyptus, the compression varies between 10% and 30% to the original feeding rollers.*

Keywords: Feeding rollers; V-winged NPR honeycomb; Forest engineering; In-plane elastic constants.

1. Introduction

The feeding rollers in the head of the harvester is the key component that converts the hydraulic energy of the chassis into driving the action of logs in the head. The rigid teeth attached to the outer ring of the feeding rollers are used to provide the driving force inside the head for logs. However, in the process of operation, the steel teeth on the surface of the feeding rollers will cause some damage to the cuticle and wood fibers, which will affect the utilization value of the log. Therefore, the steel teeth of the feeding rollers on the head of the tree harvesting operation will cause damage to the wood fibers of the log itself, which needs to be solved urgently.



Fig. 1 Damage to logs caused by spikes of feeding rollers

In order to evaluate the damage caused by spikes, six kinds of feeding rollers with different tooth shapes were used to measure the damage depth of felling logs, it is found that the traditional rollers with spikes were most effective in processing and fuel consumption, but at the same time they caused the deepest damages to the saw logs. The roller type with adaptable steel plates was the most effective for small stems,

First author：E-mail address：523864435@qq.com (Wang Dong).
*Corresponding author：E-mail address：wangdian@bjfu.edu.cn (Wang Dian).

additionally it also caused the least damage to the saw logs[1]. The damage to logs caused by feeding rollers with different wear degrees were studies, It is pointed out that improvement in the maintenance of delimbing knives can reduce the reject rates of industrial round-wood by 5%, timely restoration of worn-out rollers can increase productivity by 2% and reduce fuel consumption by 5%[2]. The influence of two mechanized debarking treatments in eucalypts (three feed roller passes and five feed roller passes along the stem surface) with feed-roller-induced log surface damage on pulp value recovery was investigated, which concluded that logs subject to manual debarking produced significantly less undesired sized chips than both three-pass and five-pass mechanically debarked logs and therefore had significantly greater pulp value recovery[3]. However, the above analysis has not studied the situation of the feeding rollers itself, and it also has not considered the improvement of the structure of the feeding rollers. Therefore, a flexible feeding rollers based on NPR structure was proposed to solve this problem.

Auxetic materials, also known as NPR material, expands laterally when it is subjected to uniaxial tension, which makes the compression area locally dense. Compared with the traditional positive Poisson's ratio material, this unique mechanical property, such as shear resistance, indentation resistance and impact resistance, has attracted wide attention[4-11]. Based on the characteristics of concave mechanism, different shapes of NPR honeycomb structures were proposed, and their mechanical properties and energy absorption mechanisms at different impact velocities, densities and structural parameters were systematically studied by many mechanical analysis methods[12-19]. There are also many studies on the application of negative Poisson's ratio structures in engineering[20-24].

So, a new V-winged Negative Poisson's ratio(NPR) honeycomb structure for feeding rollers was designed, as shown in Fig. 2. The spikes are fixed on the wings of the honeycomb, the skin-outer cover of the structure is flexible and tough. Compared with the steel feeding rollers, according to the pressure force between logs and the feeding rollers, the cells of the NPR honeycomb will be reshaped. Then, the number of spikes could be increased and the pressure of unit area could also be decreased while the relative contact area was enlarged. As a result of that, the damages may be reduced.

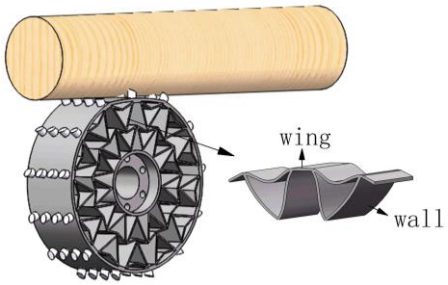


Fig. 2 The logging process for feeding rollers structured with V-winged NPR honeycomb

The mechanical properties of the single cell of feeding rollers structured with V- winged NPR honeycomb were evaluated. Firstly, the plane elastic constants model in the Y-direction and the solid models with different structural parameters were established. Secondly, FEM was used to simulate the honeycomb subjected to vertical loads. The effects of various parameters on the in-plane elastic constants under different topological densities were studied. Finally, according to the density of spikes about the roller of LAKO 43HD harvesting head, a tested was made to verify the theoretical calculation results and finite element simulation results, it is determined that when the topological density is λ_2, t is 4 mm and 5 mm, θ_2 is 70° and 75°, l is 29 mm and 31 mm, the compression of the feeding rollers with honeycomb varies between 10% and 30% to the original feeding rollers.

2. Methods and materials

2.1 The Y-direction mechanical characteristics of V-winged NPR honeycomb

As shown in Fig. 3, the cell of the V-winged NPR honeycomb is structured with 2 arrows, and 2 associated wings on the joint point. In the Y-direction, the honeycomb structure has a negative Poisson's ratio effect. By analyzing the deformation characteristics of V-winged NPR honeycomb before and after *Y*-direction loading, a theoretical model of in-plane elastic constants in *Y*-direction is derived based on displacement method.

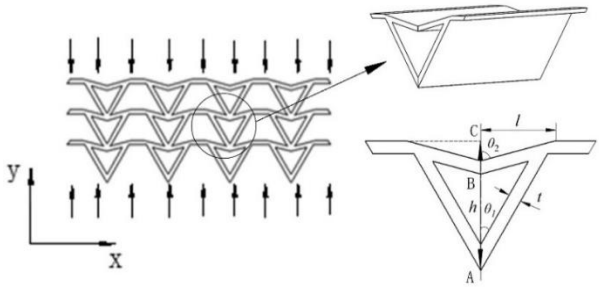


Fig. 3 The parameters of the cell of the V-winged NPR honeycomb

$$\nu_{xy} = -\frac{1}{\tan\theta_1 \tan\theta_2} \tag{1}$$

$$E_y = E_s \left(\frac{t}{l}\right)^3 \frac{\sin^3\theta_1 \cos^2\theta_2 + \sin^3\theta_2 \cos^2\theta_1}{\sin\theta_1 \sin\theta_2 \left(\sin\theta_2 \cos\theta_1 - \sin\theta_1 \cos\theta_2\right)} \tag{2}$$

E_s—Elastic modulus of honeycomb structural materials.

2.2 Finite element modelling

The entity models of honeycomb with different topological densities were established for simulation in Fig. 4. In order to minimize the influence of boundary conditions, only the displacement and deformation parameters Δ_x and Δ_y of the single cell in the center of the honeycomb were extracted (Saint Venant's principle).

The photosensitive resin was used as the material of the honeycomb. The modulus of elasticity of which is 2370MPa, and Poisson's ratio is 0.41. The boundary condition is: $F_x = 0$, and a vertical downward load F_y is applied on the plate, named AB. And terminals, named C_1-C_5, are fixed constraints.

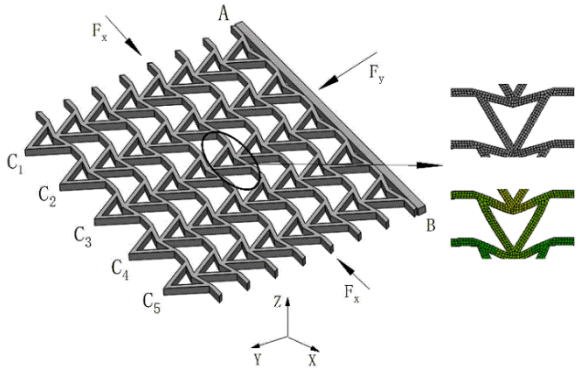


Fig. 4 Finite element simulation and boundary conditions

Based on the parameters range of size of the feeding rollers of LAKO 43HD harvesting head. As shown in Fig. 5, three different topological densities were defined correspond to different filling layers of feeding rollers structured with V-winged NPR honeycomb. In order to facilitate the subsequent analysis and comparison of the calculated results, dimensionless parameters λ were introduced here: $\lambda = l/h$, , that is to say, λ_1、λ_2 and λ_3 represent the ratio of cell half width *l* to *h* under three topological densities respectively.

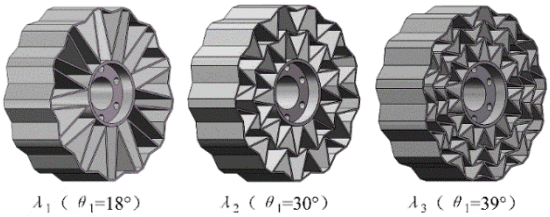


Fig. 5 Three different topological densities of feeding rollers structured with V-winged NPR honeycomb

3. Results and discussion

3.1 Geometric parameter—In plane elastic constant curve

The comparisons of equivalent elastic modulus E_y and Poisson's ratios v_{xy} between analytical results and FEM results with variation values of t and θ_2 when the honeycomb is compressed in y direction are presented in Fig. 6 and Fig..

As shown in Fig.6, the equivalent modulus of elasticity E_y varies slight when the t is constant and θ_2 increases from 60° to 80°, so angle θ_2 has a little effect on the E_y, while the cell thickness t has great influence on the E_y, and at any topological density, E_y increases with the cell thickness t and increases rapidly. the analytical results of E_y is slightly larger than that of FEM results with λ_1, the analytical results is in good agreement with the FEM results with λ_2 and λ_3 . While the topological density is λ_3, the holes of cells becomes smaller when θ_2 is small, and the honeycomb structure tends to be solid, so, only the in-plane elastic constants of honeycomb with smaller cell thickness were studied when θ_2 is small.

As shown in Fig.7, the Poisson's ratio v_{xy} is only affected by the cell angle θ_2 and θ_1. The absolute value of v_{xy} decreases with the θ_1 and θ_2, the analytical results of Poisson's ratio v_{xy} agree well with FEM results at large θ_2 regardless of the topological density. When the angle θ_2 is small, the error between the analytical results and the FEM results of v_{xy} will increase with the cell thickness t, because the theoretical analysis was based on Euler beam theory, and did not take into account the shear deformation, tensile deformation of solid honeycomb wall and the change of angle between honeycomb walls, when the wall thickness of honeycomb structure is larger, the shear deformation, tension and compression deformation of honeycomb wall and the change of angle between honeycomb walls account for a larger proportion of the total deformation of honeycomb.

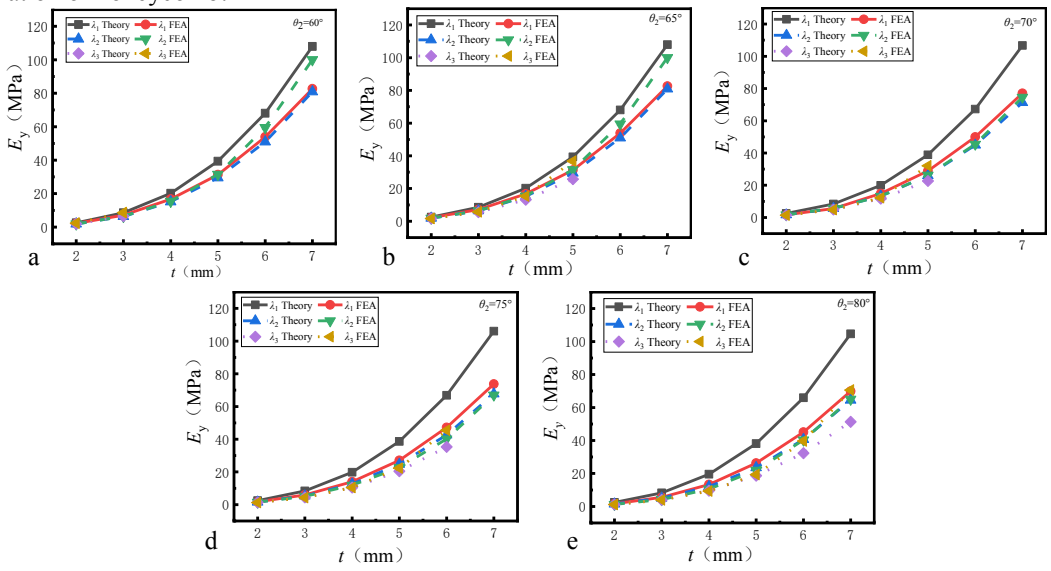


Fig. 6 The influence of geometric parameters on E_y under different topological densities

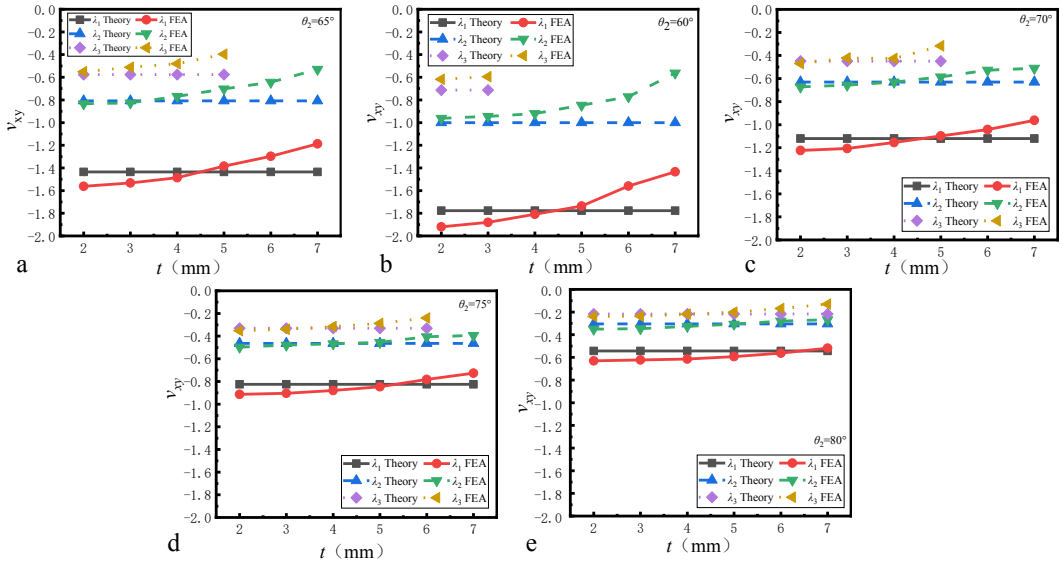


Fig. 7 The influence of geometric parameters on v_{xy} under different topological densities

3.2 Discussion

For this NPR multicellular structure, the influence of geometric nonlinearity on mechanical properties becomes larger with the strain ratio, under large deformation, the angle between cell walls will change and the shape tends to shrink inward, which increases the relative density of the structure. As shown in Fig. 8 and 9, in actual working conditions, when the cell deformation is large, the angle between the long wall and the short wall becomes smaller with the strain, the thicker the cell wall, the easier interference will occur, and the cell structure tends to be solid structure. Therefore, in consideration of the premature phenomenon of rigid interval of cell structure when the topological density is λ_1 and λ_3, the topological density of V-winged NPR honeycomb structure for feeding rollers was preliminarily selected as λ_2.

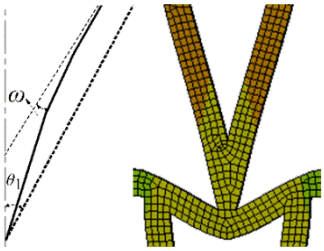


Fig. 8 Large deformation diagram of honeycomb long wall with topological density of λ_1

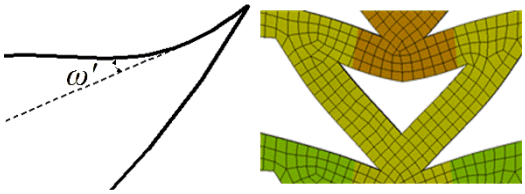


Fig. 9 Large deformation diagram of honeycomb long wall and short wall with topological density of λ_3

As shown in Fig. 10, the relationship between the cell half-width l and the plane elastic constants when the topological density is λ_2. The parameters of the solid model are t=5mm, θ_1=30 °, θ_2=75 °, and l takes five groups of values evenly between 23-31mm. The results shows that, E_y decreases with the width l and decreases more slowly, while Poisson's ratio is not affected by cell half-width l.

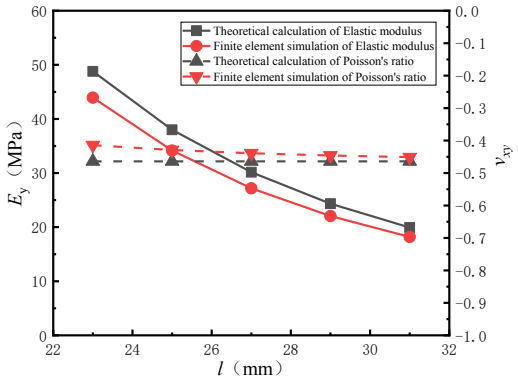


Fig. 10 The influence of cell half-width *l* on in-plane elastic constants with topological density of λ_2

3.3 Test

According to the density of spikes about the roller of LAKO 43HD harvesting head and the in-plane elastic constant contract curves, the vertical static pressure of the feeding rollers under an average pressure like the weight of an Eucalyptus was simulated， as shown in Fig. 11. When the topological density is λ_2, t is 4 mm and 5 mm, θ_2 is70° and 75°, l is 29 mm and 31 mm, the compression of the feeding rollers with V-winged NPR honeycomb structure under these parameters varies between 10% and 30% to the original feeding rollers, thus, the number of spikes contacted by the feeding rollers and the logs can be increased by 3-5 rows, which may effectively reduce the damage of the feeding rollers to the logs. Therefore, six groups of specimens were made for test verification. The specimens material is photosensitive resin with elastic modulus of 2370 MPa－2650 MPa and Poisson's ratio of 0.41.

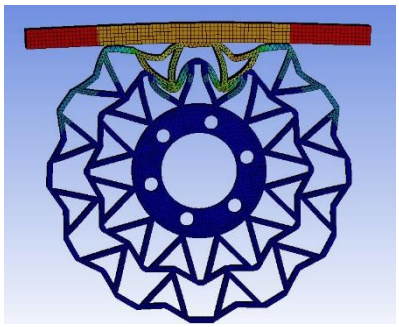


Fig. 11 The deformation of feeding rollers under an average pressure like the weight of an Eucalyptus

During the experiment, the compression speed of the test bench was set to 2.5 mm/min and the compression volume was 10 mm, as shown in Fig. 12. the comparison between analytical results、FEM results and test results of the elastic constants as shown in Table 1 and Table 2.



Fig. 12 The compression experiment of V-winged NPR structure in the Y-direction

Tab.1 Analytical results、FEM results and test results of E_y

Structural parameters	Analytical results （MPa）	FEM results （MPa）	Test results （MPa）
t=4mm	12.634	10.593	9.428
t=5mm	24.676	22.657	17.828
θ_2=70°	25.972	23.742	21.118
l=31mm	19.926	18.182	16.729

Tab.2 Analytical results、FEM results and test results of v_{xy}

Structural parameters	Analytical results	FEM results	Test results
t=4mm	−0.464	−0.467	−0.493
t=5mm	−0.464	−0.455	−0.484
θ_2=70°	−0.630	−0.618	−0.736
l=31mm	−0.464	−0.451	−0.453

4. Conclusions

In this paper, a new V-winged NPR honeycomb structure suitable for the feeding rollers of harvesting head was proposed, the rigidity of the feeding rollers can be changed, the contact area between the feeding rollers and the logs can be enlarged effectively, and the damage to the logs may be reduced. Based on Euler-Bernoulli beam theory, the theoretical model of in-plane elastic constants in Y direction was established when the range of structural parameters is suitable for feeding rollers of LAKO 43HD harvesting head. The accuracy of the theoretical model was verified by finite element simulation and test.

（1）It can be summarized that the equivalent elastic modulus E_y in Y direction of V-winged NPR honeycomb structure is greatly influenced by three parameters: cell thickness t, cell angle θ_1 and cell half-width l, and is relatively less affected by cell angle θ_2, while Poisson's ratio v_{xy} is only affected by the cell angle θ_1 and θ_2.

（2）When the topological density is λ_2, the thickness t is 4 mm and 5 mm, the θ_2 is 70° and 75° and the width l is 29 mm and 31 mm, the compression of the feeding rollers with honeycomb varies between 10% and 30% to the original feeding rollers under these parameters, thus the number of spikes contacted with the logs can be increased by 3-5 rows, which may reduce the damage to the logs.

（3）The research results have certain guiding significance for choosing parameters when the feeding rollers adopts V-winged NPR honeycomb structure. Follow-up work will analyze the mechanical properties of the honeycomb in the X direction, and the overall mechanical properties of the honeycomb after choosing the optimum parameters. Then the energy absorption of the honeycomb and the mechanical properties of the whole feeding rollers will be analyzed.

4.1 Acknowledgements

This work is supported by “The Basic Scientific Research Projects of Central Universities of China （2016ZCQ08） and The National Science and Technology Support Plan Project of China （2015BAD07B02）”.

4.2 References

[1] Yrjö Nuutinen, Kari Väätäinen, Antti Asikainen, Robert Prinz and Jaakko Heinonen. Operational Efficiency and Damage to Sawlogs by Feed Rollers of the Harvester Head[J]. Silva Fennica, 2010, 44(1): 121-139.

[2] Gerasimov, Y, Seliverstov, A, Syunev, V. Industrial round-wood damage and operational efficiency losses associated with the maintenance of a single-grip harvester head model: a case study in Russia[J]. Forests, 2012, 3(4)：864-880.

[3] van der Merwe, JP, Pulkki, R, (Ackerman, P, et al. The impact of log surface damage caused by harvester

Eucalyptus debarking on pulp value recovery[J]. Southern Forests，2018, 80(2): 105-113.
[4] Frost H J, Ashby M F. Deformation mechanism maps: the plasticity and creep of maetals and ceramics. Pergamon press, 1982.
[5] Gibson L J, Robertson C I. The Mechanics of Two-Dmensional Cellular Materials[J].Proceedings of the Royal Society of London, 1982, 382(1782): 25-42.
[6] FU Minghui，YIN Jiuren. Equivalent Elastic Parameters of Honeycomb Core Layer [J].Journal of Mechanics, 1999, 01: 113-118.
[7] Alderson A, Alderson A. A Triumph of Lateral Thought[J]. Chemistry & Industry, 1999, 17(10):384-391.
[8] Evans K E, Alderson A. Auxetic Materials:Functional Materials and Structures from Lateral Thinking![J]. Advanced Materials, 2000, 12(9): 617-628.
[9] Lakes R, Witt R. Making and characterizing negative poisson's ratio materials[J]. International Journal of Mechanical Engineering Education, 2002, 30(1): 50-58.
[10] Prawoto Y. Seeing auxetic materials from the mechanics point of view: A structural review on the negative Poisson’s ratio[J]. Computational Materials Science, 2012, 58: 140-153.
[11] Yang W, Li Z M, Shi W, Xie B H, Yang M B. Review on auxetic materials[J]. Journal of Materials Science，2004, 39(10): 3269~3279.
[12] DU Juntong. Study of mechanical properties of morphing honeycomb structures based on shape memory polymer [D]. Heilongjiang：Harbin Institute of Technology, 2016.
[13] ZHANG Yifan. Numerical analysis and experimental study of two kinds of honeycomb structures with negative poisson 's ratio [D]. Guangdong：Jinan University, 2015.
[14] LU Zixing, WANG Huan, YANG Zhenyu，et al. In-plane dynamic crushing of star-arrowhead honeycomb structure [J/OL]. Acta Materiae Compositae Sinica: 1-8[2018-12-04]
[15] Hu L L, Yu T X, Gao Z Y, et al. The inhomogeneous deformation of polycarbonate circular honeycombs under inplane compression[J]. International Journal of Mechanical Science, 2008, 50(7): 1224~1236.
[16] A. Lorato，P. Innocenti，F. Scarpa，et al. The transverse elastic properties of chiral honeycombs[J]. Composites Science and Technology, 2010, 70: 1057~1063.
[17] Jiang Wei，MA Hua. Mechanical metamaterial with negative Poisson's ratio based on circular honeycomb core [J]. Scientific Bulletin, 2016, 61(13): 1421-1427.
[18] Hou Xiuhui，YIN Guansheng. Dynamic Crushing Performance Analysis For Auxetic Honeycomb Structure [J]. Mechanical Strength, 2016, 38(05): 905-910.
[19] ZHANG Tieliang，DING Yunliang，JIN Haibo. Stability problem of honeycomb sandwich structures based on finite element method [J]. Acta Materiae Compositae Sinica, 2012, 29(03): 184-190.
[20] Wang Yuanlong, Zhao Wanzhong, Zhou Guan，et al. Suspension mechanical performance and vehicle ride comfort applying a novel jounce bumper based on negative Poisson's ratio structure[J]. Advances in Engineering Software, 2018, 122: 1~12.
[21] ZHANG Wei，HOU Wenbing，HU Ping. Mechanical properties of new negative Poisson's ratio crush box with cellular structure in plateau stage [J]. Acta Materiae Compositae Sinica, 2015, 32(02): 534-541.
[22] MA Zhengdong，LIU Yuanming，LIU Xiaoming，et al. Ultra-light weight non-inflatable tire structure based on negative Poisson's ratio structure，CN 102529583 B[P]. 2015.
[23] WANG Ruoyun，HE Jiangyun，DING Yumei，et al. Research on the Mechanic Performance of Honeycomb Plastic Tire [J]. Application of engineering plastics, 2014, 42(09): 42-45.
[24] ZHANG Ge，YANG Weiming. Finite Element Analysis on Contact Performance of Honeycomb Non-pneumatic Tire [J]. Tire industry, 2013, 33(11): 651-654.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

MULTI-STEM CTL HARVESTING OF SHORT ROTATION POPLAR PLANTATIONS

Natascia Magagnotti[1], Piotr Mederski[2], Raffaele Spinelli [1]
[1] CNR Ivalsa, Sesto Fiorentino (FI) - Italy; [2]Poznań University of Life Sciences, Faculty of Forestry, Department of Forest Utilisation, Poznań - Poland
magagnotti@ivalsa.cnr.it

Abstract: *In Europe, the short rotation forestry (SRF) concept has evolved over the past decades. SRF has transformed from shrub crops designed for producing low-value chips to proper forestry plantations geared towards the production of a mixture of logs and chips. This new approach has attracted the interest of the particle-board industry, which, in recent years, has planted considerable areas with the new crop (>20 000 ha). IKEA, in particular, has developed a new light-weight OSB board made of SRF poplar wood. In Europe, CTL is the classic solution for producing logs, but SRF poplar plantations generally offer trees that are small, making it difficult to carry out profitable CTL harvesting, when a single tree is cut and processed at a time. Mass-handling might be a solution, and CTL may be used in the multi-stem mode. This is already being done in the thinning of conventional forests, but SRF plantations are actually clearcuts, which offer different work conditions and open up new opportunities. In cooperation with IKEA and Ponsse, the authors organized a comparative time-and-motion study aimed at determining the productivity and the cost of the mechanized CTL harvesting of modern SRF poplar plantations. The objective of the study was to find out the productivity level and costs of single-stem and multi-stem harvesting. The work was carried out on eighteen 100-tree plots, randomly assigned to each treatment: single-stem and multi-stem harvesting. Each plot was characterised using conventional mensuration methods. An elemental time study was conducted on each plot using hand-held computers, while all the logs produced were scaled with a tape and caliper. Fuel consumption was obtained from the harvester's on-board computer (OBC). The results of the study in terms of productivity, fuel consumption, value recovery and cost will be presented at the conference.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

EFFECT OF TREE MARKING, THINNING METHOD AND TOPPING DIAMETER ON HARVESTER PERFORMANCE IN A FIRST THINNING OPERATION – A FIELD EXPERIMENT

Holzleitner, F.[1]; Magdalena Langmaier[2,3], Obermayer B. [1]; Hochbichler, E.[2]; Kanzian C.[1]
[1]Institute of Forest Engineering, [2]Institute of Silviculture
Department of Forest- and Soil Sciences
University of Natural Resources and Life Sciences Vienna
Peter-Jordan-Strasse 82, A-1190 Vienna, Austria
christian.kanzian@boku.ac.at

[3]Austrian Research Centre for Forests,
Department of Forest Growth and Silviculture,
Seckendorff Gudent Weg 8, A-1130 Vienna, Austria

Abstract
The effect of harvester operator tree selection or prior tree marking in thinning operations on satisfactory silvicultural results and performance is discussed frequently in Austria. In operator tree selection, the machine operator decides on the fly which trees are selected to cut. Prior tree marking requires manual marking of trees before the operation, whereby different tree marking techniques could be used. The objective of the study was to analyze the effect of prior tree marking, thinning method and topping diameter on harvester performance in low-diameter thinning operations.

Overall, 2.36 ha divided into 48 plots with 5,202 trees were thinned with an average diameter at breast height (dbh) over bark for all plots of between 12.5 and 14.7 cm. In total, 3,122 trees were harvested, resulting in 60% removal of stem number over all plots. The entire thinning operation was captured using video cameras and one third of the recorded study plots where analyzed for the time and motion study. Generalized additive and linear regression modelling was applied to test relationships between the variables tree marking, thinning method, topping diameter, tree size, time per tree and productivity.

The harvester operator achieved an average productivity of 7.4 ±1.5 m³ per productive system hour, with stem volume having the major influence on harvesting productivity. Prior tree marking, topping and thinning method did not significantly affect productivity. Without prior tree marking by the foresters, harvesting removal was shifted toward lower diameters. Within the unmarked plots, 7.0% of the residual trees were damaged compared with 3.2% in marked plots.

Keywords:
harvester productivity, thinning method, time and motion study, prior tree marking, topping diameter

This work has been submitted to Silva Fennica and is under review currently.

Acknowledgments
This work was funded by The Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management under the project number 100903. The authors want to thank the Austrian Federal Forests (ÖBf) for providing the studied operation site and the entrepreneur Huber and Tazreiter GmbH including his team for supporting the study.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

WORLDWIDE SHARE OF CUT-TO-LENGTH HARVESTING METHOD AND EXPLAINING FACTORS

Mikael Lundbäck* Carola Häggström Tomas Nordfjell
Department of Forest Biomaterials and Technology
Swedish University of Agricultural Sciences
mikael.lundback@slu.se

Almost 1.9 billion solid cubic meters under bark (m^3) of industrial roundwood is harvested each year worldwide (FAO, 2016). Out of this, 1 billion m^3 origin from the five largest producers of industrial roundwood: USA, Russia, China, Canada and Brazil. However, theirs and others ways to harvest and extract the volumes vary greatly (Heinrich & Arzberger, 2004)(Heinimann, 2004)(Arets *et al.*, 2011)(Hiesl, 2013)(Moskalik *et al.*, 2017). The aim of this study was to compile the annual harvested volume of industrial roundwood and its distribution on the main harvesting methods in the dominating roundwood producing countries. The aim was also to assess plausible explaining variables and possible relationships between those variables and the choice of harvesting method.

The distribution of harvesting methods is estimated for three pre-defined categories:

- Fully mechanized CTL – Ground based cut-to-length operations where all steps are mechanized. The category refers to what in Canada is called "CTL at stump".
- Fully mechanized FT/TL – Ground based full-tree or tree-length operations where all steps are mechanized, and the stem is bucked at earliest at roadside.
- Other – Category for all other operations, such as cable- or air-based, partly mechanized systems and systems with simple and/or old equipment.

Four different sources of material was used to obtain the state of the art distribution of harvesting methods, 1) peer reviewed papers and reports from research institutes and universities 2) official global statistics from Food and Agriculture Organization of the UN 3) Manufacturers' estimates of the world market for various forest machines and systems 4) other forestry experts´ estimates.

Table 1. Continent summary of the harvesting method estimations

Continent[a)]	Annual harvest (M m^3)[b)]	Fully mechanized CTL (%)	Fully mechanized FT/TL (%)	Others (%)
Europe (exc Russia)	355	62%	4%	34%
Russia	198	35%	10%	55%
Asia	34	1%	4%	95%
Africa (South Africa)	14	30%	60%	10%
North America	514	20%	66%	14%
South America	201	42%	24%	34%
Oceania	59	28%	52%	20%
World	1376	37%	33%	30%

a) Including only studied countries
b) Solid under bark

Of all the variables that was tested as explaining factors for the 32 countries' share of fully mechanized CTL only 5 variables ended up in the two final regression models (Table 2).

Table 2. Tested variables that are present in the final models.

Variable	Explanation
Diesel price (model 1 & 2)	The price of diesel fuel (US$/L)
GDP/capita (model 1)	Gross Domestic Product for each country (US$/capita)
Publically owned land (model 2)	Share of the forest land that is publically owned (%)
Share of steep slope >15° (model 2)	Share of the forest land that have a slope > 15°.
Share of steep slope >20° (model 1)	Share of the forest land that have a slope > 20°.

Two different regression models were created. One with a high degree of clear and explainable relations between response and explaining variables and another with slightly less intuitive interpretation but a higher R^2 value. According to model 1, a high price of diesel points toward a higher share of CTL, a large share of steep slope give less CTL and a higher Gross Domestic Product (GDP) increases the CTL share. The adjusted R^2 for model 1 is 0.63. According to model 2, a high price of diesel again points toward a higher share of CTL and a large share of flat land also give more CTL. An interaction term says that the third variable "Share of forest land that is publically owned" also contribute to explain share of CTL but is dependent on diesel price. However, at a certain diesel price, an increase in publically owned land have a negative effect on the share of CTL. The adjusted R^2 for model 2 is 0.75.

The results imply that the global distribution between CTL and FT/TL methods is quite equal, 37 % CTL and 33 % FT/TL (Table 1). This differ somewhat from the general notion of the FT/TL method as the dominating method or *group of systems* in the world, see for example (Drushka & Konttinen, 1997). The most important explanation is probably that the distribution of methods in this study is based on the harvested volume instead of the number of machines sold, FT/TL systems have usually more machines per harvested m^3 which distort the comparison in that sense. One main difference between most FT/TL operations and CTL operations is that the number and size of diesel engines is greater for the FT/TL operations. Therefore our conclusion is that countries that have low diesel prices will be more likely to favor FT/TL harvesting. In opposite, countries that have high diesel prices is more likely to be dominated by CTL operations that usually employs fewer and smaller machines. The share of steep slopes in forest land is an example of the physical environment that the harvest operation has to consider. The terrain slope together with terrain roughness, ground bearing capacity and the size of the trees are often determining factors for possible harvesting systems in a specific area or region.

Arets, E.J.M.M., van der Meer, P.J., Verwer, C.C., Hengeveld, G.M., Tolkamp, G.W., Nabuurs, G.J. & van Oorschot, M. (2011). *Global Wood Production - Assessment of industrial round wood supply from forest management systems in different global regions*. (Alterra Report). Wageningen: Alterra, Wageningen UR.

Drushka, K. & Konttinen, H. (1997). *Tracks in the forest: the evolution of logging machinery*: Timberjack Group Helsinki.

FAO (2016). *Statistics yearbook Forest products*. (FAO Statistics yearbook. Rome. Available from: http://www.fao.org/forestry/statistics/80570/en/ [2019-07-04].

Heinimann, H.R. (2004). HARVESTING | Forest Operations under Mountainous Conditions. In: Burley, J. (ed. *Encyclopedia of Forest Sciences*. Oxford: Elsevier, pp. 279-285. Available from: http://www.sciencedirect.com/science/article/pii/B0121451607000119.

Heinrich, R. & Arzberger, U. (2004). HARVESTING | Forest Operations in the Tropics, Reduced Impact Logging. In: Burley, J. (ed. *Encyclopedia of Forest Sciences*. Oxford: Elsevier, pp. 247-252. Available from: http://www.sciencedirect.com/science/article/pii/B012145160700003X.

Hiesl, P. (2013). *Productivity standards for whole-tree and cut-to-length harvesting systems in Maine.* Diss.: University of Maine.

Moskalik, T., Borz, S.A., Dvorak, J., Ferencik, M., Glushkov, S., Muiste, P., Lazdins, A. & Styranivsky, O. (2017). Timber Harvesting Methods in Eastern European Countries: a Review. *Croatian Journal of Forest Engineering,* 38(2), pp. 231-241.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

INFLUENCE OF ALTERNATIVE MACHINE RELOCATION OPTIONS ON CUT TO LENGTH LOGGINGS IN EASTERN-FINLAND

Kari Väätäinen, Juha Laitila, Tuula Packalen, Pekka Hyvönen, Hannu Hirvelä
Natural Resources Institute Finland (Luke)
kari.vaatainen@luke.fi

Abstract: *In Finland, the share of relocation time (incl. waiting of the relocation) from the total working time of the logging machine is around 3-6 %. As the total mass of logging machines has increased, the requirements for the relocation trucks to meet sufficient trafficability and operating permits have also increased. Few decades ago most general low-bed truck in forest machine relocations was based on 3-axle chassis whereas today new trucks are based on 5-axle chassis. As a result, relocation costs have increased. These expensive vehicles are demanded to utilize with higher degree even more than before. Discrete-event simulation was used to investigate CTL-logging operation models of interest. Logging site data, converted from the national forest inventory, was located in North Karelia in Eastern Finland. The impact of i) the size of the logging fleet, ii) the work shift scheduling of machine relocations, iii) the investment cost of a relocation truck, iv) the size of available logging site reserve on machine utilization, work-time division and logging costs were investigated. The logging fleet setups of one low-bed truck and 2 to 8 harvester-forwarder units varied in the simulation scenarios.*

S05 Bioenergy
Final destination?

QUANTIFICATION OF LOGGING LOSSES RELATED TO BIOMASS SUPPLY OF FOREST RESIDUES CAUSED BY ADDITIONAL DELIMBING OF HARVESTING HEADS

Markus Riebler, Elke Dietz, Herbert Borchert
Bavarian State Institute of Forestry, Freising, Germany

EVALUATION OF SCREENIG AND DRYING TO IMPROVE FUEL PROPERTIES OF LOW QUALITY WOOD CHIPS FOR THE USE IN SMALL WOOD GASIFIER CHP-PLANTS

Simon Lesche [1], Daniel Kuptz [1], Thomas Zeng [2], Anett Pollex [2], Georg Kuffer [3], Jana Mühlenberg [2], Volker Lenz [2], Hans Hartmann [1]
[1] Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ), Schulgasse 18, D-94315 Straubing, Germany [2] DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Torgauer Straße 116, 04347 Leipzig, Germany [3] Spanner Re² GmbH, Niederfeldstr. 38, 84088 Neufahrn i. NB, Germany

FOREST BIOMASS HARVESTING AND CHIP QUALITY IN MIXED HARDWOOD FORESTS FOR BIOENERGY PRODUCTION

John Vance [1], Jingxin Wang [1], Shawn Grushecky [1], Raffaele Spinelli [2]
[1] Division of Forestry and Natural Resources, West Virginia University, Morgantown, WV, USA jxwang@wvu.edu [2] CNR Ivalsa, Via Madonna del Piano 10, 50019 Sesto Fiorentino (FI), Italy spinelli@ivalsa.cnr.it

INFLUENCE OF STORAGE ON PROPERTIES OF SCOTS PINE BARK

Johanna Routa, Hanna Brännström, Jarkko Hellström, Juha Laitila
Natural Resources Institute Finland, Luke

MARGINAL COST OF BIOMASS UTILIZATION IN MECHANIZED FOREST RESTORATION TREATMENTS IN THE SOUTHWESTERN USA

Elizabeth Dodson [1], Nathanial Anderson [2]
[1] WA Franke College of Forestry and Conservation, University of Montana, USA; [2] Rocky Mountain Research Station, US Forest Service, MT, USA

SYNERGIES BETWEEN THE NEW BIOECONOMY AND FOREST OPERATIONS FOR FUEL TREATMENT AND FOREST RESTORATION

Nathaniel Anderson [1], Woodam Chung [2], Elizabeth Dodson [3]
[1] Rocky Mountain Research Station, United States Forest Service, Missoula, USA; [2] Oregon State University, Corvallis, USA; [3] WA Franke College of Forestry and Conservation, University of Montana, Missoula, USA

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

QUANTIFICATION OF LOGGING LOSSES RELATED TO BIOMASS SUPPLY OF FOREST RESIDUES CAUSED BY ADDITIONAL DELIMBING OF HARVESTING HEADS

Markus Riebler, Elke Dietz, Herbert Borchert
Bavarian State Institute of Forestry
Department of Forest Technology, Economics and Timber
Hans-Carl-von-Carlowitz-Platz 1, 85354 Freising, Germany
Markus.Riebler@lwf.bayern.de

Abstract: *Wood chip supply from whole coniferous crowns is an increasingly discussed topic in Bavaria concerning critical nutrient exports versus biomass supply form regional forests. A research project called "Nutrient preservation using the technique of roughly delimbed energy roundwood" was launched by the Bavarian State Institute of Forestry (LWF) in order to answer various questions about this controversy. A difference between motor-manual and mechanised harvesting in relation to nutrient exports was one aim of the study. Therefore, the so called "additional delimbing zone" got into focus and was investigated closely during data analyses. The term "additional delimbing zone" describes the part of the log, which gets delimbed above the actual bucking diameter for material use due to constructional matters of the harvesting heads without top-saw units, when bucking the last log for material use. During the project, a detailed biomass inventory including even step-by-step removals of whole trees by tree-climbers and several further laboratory measurements were performed. As one result, all required data for computing the mass-effects of additional delimbing, like tree heights, diameter and height of bucking limit, length of harvesting head overrun and so called mass sum curves, were available. The sample calculation shows that the additional delimbing of mechanized harvesting operation leaves 16.5 % more branches, twigs and needles on the site compared to a motor-manual harvesting method for the same tree.*

Keywords: biomass export, harvesting head, additional technical delimbing, forest residues, nutrient sustainability, nutrient export

1. Introduction

Continuous demand for energy wood makes forest residues still the most important raw material for biomass supply in Bavarian forestry. Meanwhile, wood chip production from whole coniferous crowns can be part of the controversy on critical nutrient exports, especially concerning stands on poorer sites.

Therefore, the Bavarian State Institute of Forestry conducted a research project named "Nutrient preservation using the technique of roughly delimbed energy roundwood" to answer various questions about biomass-harvesting and nutrient exports. Three logging operations at different spruce-dominated stands with low nutrient content levels were observed, including an in-depth biomass inventory and work studies [Schulmeyer et al., 2016]. Two thinnings were operated fully mechanized, whereas one was done motor-manually. The aim of this particular research question was to quantify the amount of remaining branch-wood at the site and to compare motor-manual and mechanised harvesting methods focussed on biomass extraction and nutrient export issues.

2. Material and Methods

2.1. Additional delimbing zone

The amount of remaining branches and brushwood (twigs and needles) vary from mechanised to motor-manual harvesting method, because lumberjacks do not cut more branches than necessary, whereas most harvesting heads cause a so called “technical additional delimbing zone”. This describes a delimbed part of the stem above the actual bucking diameter for material use (saw logs and pulpwood), because the saw-units of most harvesting heads are located behind the delimbing knives. The real length of the zone, usually between 1 m to 2.3 m, depends on the dimensions of the harvesting heads (Pic. 1). The additional delimbing zone leads to two major effects: Since more branches and brushwood can remain on the site, consequently less biomass for energy utilization is extracted. Leaving a higher amount of crown parts with high nutrient levels on the site, there is a disproportionate high nutrient-saving effect compared to their mass and volume.



Pic. 1: Additional delimbing zone of a spruce crown at the investigation site “Zusmarshausen”

2.2. Biomass inventory

A detailed biomass-inventory was conducted, including detailed silvicultural data like tree-heights for each stand. Even distances between every single branch whorl and therefore height information for each whorl were measured. Datasets also provide detailed information about biomass volumes and element contents for every crown compartment, as there are branches (diameter 7 cm -1 cm), twigs (diameter less 1 cm) and needles [Dietz, et al., 2018]. For further information see Dietz et al. (2019) published in these proceedings.

2.3. Sample calculation of the mass-effect caused by additional delimbing for one tree

The following explanations show the calculation of the technical additional delimbing for one tree from the investigation stand “Zusmarshausen”. See Dietz et al. (2019) for information about calculation various mass and nutrient effects caused by the chosen logging methods, e.g. additional delimbing during fully mechanized biomass utilization.

Required Information:

- tree height
- diameter of bucking limit
- height of bucking limit (=h_{ahg})

- mean diameter at breast height (dbh)
- height of additional harvesting head overrun (= h_{tad})
- mass sum curves

For the calculation of the mass-effect of additional delimbing of whole crowns (forest residues) by fully mechanised felling, the biomass which is cut off additionally by the harvesting knifes has to be removed by calculation from the stem. At first the proportional height of the bucking limit diameter has to be calculated (=h_{ahg}). Then the proportional height of the upper end of the technically additional delimbing zone (= h_{tad}) must be detected as well. Mass sum curves of branches have to be available for the particular or instead for comparable stands. The whorl, which is next above the h_{ahg} diameter's proportional whorl height, providing the value "CP_b", must be looked up therein for that particular tree or a representative group of trees. After that, the certain relative whorl height which is closest below h_{tad} can be discerned from the mass sum chart, providing the value "CP_u". Subtracting CP_b from CP_u yields the proportional mass difference (ΔCP) between a motor-manually harvested spruce crown and a mechanized harvested one (see (1)).

$$\Delta CP = CP_u - CP_b \qquad (1)$$

where ΔCP, CP_u and CP_b are the delta of compartment-mass, compartment-mass up, and compartment-mass below

3. Results of exemplary calculation

The calculation will be shown exemplarily for tree number 264 (see Figure 1). At first tree height has to be known or measured. In that case tree #264 was tape measured 26.9 m, as well as bucking diameter and height of bucking diameter. The mass of branches at the height of bucking diameter can be taken out of the mass sum curve figure easily.

The number of whorls which will be delimbed additionally can be calculated using the specification of the harvesting head. The additional overrun by harvesting head in this case was calculated with a size of 1.5 m. In that particular stand a Waratah 480C with a length slightly below 1.5 m, was used.

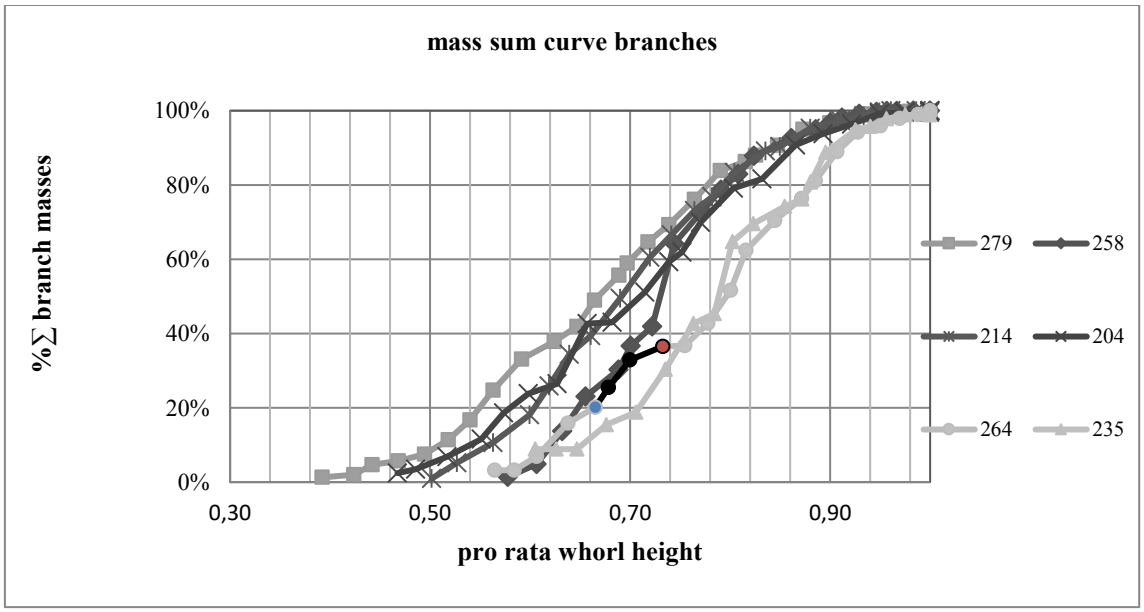


Figure 1: Mass sum curve for branches for the site of Zusmarshausen. Blue: %-h_{ahg}/ %-CP_u; Red: %-h_{tad}/ %-CP_b ^

This figure puts the mass sum of branches in relation to the proportional height of each whorl. During the biomass inventory the height of every whorl was tape measured. Each curve represents one of the trees, which were removed step-by-step by tree-climbers during biomass inventory, at the investigation-stand "Zusmarshausen". All further input values for the calculation of logging losses caused by the additional delimbing are the actual height of bucking limit, diameter of that height, size of harvesting head and were available out of the data-set.

For the sample calculation of the mass-effect of additional delimbing, tree #264 was chosen. The initial data for that example can be seen in Table 1.

Table 1: Input data for mass-calculation approach example tree #264

tree-height	26.9 m
bucking limit diameter (bld)	14 cm
height of bucking limit (h_{ahg})	18.0 m
Size of harvesting head (Waratah 480 C)	1.5 m
Height of upper end of additional delimbing (h_{tad})	19.5 m

Table 2: Data gathered from function of mass sum curves for tree #264 of Figure 1

%-h_{ahg}	67 %	⇔	%-CP_u	36.6 %
%-h_{tad}	73 %	⇔	%-CP_b	20.1 %

The sample calculation of the mass-effect caused by additional delimbing was calculated as shown in the following. The tree height and bucking limit diameter were results of the biomass-inventory. The h_{tad} of 19.5 m is the sum of h_{ahg} plus the size of harvesting head. These two heights have to be expressed relatively to the overall tree-height (see Table 2), then named %-h_{ahg} and %-h_{tad}.
The mass sum curves of Figure 1 are used to find out the relative sum of biomass per compartment (= CP) for %-h_{ahg} (=%-CP_u) and %-h_{tad} (=%-CP_b). In the case of tree #264 the values are 36.6 % (%-CP_u) and 20.1 % (%-CP_b). Then %-CP_b was subtracted from %-CP_u. The result of the calculation of Δ CP is 16.5 %. Consequently, 16.5 % more branches remain on the site to provide extra biomass for the nutrient circle and might even lead to a better fuel quality.

4. Discussion and Outlook

The first attempt to quantify logging losses caused by the additional delimbing and its positive effect on nutrient sustainability is a promising approach. It is now possible to calculate the mass-effect of additional delimbing because of the harvesting method of biomass from forest residues. The mass-effect of additional delimbing caused by the mechanised harvesting method on branches is in that case 16.5 %, compared to a motor-manual forest operation. But this particular case has no general universality. At the moment, the mass sum curves are only valid for spruce trees or stands with the very similar specifications, which are for example age, bucking dimensions or mean height.

In the future, generally valid relations between mass sum curves of different stands have to be analysed. Furthermore, yield tables in combination with the specifications of different harvesting heads could be used to develop either a decision support tool or a mobile app for smartphone use. That would hopefully support further optimization for forest owners or practioners concerned with forest operation planning. Forest owners or operators should then be able to predict the potential nutrient saving (see Dietz et al., 2019) and gatherable biomass amounts more precisely and in an even more sustainable way. A calculation tool based on objective facts could maybe even improve the acceptance of mechanized forest operations in the broad population.

5. Acknowledgements

This study was funded by the Bavarian State Ministry of Food, Agriculture and Forestry (EW/13/47) and was conducted by the department of Forest Technology, Economics and Timber of the Bavarian State Institute of Forestry from 2015 to 2018. Special thanks to our colleagues Fabian Schulmeyer, Martin Högl, Birgit Reger, Marianne Schütt, Stefan Schuster and Karl Hüttl for their input and support. We also thank our partners from the Bavarian State Forest Enterprise (BaySF), especially the team from the Centre for Energy Wood and the regional forest offices involved (Selb, Rothenkirchen, Roding and Zusmarshausen) for providing investigation stands and practitioner's expertise.

6. References

Schulmeyer, F., Dietz, E., Reger, B., Hüttl, K., Borchert, H. (2016): Effects of rough delimbing of coniferous crowns on biomass and nutrient exports and the productivity of the forest wood chip production chain. Proceedings of the 49th FORMEC Symposium 2016, Warsaw, Poland

Dietz; E. Riebler, M., Schulmeyer, F., Schütt, M., Reger, B., Hüttl, K., Schuster, S., Borchert, H., (2018, unpublished): Ressourcenschonung durch „Grob entastetes Energierundholz". Research report of LWF-Project EW/13/47. 240 S.

Dietz, E., Riebler, M., Borchert, H. (2019): "Nutrient saving effects of roughly delimbed energy roundwood in comparison to biomass supply of whole coniferous crowns caused by harvesting method and bucking". FORMEC Proceedings 2019.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

EVALUATION OF SCREENIG AND DRYING TO IMPROVE FUEL PROPERTIES OF LOW QUALITY WOOD CHIPS FOR THE USE IN SMALL WOOD GASIFIER CHP-PLANTS

Simon Lesche[1]*, Dr. Daniel Kuptz[1], Thomas Zeng[2], Dr. Anett Pollex[2], Georg Kuffer[3], Jana Mühlenberg[2], Dr. Hans Hartmann[1]
[1]Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ), Schulgasse 18, D-94315 Straubing, Germany, Phone.: (+49) 9421-300-064, Fax: (+49) 9421-300-211, Email: simon.lesche@tfz.bayern.de
[2]DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Torgauer Straße 116, D-04347 Leipzig, Germany
[3]Spanner Re² GmbH, Niederfeldstr. 38, D-84088 Neufahrn i. NB, Germany

Abstract: *Small-scale wood gasifier CHP-plants might strongly contribute to the transition from fossil to renewable energies. Currently, high quality wood fuels such as stemwood are usually used in these plants. In the future, increasing shares of low quality fuels from circular or cascade use will also approach this market. These fuels can cause problems for failure-free plant operation due to their high fuel heterogeneity and their lower chemical and physical fuel properties. In this study, three different supply chains for processing low quality wood chips by screening and drying were investigated. Processing was tested with wood chips from forest calamities and from roadside maintenance. After processing, problematic physical fuel parameters and combustion critical elements such as potassium were reduced. Upgraded fuels were applied in three wood gasifier CHP-plants Thereby, results indicate that a decrease of moisture content, and the fine particle fraction can lead to an increase in electrical efficiency.*

Keywords: wood chips, fuel upgrading, gasification, combined heat and power generation (CHP), fuel quality

1. Introduction

Due to the growing social awareness regarding climate change and due to national and international legal frameworks for the transition from fossil fuels to renewable energies, the share of renewable energy sources in the German energy mix should increase in the near future. A major part of the renewable electricity generation will most likely be provided by solar and wind power. However, these energies are considered very volatile and other sources such as decentralized small-scale wood gasifier CHP-plants will be necessary as they help to balance volatile energy production and are therefore needed for the stabilization of the electricity grid. Currently, these plants require wood fuels with a high quality concerning both physical and chemical properties to achieve suitable energy efficiencies and failure-free plant operation.

Considering a growing competition for high quality wood for material use (e. g. for biorefinery processes), biomass residues from circulatory and cascade use might increasingly be applied in small-scale wood gasifier CHP-plants (Scarlat, 2015). Due to the high heterogeneity of such low quality wood fuels and their overall higher shares of fuel properties that are considered critical for combustion and gasification compared to stemwood, failure-free plant operation might be a challenge. Flexible, energy efficient and cost-effective secondary fuel processing steps such as screening and drying might help to increase fuel properties of low quality fuels to make them suitable for the use in small-scale CHP-plants.

2. Materials and Methods

During this study, two wood chip assortments were processed by screening and drying, i. e. wood chips from forest calamities (coniferous wood from windthrow and bark beetle attacks) and from roadside maintenance while a third trial with chemically untreated scrap wood was planned to be carried out. Dried and screened wood chips from stemwood of Norway spruce (*Picea abies*) were gasified as a reference.

Wood chips from forest calamities and from roadside maintenance were chipped using the same self-propelled chipper (Albach Diamant 2000). New sharp knives were installed before each chipping process. The machine was always operated by the same driver to avoid an influence of the chipping process on the fuel quality (Figure 1). The installed on-board screen in the chipper was 50 mm × 50 mm.



Figure 1: Chipping with the self-propelled Albach Diamant 2000 (left) was carried out with new and sharp knifes (right)

The wood chips from calamity wood and from roadside maintenance were upgraded by screening and drying in three supply chains while the reference wood chips were only upgraded in supply chain I:

I. Continuous drying in a walking floor dryer (Spanner Re²) with a subsequent continuous screening in a self-constructed, small-scale drum screen with round holes (48 mm) followed by rectangular holes (3 mm × 20 mm)

II. Continuous drying in a walking floor dryer (by Spanner Re²) which represents at the same time the bunker of the gasification plant (see below) with a continuous sieving in the screw conveyer of the plant (round holes: 4.5 mm, followed by rectangular holes: 50 mm × 85 mm)

III. Batch drying in a self-constructed container dryer (15 m^3) and screening in a self-constructed drum screen (rectangular holes, 10 mm × 40 mm)

All drying techniques use heated air for drying (i. e. excess heat from small-scale wood gasifier CHP-plants, see below). The amount of thermal power varied and depended on parameters such as the specific type of plant or the temperature of the ambient air.

During the project, it was planned to upgrade chemically untreated, shredded scrap wood in two of the three supply chains, as well. However, this delivered material could not be processed as planned mostly due to problems in the screw conveyors as a result of an unfavorable particle size distribution and the corrugated shape of the hog fuel material. However, a determination of the fuel parameters was done in order to be able to make a theoretical statement concerning the properties of unsuitable fuel.

For each supply chain and raw material, fuel property analyses were performed before, in between and after processing, according to international standards for solid biofuels listed in Table 1 (particle size distribution (n = 5), ash content (n = 5), moisture content (n = 10), net calorific value (n = 5), ash melting behavior (n = 1) and elemental composition (n = 1)).



Figure 2: Screening in supply chain I (left) and in supply chain III (right)

Table 1: International standards to determine the physical fuel properties of solid biofuels (d. b. = dry basis)

Parameter	Unit	ISO-Standard
Moisture content	w-%	18134-2
Ash content (d. b.)	w-%	18122
Net calorific value (d. b.)	MJ kg^{-1}	18125
Particle size distribution	w-%, mm	17827-1

After processing, fuels were employed in three different commercially installed wood gasifier CHP-plants (Figure 3). Thereby, fuels from each supply chain were gasified in at least two of the three plants.

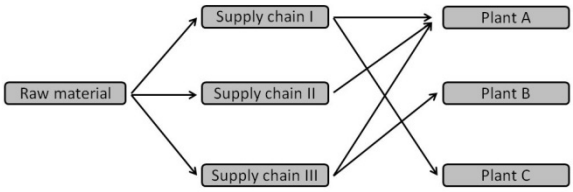


Figure 3: Simplified flowchart of the experimental design for calamity wood chips and for wood chips from roadside maintenance

The plants used in the project were constructed by Spanner Re^2 GmbH (Neufahrn i. NB., Germany). The gasifiers produce wood gas according to the direct current principle with a fixed bed. Ambient air is used as a gasification agent in the downdraft systems. The plants generate both electricity and heat. The overall generated power depends on the individual system components that are applied. The three plants A to C differ only in their engine size and their cooling systems and are operated throughout the year.

Plant A is a HKA 45 which is installed on the manufacturer's premises, Spanner Re^2. It supplies 45 kW of electrical power as well as 100 kW of thermal power. Plant A was used as a reference. Processed materials from all supply chains were gasified in this plant to ensure a high comparability between fuels (Figure 3). Thereby, Plant A comprises supply chain II, i. e. the bunker of Plant A is the walking floor dryer of supply chain II and the screw conveyor system between bunker and CHP-plant allows for screening of the fuels. Fuel treatment via the screw-integrated screen was not activated when delivered fuels had already been screened (i. e. coming from supply chain I and III, see Figure 3).

Plant B is located on an agricultural farm that is also the location of supply chain III (Figure 3). It is a HKA 35 that was upgraded with a more powerful engine. It delivers about 50 kW of electric power and 110 kW of thermal power.

Plant C is also located on an agricultural farm and uses the materials that are processed in supply chain I. It is a HKA 35 with its original engine that provides 35 kW of electrical power and 80 kW of thermal power.

In the field trials, 30 to 60 m^3 wood chips were upgraded for each raw material and processing chain. The resulting amount was sufficient for 6 to 10 days of gasification in the respective plants.

According to the manufacturer Spanner Re^2, moisture content, particle size distribution and ash content are the most important fuel properties in order to ensure energy efficient and failure-free plant operation (Spanner Re^2, 2019). The moisture content of the wood chips should not exceed 13 w-% for ideal conversion conditions in the gasifier unit. Particle size distribution should be low in fines (i. e. particles ≤ 3.15 mm) and oversized particles (> 45 mm), with a maximal particle length shorter than 150 mm since these can lead to blockages in the feeding system and to increased shares of tar in the product gas (Spanner Re^2, 2019). Increased ash contents and individual chemical elements (i. e. silicon and potassium) also have negative effects on failure-free plant operation as they influence ash melting temperature (slagging) (Kuptz, 2016). During fuel processing and gasification, energy balances (electrical and thermal) and fuel throughput rate were recorded.

3. Results and discussion

The reference material, the calamity wood chips and the roadside maintenance wood chips were produced, upgraded and gasified as planned. The shredded scrap, however, proved to be unsuitable for the supply chains and the gasifier CHP-plants due to its physical fuel properties. In the following the results of analyzing and balancing of the supply chains and the gasification are shown. For the scrap wood, only fuel properties of the unprocessed raw material are presented.

3.1 Moisture content before and after processing

Before drying, the used raw materials had typical moisture contents of recently harvested wood of approx. 43 w-% (calamity wood) and 50 w-% (roadside maintenance wood, Figure 5) (Dietz 2016). Thus, moisture contents strongly exceeded the value of 13 w-% that is recommended by the plant manufacturer.

Within every supply chain, the moisture content strongly decreased due to the used drying systems (Figure 5). In all cases, the recommendations regarding the maximal moisture content of 13 w-% could be met. The individual drying systems differ in moisture content homogeneity after drying. Thereby, the batch processes (supply chain III) provided moisture contents with a higher standard deviation compared to continuous drying systems (supply chain I and II).

Concerning the time required for drying, no direct comparison between supply chains is possible because the thermal power used for the drying process differed significantly. For instance, wood chips in supply chain I were dried with a maximum thermal power of more than 300 kW, while in supply chain III only a maximum power of about 100 kW was available for the drying process. In addition, ambient air temperatures that might also affect the drying process strongly differed in between individual drying periods of the same supply chains.

Considering the overall drying success, the three applied drying systems differ also in terms of disturbance and workload for the operator. Drying in supply chain I applies continuous drying, but the dryer is not integrated into the CHP-plant. Thus, the same workload for transferring wood chips as in supply chain III is necessary. In contrast, supply chain II is integrated directly into the storage bunker of the CHP-plant and, thus, requires no additional work after processing. Supply chain III requires a high level of manpower to operate. After the screening step, the batch dryer has to be filled using a wheel loader. After drying, the material has to be transported into the bunker of the CHP-plant.

3.2 Ash content before and after processing

Ash content (on dry basis) of the reference material was significantly lower than that of the calamity wood and the wood from roadside maintenance ($p < 0.05$, T-test, Figure 5). The ash content of the unprocessed calamity wood was 0.86 w-% (dry basis (d. b.)) and therefore lower than the usual ash values for this assortment. This indicates that the used assortment consisted to high shares of stemwood and had only low contents of bark, needles or impurities such as mineral soil (Dietz, 2016).

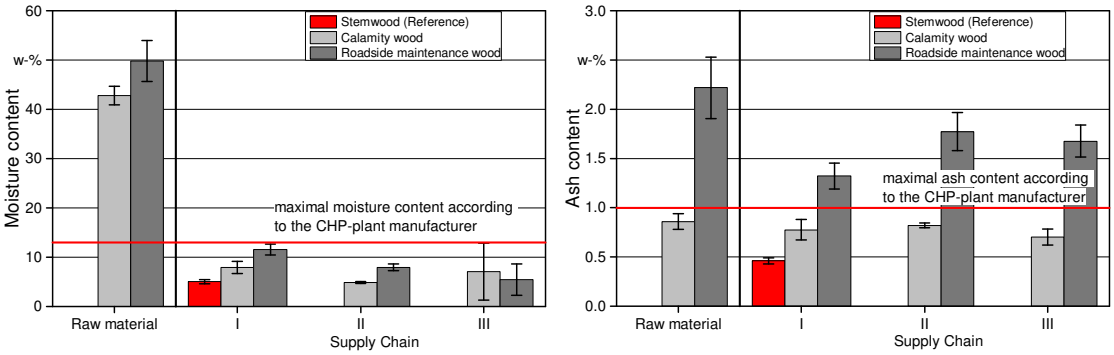


Figure 5: Left: Moisture content (in w-%) for the raw materials and after processing with the three supply chains and the maximal recommended moisture content (mean values ± standard deviations). Right: Ash content (in w-%, dry basis) for the raw materials and after processing with the three supply chains (mean values ± standard deviations) and the maximal recommended ash content

In case of the calamity wood, no real difference in ash content was measured before and after screening (Figure 5). This was rather unexpected as the ash content of the fine particle fraction was much higher (e. g. 3.61 w-% (d. b.) in supply chain I). Since the mass fraction of the separated fines was 12 w-% of the whole raw material, the calculated ash content of the processed calamity wood chips should be much lower (i. e. 0.37 w-% instead of 0.78 w-% in supply chain I). This effect was also observed in previous studies that found a reduction in ash content through screening (Kuptz, 2019). As the measured ash content of the calamity wood after processing was on a similar level in all 3 supply chains, the measured value for the unprocessed raw material was suspected to be too low, probably due to sampling errors in the field.

In the case of the roadside maintenance wood, the original ash content of 2.2 w-% (d. b.) decreased by the treatment in every supply chain (Figure 5). Thereby, supply chain I reached the lowest ash content of approx. 1.3 w-% (d. b.). Only reference stemwood and calamity wood met the maximal ash content specification 1.0 w-% that is recommended by the plant manufacturer.

Table 2: Fuel-related number of disorders in the respective CHP-plant in relation to the supply chain and the raw material
0 means no disorders; - means that the corresponding material was not gasified in the mentioned plant.

Raw Material	Supply chain	Number of disorders per CHP-plant		
		A	B	C
Reference	I	1	0	0
Calamity wood	I	6	-	8
	II	1	-	-
	III	3	0	-
Roadside maintenance wood	I	4	-	2
	II	7	-	-
	III	0	1	-

No clear correlation could be observed between the ash content and the functional stability of the CHP-plants (Table 2). For example, ash contents of the roadside maintenance wood in supply chain II and III had similar values after processing. Both materials were gasified in the CHP-plant A. In the case of the material from supply chain II, a total of seven fuel-related disorders appeared in the system. The material

from supply chain III, on the other hand, could be gasified without any fuel-related disturbance (Table 2). Plant malfunction was recorded by the individual plant operators and no qualitative assessment was provided on the type of disturbance. Thus, plant malfunction may also have been caused by other impacts such as an unfavorable particle size distribution or the concentration of chemical elements (critical composition of the producer gas).

3.3 Particle size distribution before and after processing

Regarding particle size distribution, the reference material (stemwood of Norway spruce) contained significant lower shared of very fine particles (≤ 3.15 mm) and oversized particles (> 45 mm) compared to the other fuels (Figure 7). These differences were also visible by optical assessment of the processed wood chips (Figure 6).

In the case of the wood chips from calamity wood, processing by screening resulted in a reduction of both the coarse and the fine fraction (Figure 7). This explanation is supported by the results from previous projects (Kuptz, 2019). In case of the wood chips from roadside maintenance, no reduction of fines was recorded for supply chain II. This was most probably due to water vapor condensing on the screen within the screw conveyor. Due to the very low outside temperatures at the time of the experiment (December 2018), the condensation water froze and, thus, restricted the functional capability of the sieving unit.



Figure 6: Left: Reference wood chips (stemwood of Norway spruce) after processing in supply chain I (size of the rectangular frame = DIN A5). Right: Roadside maintenance wood chips upgraded in supply chain I (size of the rectangular frame = DIN A5)

The most effective way to reduce the amount of fines was the screening in supply chain I. There the continuous screening using rectangular holes (3 mm × 20 mm) (Figure 2) provided the highest degree of fines separation in the tested materials (Figure 7, left). In case of critical oversized particles, the screening method of supply chain III, i .e. the drum screen with 50 mm round holes provided the best results (Figure 7, right).

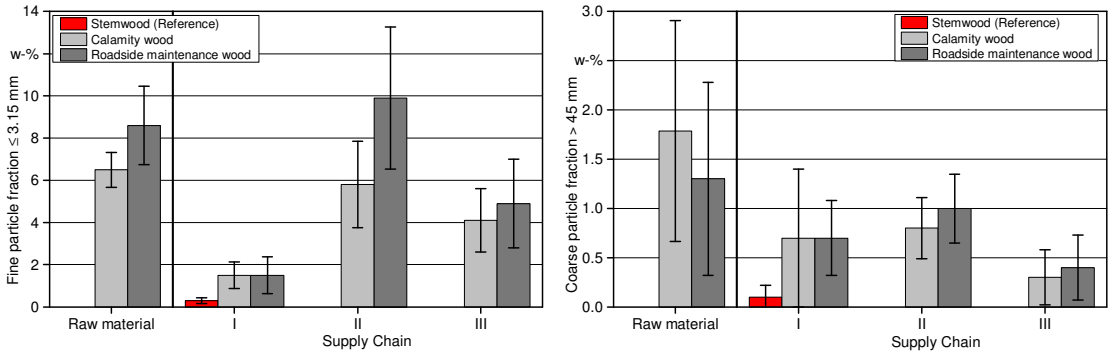


Figure 7: Left: Fine particle fraction (≤ 3.15 mm) in w-% for the raw materials and after processing with the three supply chains (mean values ± standard deviations). Right: Coarse particle fraction (> 45 mm) in w-% for the raw materials and after processing with the three supply chains (mean values ± standard deviations)

3.4 Chemical analysis and ash melting behavior

The chemical composition of wood chips also determines the fuel quality of the materials as it influences the combustion behavior, e. g. in terms of gaseous and particular emissions and in terms of ash melting tendencies. The overall chemical analyses showed values that were in a typical range for the investigated assortments (Figure 8, Dietz 2016). In all cases, combustion-critical elements such as K, Si and P are reduced in the main particle fraction compared to the fine fraction (Figure 8). This coincides with the results of previous research projects which locate a large part of the combustion critical substances in the fine particle fraction due to higher shares of needles, bark or impurities from mineral soil (Kuptz, 2019, Zeng, 2019). Screening removes this fine fraction and, thus, it reduces high shares of the combustion critical elements.

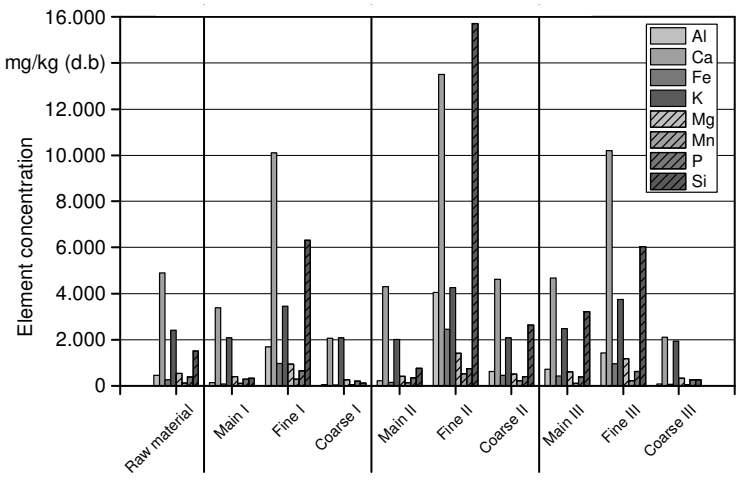


Figure 8: Element analyses of roadside maintenance wood for the three supply chains

In the following, the focus will be on the elements that influence ash melting properties since the gasification systems of Spanner Re^2 are rather inconspicuous in terms of emissions. For the evaluation of slagging tendency of solid biofuels, one chemical fuel index is usually applied (Zeng, 2019; Sommersacher, 2013), i. e. the molar (Si+P+K)/(Ca+Mg)-ratio:

$$\frac{(Si+P+K)}{(Ca+Mg)} \ (in \ \frac{mol}{mol}). \qquad (1)$$

With an increasing ash melting index, ash slagging tendencies of solid biofuels should increase. Figure 9 shows the deformation temperature (DT) of the wood chips from supply chain I compared to the ash melting index. The DT was determined according prEN ISO 21404. All three upgraded fuels (main fraction) had a similar index and DT's in a comparable range. The fine fractions showed higher ash melting indexes and consequently also lower DT's. Thereby, all processed main fractions showed DT's that were above the typical temperature level (1,200 °C- 1,300 °C) in the gasifier while the separated fine particles showed a lower and thus rather problematical DT (i. e. < 1,300 °C). The results are in line with the experience gained in the field trials. During the gasification trials no slag related problems occurred.

The ash melting index of the raw materials differs only slightly from that of the treated assortments (Table 3), so that a consideration of the associated ash melting properties (of raw materials) is necessary. This was not determined at the first attempt, but is currently in progress.

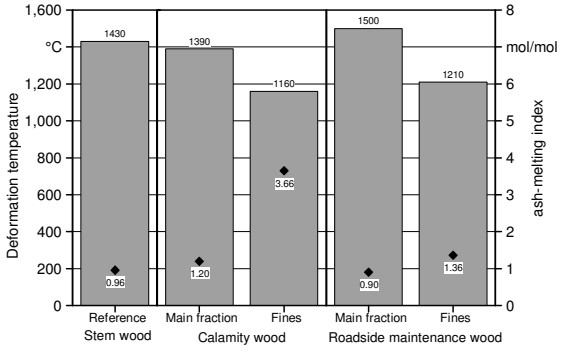


Figure 9: Deformation temperature of the assortments from supply chain I compared to ash- melting Index (Si+P+K)/(Ca+Mg)

Table 3: Ash melting indexes of raw materials and the main fraction of supply chain I

		$\frac{(Si+P+K)}{(Ca+Mg)}$
Calamity wood	Raw material	1.17
	Main fraction	1.20
Roadside maintenance wood	Raw material	1.07
	Main fraction	0.90

3.5 Gasification performance (efficiency)

Due to difficulties with monitoring the mass flow of the fuels in some of these full scale trials, only the electrical energy efficiencies of Plant A (i. e. that was linked to supply chain II) could be investigated in detail. Thereby, electrical efficiency decreased with increasing share of fines (Figure 10). Although this effect was rather small, the findings coincide with the manufacturer's fuel recommendations that identify low fines as one of the most important parameters for efficient operation.

Comparing the influence of the fine fraction on the electrical efficiency with the influence of the moisture content (Figure 10), it can be seen that the influence of the moisture content is less pronounced. Still, the electrical efficiency tends to decrease with increasing moisture content. Since moisture contents were below the maximal value that is recommended by the plant manufacturer, only a small effect was to be expected.

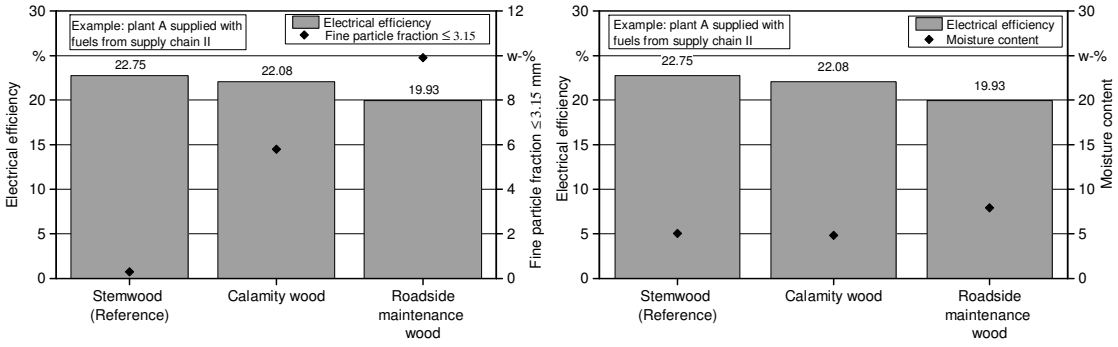


Figure 10: Left: Electrical efficiency (in %) of Plant A in relation to fine particle fraction (≤ 3.15 mm in w-%) for fuels processed with supply chain II. Right: Electrical efficiency (in %) of Plant A in relation to moisture content (w-%) of fuels processed in supply chain II

3.6 Outlook on further fuel alternatives (scrap wood)

Based on the results of fuel analyses, it is obvious that the unprocessed shredded scrap wood needs to be upgraded by drying and screening in order to be used in a wood gasifier CHP-plant. The assessed shredded wood showed a too high moisture content for gasification of 21.8 w-% (SD: 0.71 w-%), which is in the typical range for this assortment (Thrän, 2016). The material had an ash content of 0.47 w-% (SD: 0.15) and a high amount of coarse particles (> 45 mm) with an average of 10.5 w-%, the maximum value was over 14 w-%. The maximal particle length was 215 mm with a cross section of 2.5 mm^2. Thus, this hog fuel could not be upgraded due to foreseeable major problems with the screw feeding into the screening machines used in this project. For the use of shredded scrap wood in small scale wood gasifier CHP-plants, alternative supply chains have to be considered. To remove the very large coarse particle fraction, for example, a drum screen with a feeding system for larger particles (i. e. screw conveyors with a larger diameter, conveyor belts, etc.), a star screen or a jigger screen could be used. All these techniques are currently used in German biomass terminals for processing wood chips (Kuptz, 2019). After separation of oversized particles, drying of the material would be possible in the dryers used in this project.

However, in opposition to wood chips, hog fuel assortments will always remain problematic in terms of their mechanical properties. This is due to the shape of the corrugated particles which also are rather long and thin because comminution was done by splitting tools rather than by cutting knives. Alternative comminution methods are restricted by the high content of foreign material (stones, metals), which are usually prevailing in waste wood.

Chemical analysis of the fuel is still ongoing. However, since chemically untreated scrap wood was used, no gasification problems due to chemical fuel properties are to be expected. Overall the use of scrap wood may cause legal conflicts with the infeed privilege for renewable energy sources.

4. Summary and conclusion

Results on fuel quality indicate that none of the unprocessed raw materials was suitable for the use in the CHP-plants without secondary fuel treatment due to high moisture contents or unsuitable particle size distributions. After upgrading in the supply chains, all low quality wood chips became suitable for the gasification in the investigated plants. This assessment coincides with the recorded experience of the involved plant operators. Still, even with the processed (upgraded) fuels, more plant disturbances were recorded compared with the combustion of high quality wood chips from stemwood. Thus, using these fuels requires trained plant operators.

Individual processing techniques differed in terms of final fuel quality, but also in investment costs and required manpower. Final cost calculations and some chemical analyses are still ongoing. However, the results already confirm that operation of wood gasifier CHP-plants with processed wood chips from low quality and low cost raw materials is possible and might contribute to future energy systems at reduced operating costs.

5. Acknowledgements

The authors like to thank the operators of the supply chains and of the CHP-plants for their support during this study. This project was funded by the German federal ministry for economic affairs and energy (BMWi) on decision of the German Bundestag under the grant number 03KB135B.



6. References

Dietz, E.; et al. (2016): Qualität von Holzhackschnitzeln in Bayern. Gehalte ausgewählter Elemente, Heizwert und Aschegehalt. Technologie- und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe (TFZ); Straubing; in: Berichte aus dem TFZ, 46).

Kuptz, D.; et al. (2016): Fuel quality of wood chips - chemical elements and fuel indexes. Proceedings of the 24th European Biomass Conference & Exhibition.

Kuptz, D.; et al. (2019): Evaluation of combined screening and drying steps for t6he improvement of the fuel quality of forest residue wood chips – results from six case studies. In: Biomass Conversion and Biorefinery 8, DOI: 10.1007/s13399-019-00389-2.

Scarlat, N.; Dallemand, J.-F.; Monforti-Ferrario, F.; Banja, M.; Motola, V. (2015): Renewable energy policy framework and bioenergy contribution in the European Union – An overview from National Renewable Energy Action Plans and Progress Reports. In: Renewable and Sustainable Energy Reviews 51, DOI: 10.1016/j.rser.2015.06.062.

Sommersacher, P.; et al. (2013): Application of Novel and Advanced Fuel Characterization Tools for the Combustion Related Characterization of Different Wood/Kaolin and Straw/Kaolin Mixtures. In: Energy & Fuels 27 (9), DOI: 10.1021/ef400400n.

Spanner Re² (2019): Biofuels usable in wood gas CHP-plants, A list of the manufacturer Spanner Re2: https://www.holz-kraft.com/de/produkte/brennstoffe-holzvergaser-bhkw.html accessed: 15.05.2019

Spanner Re² (2019): Mit Holzgas hocheffizient Energie erzeugen – Spanner Re² Holzvergaser & Blockheizkraftwerk (BHKW). https://www.holz-kraft.com/de/produkte/holzvergaser-bhkw-hka-35-45-49.html accessed: 15.05.2019

Thrän, D.; et al. (2016): Nebenprodukte, Rückstände und Abfälle. In: M. KALTSCHMITT (Hrsg.): Energie aus Biomasse. Grundlagen, Techniken und Verfahren. 3. Auflage. Dordrecht, Heidelberg, London, New York, NY: Springer.

Zeng, T.; et al. (2019): Impact of adhering soil and other extraneous impurities on the combustion and emission behavior of forest residue wood chips in an automatically stoked small-scale boiler In: Biomass Conversion and Biorefinery, https://doi.org/10.1007/s13399-018-00368-z

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

FOREST BIOMASS HARVESTING AND CHIP QUALITY IN MIXED HARDWOOD FORESTS FOR BIOENERGY PRODUCTION

John Vance [1], Jingxin Wang [1], Shawn Grushecky [1], Raffaele Spinelli [2]
[1] Division of Forestry and Natural Resources, West Virginia University, Morgantown, WV, USA
jxwang@wvu.edu [2] CNR Ivalsa, Via Madonna del Piano 10, 50019 Sesto Fiorentino (FI), Italy
spinelli@ivalsa.cnr.it
jxwang@wvu.edu

Abstract: *A mechanized harvesting system combined with whole-tree chipping was investigated on two harvesting sites in central Appalachia, USA. Production and machine rate data of the operations were collected through time-motion study, with chipping elements defined as feeding, chipping, and loading. Chipping cycles averaged 21.5 minutes to produce 13.35 dry metric tons per truckload, providing hourly rate of 37.31 dry metric tons/PMH. Total cycle time including truck delivery averaged 183 minutes, giving hourly production rate of 4.38 dry metric tons/PMH delivered. The unit cost of the harvesting system including one feller-buncher ($4.16/odMg), two grapple skidders ($7.22/odMg), and the chipper ($3.33/odMg) was combined for total per unit cost of $14.70/dry metric ton to produce in-woods chips at the landing. Total operational costs for felling, skidding, chipping, and truck delivery is estimated at $18.01 to $24.62 per dry metric ton dependent upon transportation cost. Chips were sampled from the operations to characterize properties and evaluate whole-tree chips as a bioenergy feedstock according to ANSI Standard AD17225-4:2014 Solid Biofuels. Results of properties testing indicated 37.5% green moisture, 0.212 g/cm3 bulk density, 10.5% bark content, 0.49 % ash, and 18.59 Mj/Kg calorific heating value. Size distribution of wood chips were categorized into small (3-16mm), medium (16-45mm), and large (45-63mm). Chip sizes captured 46% small, 45% medium, and 3% large by total mass, respectively. Fines (63mm). These whole-tree chips were found to meet the highest grade A1 requirements of the U.S. wood chip fuel quality standard.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

INFLUENCE OF STORAGE ON THE PHYSICAL AND CHEMICAL PROPERTIES OF THE SCOTS PINE BARK

Johanna Routa*, Hanna Brännström, Jarkko Hellström, Juha Laitila
Natural Resources Institute Finland
Yliopistokatu 6B,
80101 Joensuu, Finland
johanna.routa@luke.fi

Abstract: *Bark is currently used mainly for producing energy but extraction of valuable components before combustion offer an interesting cascading use for debarking biomass. Buffer storing is an inevitable part of bark biomass logistics but during storing substantial dry matter losses can reduce the properties and the economic value of the raw material. As delivery volumes and commercial values have increased, the economic losses associated with poor storage management of bark biomass have raised concerns. Behind the increasing interest in bark is the aim of resource efficient utilization of forest biomass. The content of many valuable extractives starts to decrease immediately after tree felling and this degradation continues during storage of bark biomass.*
In our study, the bark quality characteristics of Scots pine bark during 2 months buffer storing was measured, and energy content change during storing calculated. In addition, the amount of extractives was measured after 2, 4 and 8 weeks of buffer storing period, to monitor how the chemical composition of bark changes during storage. The temperature of the bark at the terminal stack was monitored with temperature loggers. The produced parameters are valuable information when developing novel storing systems for bark biomass logistics.
According to the preliminary results, the basic density of pine bark decreased significantly during the two months storing period. Furthermore the moisture content of the bark decreased remarkably due to the self-warming of the bark stack. After establishment of the pile, temperature in the middle of the pine bark stockpile rose rapidly, reaching 60°C within three days, but declined fast. After two months, the temperature in pile has lowered to ca. 25 °C. At the beginning of the storage period the condensed tannin (CT) content in pine bark decreased drastically being less than 50 % of the original amount after two weeks of storing. Some further loss of CT could be seen in the samples analyzed after 4 and 8 weeks of storing but it was clearly evident that the major loss appeared during the first two weeks.

Keywords: bark, storing, Scots pine, basic density, extractives

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

MARGINAL COST OF BIOMASS UTILIZATION IN MECHANIZED FOREST RESTORATION TREATMENTS IN THE SOUTHWESTERN USA

Elizabeth Dodson*
Department of Forest Management
W.A. Franke College of Forestry and Conservation
University of Montana, 32 Campus Dr., Missoula, MT, 59812 USA
elizabeth.dodson@umontana.edu

Nathanial Anderson
Rocky Mountain Research Station
US Forest Service
800 East Beckwith, Missoula, MT, 59801 USA
nathanielmanderson@fs.fed.us

Lucas Townsend
Bureau of Land Management
lucas.townsend@umontana.edu

Abstract: *Much of the active forest management taking place in the southwestern United States, particularly on public lands, can be categorized as forest restoration. Treatments may include mechanized extractive removals (e.g. timber and biomass harvest), mechanical in-place treatments (e.g. mastication), manual treatments (e.g. hand pile), prescribed burning (e.g. pile and broadcast burning), or a combination of these options. Though forest restoration uses many of the same machines and harvesting systems as traditional timber sales prescribed with a goal of profitability, the economics of these treatments can be extremely challenging. The small diameter and poor quality of stems removed during restoration can make it very difficult to cover costs with revenues, and such treatments can be very costly to implement as a result. Based on intensive study of five operations, this presentation examines the marginal cost of biomass utilization compared to other methods of treating stands dominated by small-diameter stems.*

Keywords: utilization, mastication, prescribed fire, small-diameter timber

1. Introduction

The forests of the US Southwest are dominated by ponderosa pine (Pinus ponderosa) and, at higher elevations, may contain a mix of other conifer species. These forests have evolved under a low-severity, high-frequency fire regime leading to open stands dominated by large diameter, unevenly-spaced trees with a grass understory (Covington and Moore 1994; Reynolds et al. 2013). These fires were the result both of natural ignitions from lightening associated with monsoonal weather patterns as well as human-caused ignitions as part of native cultural practices. Over the past century-and-a-half, fire exclusion in the form of suppression of fire starts and livestock grazing that removed fine fuels (grass) has led to forest stands dominated by high stem densities and more susceptible to stand-replacing fires (Allen et al. 2002). Large wildfires, such as the Rodeo-Chediski fire in 2002 that burned 1,900 km^2 and the Wallow fire in 2011 that burned 2,177 km^2, have underscored efforts to actively restore historic forest structure and function. The reintroduction of fire to these forests is a common goal, but is often not practical without initial mechanical or manual treatment to remove woody fuel (Allen et al. 2002; Hampton et al. 2008). Without this treatment, any prescribed fire is likely to burn too hot, killing and consuming too many live trees, and runs an unacceptably-high risk of escaping containment lines. Mechanical restoration treatments have proven to restore stand structure (Larson and Churchill 2012), ecosystem function in both vegetation and soils (Falk

2006; Grady and Hart 2006), species richness (Stoddard et al. 2011), and resilience to fire even with a changing climate (Fulé 2008). The challenge for these treatments lies in the low value and high cost to treat the large volume of small-diameter stems that need to be removed in order to meet treatment objectives.

Forest restoration treatments in the US Southwest are further challenged by limited markets for wood products removed during treatment (Hayes et al. in press; Townsend et al. 2019). Wood processing facilities are generally small with limited capacity, are scattered geographically, and are constrained by limited markets for wood products and low-quality wood properties. Ponderosa pine is a relatively weak wood and therefore not appropriate for structural lumber in residential or commercial applications. Currently there are no dry kiln operations in the southwest, limiting products to the green market. Common traditional wood products produced include pallet stock, railroad ties, fuel wood for home heating, vigas (hand-peeled roundwood used as beams in the traditional adobe architecture of the region), dimensional lumber that is heat-treated and exported to Mexico, and posts and rails. More recently, however, biomass markets such as whole-tree grindings for electricity generation, pellets for home and industrial heating, animal bedding, landscaping and erosion control products have exceeded traditional sawn wood markets in terms of total value of sales (Hayes et al. in press).

Townsend (2019) and Townsend et al. (2019) used repeated measures of five mechanical harvesting contractors during the summers of 2017, 2018, and 2019 to evaluate the production and costs of integrating biomass harvest into forest restoration treatments. All of the treatments evaluated had sufficient sawlog-sized material that also was designated for removal to justify a commercial operation, even though many of the operations were not able to cover all costs with product value. This paper will compare the marginal cost of this biomass harvest in conjunction with a commercial timber harvest operation with other options for treating this small-diameter stand component.

Other methods beyond extraction as part of an integrated harvest are available to land managers to treat small-diameter stems. For example, motor-manual felling can be used to remove these undesired stems from the growing stock of a site. This generally will not remove the biomass material from the site. Hand felling may be paired with the piling of these stems for later burning. Mechanical mastication can also be used to remove unwanted stems from the growing stock. Like hand felling, fuels are merely rearranged and not removed. In some instances, prescribed burning without pretreatment may be used to kill and potentially consume growing stock. Many tradeoffs exist between these options and include factors associated with: treatment cost, revenue potential, residual stand damage, soil impacts, leave tree selection, fuel loading and implications for fire behavior over a many year time horizon, visual impacts, and social acceptability. Of these tradeoffs, this paper will attempt to provide data regarding treatment costs and revenue potential.

2. Methods

Townsend (2019) selected five harvesting contractors that spanned the geographic range of the project area with two contractors in east-central Arizona, two in northwest New Mexico, and one in southeast Colorado (Figure 1). These contractors were selected based on their willingness to participate in the research project, logging systems typical of the region, and contracts in place for forest restoration work appropriate for the larger research project. In the first year (2017), detailed time study data was collected for approximately 10 operational days for each contractor. This effort was intended to establish a baseline of current state-of-the-art production and cost rates. After analysis of data from the first field season, recommendations for improvements were delivered to each contractor. These recommendations ranged from equipment selection, to workflow and methods (ex. bunch size, skidding pattern), to training needs.

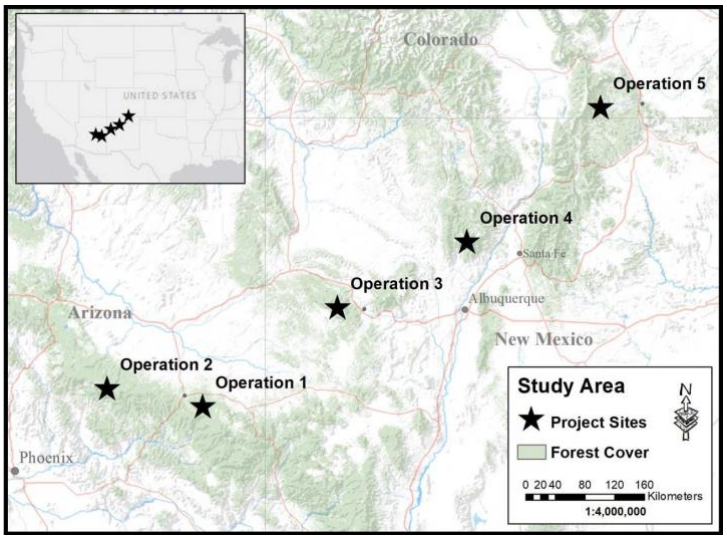


Figure 1: Study sites

Three of the five operations studied were ground-based, mechanical whole-tree systems. The two operations in Arizona typically operated on ground with gentle slopes therefore utilized rubber-tired hotsaws (rotary disk saws) for felling. Operation 4 in New Mexico typically operated in units with higher average slopes and therefore used a tracked, self-leveling hotsaw for felling. All three of these operations used rubber-tired grapple skidders for transporting bunches of logs to roadside followed by processing using an excavator-mounted dangle-head processor for manufacturing whole stems into logs. Operation 5 in southern Colorado used a conventional whole-tree system in the first year, with motor-manual felling and delimbing, transport to the landing using a rubber-tired grapple skidder, and further delimbing and bucking at road-side using a pull-through delimber. During second year operations some of the felling was completed using a rotary disk harvester operated as a feller-buncher. Operation 3 in New Mexico used a modified cut-to-length operation in the first year, with felling and processing at the stump using a tracked harvester, followed by skidding with a rubber-tired grapple skidder. In the second year this operation had transitioned to a mechanical whole-tree system using a rubber-tired hotsaw for felling, skidding with a rubber-tired grapple skidder, and road-side processing with an excavator-mounted dangle-head processor. Changes in operations from the first year to the second allow for the evaluation of the marginal cost of treating small-diameter biomass stems along with more traditional sawlog harvest.

Table 1 shows the findings from Townsend (2019) for three of the five operations. Observed costs were calculated from average observed conditions on each site in each operational year. Modeled costs were developed from productivity models where variables such as piece size and travel distance have been standardized between operations and years. All costs are in 2019 US dollars per green tonne. Table 2 details pre-treatment stand conditions.

Table 1: Cost results from Townsend (2019)

Operation	2		3		4	
Year	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Function	**Observed Costs ($ gt^{-1})**					
Felling	$7.74	$5.83	$13.17	$5.85	$3.76	$3.08
Skidding	$11.64	$3.26	$11.37	$3.95	$4.65	$4.89
Processing	$7.38	$7.19	NA	$5.07	$5.89	$5.56
Cold Decking Loader	NA	$1.28	NA	NA	NA	NA
Loading	$2.54	$2.05	$9.38	$3.55	$3.59	$2.29
Grinding	$9.24	$6.63	N/A	N/A	N/A	N/A
Round wood cost	$34.97	$19.61	$33.93	$18.43	$17.89	$15.82
	Modeled Costs ($ gt^{-1})					
Felling	$4.05	$3.74	$12.39	$4.91	$4.90	$4.38
Skidding	$4.89	$3.86	$4.15	$4.61	$4.62	$3.71
Processing	$5.09	$6.87	NA	$3.62	$8.32	$7.01
Cold Decking Loader	NA	$2.03	NA	NA	NA	NA
Loading	$2.54	$2.05	$9.38	$3.55	$3.59	$2.29
Grinding	$9.24	$6.63	N/A	N/A	N/A	N/A
Round wood cost	$16.57	$18.54	$25.92	$16.69	$21.43	$17.40

Table 2: Pre-treatment stand conditions by operation and year (Townsend 2019). Species key: PIPO = *Pinus ponderosa*, PSME = *Pseudotsuga menziesii*, ABCO = *Abies concolor*, QUGA = *Quercus gambelii*, PIST = *Pinus strobiformus*

Operation	Slope %	TPH < 10 cm	TPH > 10 cm	BA > 10 cm (m^2/ha)	QMD > 10 cm	Avg Ht (m) > 10 cm	% by Basal Area			
							PIPO	PSME	ABCO	QUGA	PIST
2 – 2017	7	618	404	29.9	30.7	14.3	97.3	0.2	0.1	2.4	0
2 – 2018	9	706	496	34.2	33.5	17.4	24.3	31.6	33.8	5.2	5.0
3 – 2017	7	41	315	19.0	27.7	12.4	100	0	0	0	0
3 - 2018	7	395	227	21.5	37.9	15.4	100	0	0	0	0
4 - 2017	15	280	694	30.0	23.5	15.3	96.5	1.4	2.1	0	0
4 - 2018	16	165	478	32.0	29.5	17.1	98.9	1.1	0	0	0

3 Results

3.1 Felling

Two cases allow insight into the marginal cost of felling small-diameter stems using feller-bunchers. In 2017, Operation 2 had the feller-bunchers sorting stems during cutting such that small-diameter stems were

bunched separately from stems containing sawlogs. On average, 2.91 stems containing sawlogs were cut per minute as opposed to 7.1 small-diameter stems per minute when cutting was segregated. Given this stand contained 618 stems ha^{-1} less than 10 cm DBH, and assuming a rubber-tired feller-buncher costs \$133/hour, felling small-diameter stems cost \$192 ha^{-1}. For comparison, a unit with 500 stems ha^{-1}would cost \$156 ha^{-1} for felling small-diameter stems.

The second case was the result in a change in contract specifications between years for Operation 4. In 2017 all stems were cut by the feller-buncher. In 2018, only stems greater than 10 cm DBH were required to be cut. This change in contract specification resulted in an average decrease in felling costs of \$0.52 t^{-1}. The productivity model from 2017 found no difference in the time to cut a stem based on stem size; all stems averaged 0.0644 min $stem^{-1}$. Given 280 stems ha^{-1} less than 10 cm DBH in the unit and an hourly cost for a tracked feller-buncher of \$187, the felling of small-diameter stems cost \$56 ha^{-1}. For a stand with 500 stems ha^{-1}, this cost would be \$100 ha^{-1}.

3.2 Skidding

In 2017, Operation 2 skid small-diameter stems separately from sawlogs. For the observed stand with 618 stems ha-1, assuming hourly cost of a rubber-tired grapple skidder at \$143 hr^{-1}, the resulting cost to bring small stems to the roadside is \$707 ha^{-1}. For a stand with 500 stems ha^{-1}, this cost is \$572 ha^{-1}.

3. Discussion

Mechanical felling costs for small-diameter stems treated in conjunction with a commercial timber harvest were found to be approximately \$100-150 ha^{-1}. Small diameter felling costs were found to be lower for the tracked feller-buncher as compared to the rubber-tired feller-buncher. This difference is to be expected as the tracked machine is able to swing the head to each stem with minimal repositioning of the machine. The rubber-tired feller-buncher, on the other hand, must drive to every stem cut regardless of stem size.

By comparison, motor-manual thinning of small-diameter stems in a stand-alone operation may cost \$700-1850 ha^{-1}. Mastication costs may range \$1000-2500 ha^{-1}. Both of these options would leave the biomass material in the woods. These results indicate that if a commercial timber harvest is to occur in a stand, the lower cost option is likely to treat small-diameter stems concurrent with sawlog-sized material regardless of if a market for biomass material is available.

Removal of fuel from the stand may occur by felling and skidding trees or through operations such as a prescribed burn. Felling and skidding costs found here are approximately \$875-925 ha^{-1}. Prescribed burning costs are highly variable depending on terrain, stand conditions, season of operation, resources at risk, and unit size. Costs for prescribed burning may range \$300-1200 ha^{-1}. However, many areas that have not been previously treated or burned may need additional treatment, such as motor-manual thinning or mastication, prior to burning. These costs would be added to the cost of burning.

Comminution of slash prior to on-road transportation occurs when markets exist. In the case where commercial sawlogs and other roundwood products are utilized from the restoration treatment, small-diameter whole trees are added to the slash (limbs and tops) resulting from log production. The proportional volume of biomass from small-diameter stems as compared to the slash from log production is highly variable and depends on the pre-treatment stand conditions, prescription, and log market specifications. For slash, regardless of source, that reaches roadside piles, the common options are either open burning of

piles, chipping or grinding into containers for transportation to a conversion facility, or return skidding of slash in cases where the material is needed either for nutrient cycling or to provide fuel for a subsequent prescribed burn. Townsend (2019) found chipping costs in Arizona to average \$6.63 t^{-1}, which included chipping directly into chip vans. On-road transportation costs are highly dependent on distance and speed and were not discussed by Townsend. Operation 4 did return skid slash during the 2017 operational period. No statistical difference was found between those skidding turns where slash was returned (in this case the prescription called for slash to be scattered over skid trails to minimize erosion) and those where the skidder returned to the unit empty (Townsend et al. 2019).

4. Conclusion

Treatment of small-diameter stems is a necessary component of most forest restoration in the Southwestern US. In many cases, particularly with public land management, ecological and community safety concerns outweigh financial consideration. However, treatment costs need to be understood in order for managers to make informed, efficient decisions.

5. Acknowledgements

This project is supported by the Biomass Research and Development Initiative of the U.S. Department of Agriculture, National Institute of Food and Agriculture, competitive grant no. 2016-10008-25636.

6. References

Allen CD, Savage M, Falk DA, Suckling KF, Swetnam TW, Schulke T, Stacey PB, Morgan P, Hoffman M, Klingel JT. 2002. Ecological restoration of southwestern ponderosa pine ecosystems: A broad perspective. Ecological Applications. 12(5):1418.

Covington W, Moore M. 1994. Southwestern ponderosa pine forest structure: Changes since Euro-American settlement. J For. 92(1):39-47.

Falk DA. 2006. Process-centered restoration in a fire-adapted ponderosa pine forest. Journal for Nature Conservation. 14(3):140-51.

Fulé PZ. 2008. Does it make sense to restore wildland fire in changing climate? Restoration Ecology. 16(4):526-31.

Grady KC, Hart SC. 2006. Influences of thinning, prescribed burning, and wildfire on soil processes and properties in southwestern ponderosa pine forests: A retrospective study. Forest Ecology and Management. 234(1):123-35.

Hampton HM, S.E. Sesnie, B.G. Dickson, J.M. Rundall, T.D Sisk, G.B. Snider, J.D. Bailey. 2008. Analysis of small-diameter wood supply in northern Arizona. Forest Ecosystem Restoration Analysis Project, Center for Environmental Sciences and Education, Northern Arizona University.

Hayes SW, Bingaman CA, Morgan TA, Simmons EA, Marcille KC, Shaw J. 2019. The Four Corners timber harvest and forest products industry, 2016. Resour. Bull. RMRS-RB- XXX. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 p. (In press)

Larson AJ, Churchill D. 2012. Tree spatial patterns in fire-frequent forests of western North America, including mechanisms of pattern formation and implications for designing fuel reduction and restoration treatments. Forest Ecology and Management. (267):74-92.

Reynolds RT, Sánchez Meador AJ, Youtz JA, Nicolet T, Matonis MS, Jackson PL, DeLorenzo DG, Graves AD. 2013. Restoring composition and structure in Southwestern frequent- fire forests: A science-based framework for improving ecosystem resiliency. Gen. Tech. Rep. RMRS-GTR-310. Fort Collins, CO: U.S. Dept of Ag, Forest Service, Rocky Mountain Research Station. 76 p.

Stoddard MT, McGlone CM, Fulé PZ, Laughlin DC, Daniels ML. 2011. Native plants dominate understory vegetation following ponderosa pine forest restoration treatments. Western North American Naturalist. 71(2):206-14.

Townsend L, Dodson E, Anderson N, Worley-Hood G, Goodburn J. 2019. Harvesting forest biomass in the US southern Rocky Mountains: Cost and production rates of five ground- based forest operations. Int J of For Eng. 30(2):163-172.

Townsend L. 2019. Harvesting forest biomass in the US southern Rocky Mountains. MS Thesis. University of Montana. 136 p.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

SYNERGIES BETWEEN THE NEW BIOECONOMY AND FOREST OPERATIONS FOR FUEL TREATMENT AND FOREST RESTORATION

Nathaniel Anderson [1], Woodam Chung [2], Elizabeth Dodson [3]
[1] Rocky Mountain Research Station, United States Forest Service, Missoula, USA; [2] Oregon State University, Corvallis, USA; [3] WA Franke College of Forestry and Conservation, University of Montana, Missoula, USA
nathanielmanderson@fs.fed.us

Abstract: *Silvicultural treatments to restore forest ecosystems, reduce wildfire risk, and improve conditions for fire suppression can be very costly to implement. In the interior western United States, public land managers have struggled to meet restoration and fuel treatment targets in part because of the low economic viability of these operations. Though they often include the harvest of marketable timber products, the low grade and poor quality of trees and vegetation cut and removed generally limit value recovery. In most cases, large volumes of unmerchantable logs and biomass are burned for disposal, which has negative impacts on air quality and soil. This presentation synthesizes the results of multiple research studies in the Rocky Mountain region of the United States and is focused on understanding the potential for using this biomass as feedstock for the production of advanced biofuels, bioproducts and distributed-scale combined heat and power. Recommendations are made to enhance value recovery from the low grade and low value materials flowing from fuel treatment and forest restoration operations. The goal is to better coordinate on-unit operations with the planning and implementation of such treatments in ways that encourage market links with existing and new biomass end users. The emphasis is on efficient and effective production and delivery of the biomass products that down-stream users demand. Given the vast extent of treatment required in the region under constrained budgets, leveraging the emerging bioeconomy to improve the financial viability of fuel treatment and forest restoration will be critical to treating more acres at lower cost, and improving fire suppression success in the future.*

S06 Wood transportation & Simulation
Playing with model trucks

IMPLEMENTATION OF COMPUTER VISION ALGORITHMS FOR AUTOMATED DETECTION AND DIAMETER ESTIMATION OF LOGS ON TRUCKS
Mauricio Acuna [1], Amanda Sosa [2], Mark Brown [1]
[1] University of the Sunshine Coast, Hobart, Australia [2] Waterford Institute of Technology, Waterford, Ireland

WOOD TRANSPORTATION PLANNING 4.0
Peter Rauch, Christoph Kogler
University of Natural Resources and Life Sciences, Vienna

MODELING TIMBER TRUCK SPEED AND FUEL CONSUMPTION IN FINLAND BASED ON CAN BUS DATA AND AUXILIARY INFORMATION
Perttu Anttila, Tuomas Nummelin, Kari Väätäinen, Juha Laitila
Natural Resources Institute Finland (Luke)

AGENT-BASED SIMULATION IN CABLE YARDING AND TRANSPORT OPERATIONS
Thomas Holzfeind [1], Manfred Gronalt [2], Christian Kanzian [1]
[1] Institute of Forest Engineering, University of Natural Resources and Life Sciences, Vienna, Austria [2] Institute of Production and Logistics, University of Natural Resources and Life Sciences, Vienna, Austria

OPTIMAL TRANSPORT SCHEDULING: DEMONSTRATION OF SOFTWARE CAPABILITY AND POTENTIAL GAINS
Mauricio Acuna [1], Glen Murphy [2]
[1] University of the Sunshine Coast, Hobart, Australia; [2] GE Murphy & Associates Ltd, Rotorua, New Zealand

INNOVATION IN THE FIELD OF WOOD TRANSPORT IN FRANCE
Thomas Carrette, Christophe Ginet
Technology Institute for the French forest-based sector – FCBA

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

IMPLEMENTATION OF COMPUTER VISION ALGORITHMS FOR AUTOMATED DETECTION AND DIAMETER ESTIMATION OF LOGS ON TRUCKS

Mauricio Acuna [1], Amanda Sosa [2], Mark Brown [1]
[1] University of the Sunshine Coast, Hobart, Australia [2] Waterford Institute of Technology, Waterford, Ireland
macuna@usc.edu.au

Abstract: *Manually measurement of logs stacked at the roadside or on trucks is time-consuming and labour expensive. Common features of interest include but are not limited to, number of logs, diameter distribution, and volumes. Recently, a number of computer vision algorithms and software solutions have been developed and implemented in real life applications. In this study, we tested a solution method based on OpenCV computer vision algorithms, which were implemented in a tool named LogVision, using the Qt/C++ programming framework.*

The data used in this study are digital images of end faces from logs carried on trucks and collected at the weighbridge of sawmills. The images size of each image was 640 x 480 pixels. In total, the data consisted of 22 digital images containing a total of 252 Radiata pine logs. The diameter of each log was measured manually with a measuring tape. The processing for the automated detection and diameter estimation of logs included the following functions/algorithms: 1. 2D filtering with a 5x5 kernel, 2. Changing of colour channels, 3. A Gaussian Blur algorithm, 4. A Hough Circles algorithm, and 5. A function to draw circles around the faces of the logs. All these algorithms and functions were implemented in a software named LogVision, which counts the number of logs and estimates diameters of the logs in the image. The tool also allows data export to MS Excel and the image (jpg format) with the diameters calculated. The diameters measured and recorded in the forest were compared with the diameters calculated by the LogVision tool. The difference (cm) between the diameters calculated manually and with the algorithm was on average 0.52 cm, with a maximum of 9.3 cm and a minimum of -8.9 cm. Approximately 71% of the variation was less than 3 cm.

Preliminary results show that our solution method has the potential to detect and estimate diameters of logs on trucks quickly and with a relatively high accuracy, which makes it suitable for use in operational conditions.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

WOOD TRANSPORTATION PLANNING 4.0

Peter Rauch and Christoph Kogler
Institute of Production and Logistics
Department of Economics and Social Sciences
University of Natural Resources and Life Sciences Vienna
Feistmantelstrasse 4, A-1180 Vienna, Austria
Peter.rauch@boku.ac.at

Abstract: *Increasing occurrence of natural disturbances such as windstorms and high snow cover as well as uncertainty according to queuing and lead times, bottlenecks, utilization, stock level, wagon and truck availability and machine breakdowns lead to supply chain risks and seasonal irregularities in wood harvest and transport. Innovative multimodal systems via rail terminals offer the potential to increase buffer capacity and reduce greenhouse gas emissions. Therefore, a train terminal is included in a new virtual environment spanning the whole wood supply chain and enabling manager involvement in testing, analysis and evaluation of a complex multimodal transport system. The simulation model facilitates carrying out experiments and scenario designs for strategy comparisons in workshops with supply chain managers and provides intuitive decision support by animation and a KPI-cockpit. Adapting collaborative supply chain control strategies in participatory simulation enhances the development of advanced risk management and therefore improves supply chain resilience, efficiency and sustainability.*

Keywords: wood supply chain, DES, stakeholder workshop

1. Introduction

The forest based sector in Austria is lacking a comprehensive multimodal concept to improve sustainability, resilience, efficiency and cost-effectiveness along the wood supply chain. Significant new challenges for wood supply management require an integrated framework for modelling and analysis of efficiency and resilience to supply chain risks. Therefore, the need for an integrated framework focusing on risks will be satisfied by a discrete event simulation model to support managers in their decisions and contribute to a better understanding of the multimodal wood supply chain. Discrete event simulation provides a powerful method for decision support, but simulation models are rarely used in university education and industrial training mainly because they are complicated and customized for scientific use only. In addition, within science, documentation of highly specific simulation models provides mainly a rough overview, failing to facilitate external expert evaluation and valuable feedback. Consequently, a scientific discrete event simulation model extending from forest to industry was further developed with special focus on animation, visualization and intuitive usability in a workshop setting. Tested in several workshops, it proved to facilitate decision support for managers and to provide means to train students and sensitize researchers on how to deal with challenging supply situations.

2. Literature

DES models have a high potential for pedagogical purposes and stakeholder participation due to the active involvement of trainees, their suitability in providing experience of complex system characteristics and decision support within a safe learning environment (Van der Zee et al. 2012). Guidance for developing these models is rare, but conceptual modeling (Robinson 2008) as well as simplification (Van der Zee et al. 2018) and gamification (Despeisse 2018) play fundamental roles. So far, stakeholder participation has been mainly focused on SWOT analyses combined with strategy formulation, analytic hierarchy processes as well as the delphi method. Furthermore, stakeholder workshops were held primarily for scenario design, building, development or back-casting. Regarding knowledge transfer through simulation education, earlier studies concentrated mainly on course and workshop designs for teaching simulation model development to one class or audience. Others authors developed simulation games to teach special principles and motivate students. In the wood-based industry, the freely available and prize-winning online wood supply game is a successful example, teaching supply chain challenges such as the burdens of the bullwhip effect, bottlenecks and system capacities (D'Amours et al. 2017). However, the integration of adapted, professionally developed, scientific simulation models in classes and workshops is rarely discussed.

3. Case Study

A comprehensive case study of a multimodal supply chain in Austria was conducted with special focus on a train terminal in Großreifling (Styria). The case study was supported by interviews and data collection of the Austrian Federal Forests, Rail Cargo Austria, carriers and the central agency for meteorology and set the stage for the development of a simulation model based on a real life case. The Austrian Federal Forests are property of the Austrian state and administered in a stock company. Their 1100 employees are responsible for 15% of Austrian forests and deliver a wood supply volume of more than 1,5 million cubic meters, of which a quarter is handled multimodal. Four of 121 forest districts directly supply the observed train terminal Großreifling. Regularly, three regional carriers transport about 2000 cubic meters wood per month to the terminal or directly to the industry. Once (twice after storms) a day a locomotive picks up two to four (up to nine after storms) wagons and leaves empty wagons until the next day at one of the loading railroad tracks. After natural disturbances like wind storms up to 30000 cubic meters per month pass through the terminal. In this case up to 10000 cubic meters can be stored directly at the terminal.

4. Simulation Model

The simulated supply chain reaches from the forest to the industry and covers wood harvest and truck pre-carriage to wood terminals or industry, storage in a terminal, transshipment to rail wagons and final rail transport to and unloading at woodworking plants. Therefore, the AnyLogic simulation model consists of parameterization, animation, scenario, statistics, logic and code views and modules for forest, truck transport, terminal, train transport and industry. In the parameterization view prepared transport plans (BAU = business as usual, SNOW -75% production in the first quarter, STORM = +300% in the third quarter) can be selected, new ones entered or read from excel files. Additionally, also other parameters e.g. the number of wagons and trucks, distributions for drive times, capacities and costs can be adjusted. Moreover, scenarios based on number of train pickups, transport mode, transport priority and runtime can be designed. These parameters can be adapted during runtime and the changes can be observed in the animation window, where trucks and trains transport wood according the transport plan. Simulation results are provided in the management cockpit where KPIs for stock levels over time, CO2 emissions, costs, utilization, lead times, queuing times and service level are presented.

5. Workshops

A variety of workshops designs can be supported by the workshop edition of the DES model. Therefore, the objectives of the workshop have to be clearly defined based on Bloom's taxonomy, methods that contribute to achieve the desired goals have to be chosen and the actual schedule, setting, content and scenario needs

to be designed. The generic structure of workshops for students, scientists and managers can be organized in the stages: input, learning by doing and analysis, where each stage will take between 30 and 60 minutes. The input stage answers the initial question of participants, "Why are we here?", by giving an overview of the workshop agenda, problem setting and goals. This guides to the question, "How can we experience, observe or analyze the problem?". Consequently, the workshop edition is introduce by a live demonstration of process flows in the Animation View as wells as the change of KPIs in the Management Cockpit View. The learning by doing stage starts with a clear problem definition, before participants get hands-on experience and play the defined simulation scenario (i.e., period, harvesting volumes, system capacities) usually in small groups from 3 to 5 people. Week-by-week, every group discusses their strategies and decides on the transport plan (e.g., number of trucks, wagons, train pickups, unimodal/multimodal ratio) for the next week based on harvesting volumes, stockyard utilization as well as other KPIs. At the end of the simulation period, all KPIs are exported to an Excel file and this provides the basis for the last stage. The analyses stage reflects strategies, problems, solutions and findings. KPIs like transport volume, stockyard sizes, delivery quotas, number of full loaded wagons, fulfillment levels, CO2 emissions, truck utilizations, lead times, queuing times or transport costs are compared over time and between groups in different graphs. Finally, the discussion is wrapped up, results are documented and next steps to tackle outstanding problems are defined before a final feedback session.

First delivered workshops to various groups of scientists, managers and students in different levels of mastery according to their experience in wood supply chain management indicated, that the adaption of a scientific DES model in an early development stage to a workshop edition increases model's reliability and suitability to address real world challenges. Future research would benefit from simplification, visualization and collaboration at the earliest development stages of next level DES models.

6. References

Asikainen, A. 2001. "Simulation of Logging and Barge Transport of Wood from Forests on Islands". International Journal of Forest Engineering 12(2):43–50.

D'Amours, S., Marier, P., Rönnqvist, M., Azouzi, R., and Fjeld, D. 2017. "The Online Wood Supply Game". INFORMS Transactions on Education 18(1):71–87. https://doi.org/10.1287/ited.2017.0174.

Despeisse, M. 2018. "Games and Simulations in Industrial Engineering Education: A Review of the Cognitive and Affective Learning Outcomes". https://doi.org/10.1109/WSC.2018.8632285.

Gronalt, M., and P. Rauch. 2018. "Analyzing Rail Road Terminal Performance in the Timber Industry Supply Chain – a Simulation Study". International Journal of Forest Engineering. Published online: 2.8.2018:1–9.

Karttunen K., L. Lättilä, O.-J. Korpinen, and T. Ranta. 2013. "Cost-efficiency of Intermodal Container Supply Chain for Forest Chips". Silva Fennica 47(4):1–24.

Karttunen, K., K. Vaatainen, A. Asikainen, and T. Ranta. 2012. "The Operational Efficiency of Waterway Transport of Forest Chips on Finland's Lake Saimaa". Silva Fennica 46(3):395–413.

Kogler, C., and Rauch, P. 2018. "Discrete Event Simulation of Multimodal and Unimodal Transportation in the Wood Supply Chain: A Literature Review". Silva Fennica 52(4):1–29. https://doi.org/10.14214/sf.9984.

Kogler, C., and Rauch, P. (accepted). "A Discrete Event Simulation Model to Test Multimodal Strategies for a Greener and more Resilient Wood Supply". Canadian Journal of Forest Research.

Robinson, S. 2008. "Conceptual Modelling for Simulation Part I: Definition and Requirements". Journal of Operational Research Society 59(3):278–290. https://doi.org/10.1057/palgrave.jors.2602368.

Mobini, M., J. C. Meyer, F. Trippe, T. Sowlati, M. Frohling, and F. Schultmann. 2014. "Assessing the Integration of Torrefaction into Wood Pellet Production". Journal of Cleaner Production 78:216–225.

Mobini, M., T. Sowlati, and S. Sokhansanj. 2013. "A Simulation Model for the Design and Analysis of Wood Pellet Supply Chains". Applied Energy 111:1239–1249.

Saranen, J., and O.-P. Hilmola. 2007. "Evaluating the Competitiveness of Railways in Timber Transports with Discrete-event Simulation". World Review of Intermodal Transportation Research 1(4):445–458.

Van der Zee, D. J., Holkenborg, B., Robinson, S. 2012. „Conceptual Modeling for Simulation-Based Serious Gaming". Decision Support Systems 54:33–45. https://doi.org/10.1016/j.dss.2012.03.006.

Van der Zee, D. J., Tako, A., Robinson, S., Fishwick, P., and Rose O. 2018. “Panel: Education on Simulation Model Simplification – Beyond Rules of Thumb“. https://doi.org/10.1109/WSC.2018.8632544.
Wolfsmayr, U. J., R. Merenda, P. Rauch, F. Longo, and M. Gronalt. 2016. “Evaluating Primary Forest Fuel Rail Terminals with Discrete Event Simulation: a Case Study from Austria”. Annals of Forest Research 59(1):145–164.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

MODELING TIMBER TRUCK SPEED AND FUEL CONSUMPTION IN FINLAND BASED ON CAN BUS DATA AND AUXILIARY INFORMATION

Perttu Anttila, Tuomas Nummelin, Kari Väätäinen, Juha Laitila
Natural Resources Institute Finland (Luke)
perttu.anttila@luke.fi

Abstract: *In 2017 the total timber volume transported by trucks in Finland was nearly 48 million solid cubic metres and the corresponding transport cost 326 million euros. Therefore, it is of utmost importance that transport is cost-efficient. In order to minimize driving time of a single truck, a prediction model for truck speed in varying driving conditions is needed. Likewise, there is growing interest to minimize fuel consumption and, thus, GHG emissions arising from transportation. In this study prediction models for timber truck speed and fuel consumption will be derived. A one-year follow-up study of 13 timber trucks was started in April 2018. Data on timber truck speed and fuel consumption are being extracted from the trucks' CAN bus at 10-minute interval. The 76-t trucks are operated in Southern and Central Finland by three entrepreneurs. Auxiliary data explaining driving conditions will be spatially joined with the CAN bus data and statistical models for predicting driving speed and fuel consumption estimated. Potential explanatory variables include gross vehicle mass, functional road class and attributes describing road geometry. Preliminary results have indicated correlation between the response and explanatory variables.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

AGENT-BASED SIMULATION IN CABLE YARDING AND TRANSPORT OPERATIONS

Thomas Holzfeind[1], **Manfred Gronalt**[2], **Christian Kanzian**[1]

[1]Institute of Forest Engineering
Department of Forest- and Soil Sciences
University of Natural Resources and Life Sciences Vienna
Peter-Jordan-Strasse 82/3, A-1190 Vienna, Austria
thomas.holzfeind@boku.ac.at

[2]Institute of Production and Logistics
Department of Economics and Social Sciences
University of Natural Resources and Life Sciences Vienna
Feistmantelstraße 4, A-1180 Vienna, Austria

Abstract: *In recent decades, forest owners as well as logging and transport companies have become increasingly under pressure due to developments in the forestry sector. The desire for high productivity to keep the cost of timber harvesting low and to improve operations led to an increasing mechanization of timber harvesting systems. Often not only the productivity of timber harvesting systems causes problems, but also the inadequately coordinated transport of produced timber. In whole-tree cable yarding operations with processing of the trees at the forest road, transport must be well coordinated to avoid standstills of the harvesting system or trucks. Therefore, proper harvest and wood transport planning is essential to carry out efficient and cost-effective operations. In recent years, agent-based simulation (ABS) has become a widely used tool for analysing problems and solving different issues. In this study, an ABS model is created for the harvesting process with cable yarder in whole-tree method and subsequent the transport of the harvested wood to the sawmill, paper mill or heating plant. Within the ABS model, the impacts of technological changes, the introduction of information and communications technology (ICT) systems, the influence of unfavourable weather and the availability of trucks on the performance and costs of the whole system are analysed. A case study with example data is carried out, and through parameter variation, different iterations (i.e., scenarios) are simulated with 50 replications each and subsequently analysed. The harvesting process includes 150 yarding lines at 65 different locations with 52,500m^3 of wood. The case study shows that all analysed parameters interact, but increasing the storage capacity at the forest road and timely information flow between yarders and trucks decreases the cost of standstills in each scenario most. Summarized, it can be said that ABS is an appropriate tool for simulating harvest and transport operations in the forestry sector. Through ABS models, recommendations for proper harvest and wood transport planning can be derived and possible bottlenecks can be determined.*

Keywords: agent-based simulation, cable yarding, wood transport, logistics, ICT

1 Introduction

Forest simulation models have been available since 1965 at least when Gould and O'Regan (1965) created one of the first forest management simulation models. Since the beginning, simulation models have been developed to serve as decision aids and training tools in forest resource management (Pelz 1977). The main focus of forest simulations at that time was on the management of forest land and not on operations research. itself.

One of the first discrete event simulation (DES) model that took the logging system into account was created by Johnson and Fischer (1978), who analysed alternative methods of residue recovery. Today, within the forest sector, there are many studies applying DES to solve practical problems (e.g., Gronalt & Rauch 2018, Windisch et al. 2015, She et al. 2018, Asikainen 2010, Eriksson et al. 2017, Väätäinen et al. 2005). Besides DES and System Dynamics (SD) agent-based simulation (ABS) is a relatively new method, which has already been used to investigate different forestry issues (e.g., Korpinen et al. 2019, Aalto et al. 2018, Holm et al. 2018, Huff et al. 2015, Kostadinov et al. 2012).

ABS focuses on individual objects, their behaviour and how they interact. This means that the behaviour of the global system comes from the communication of many individual objects, which all follow their own behaviour rules (Borshchev & Filippov 2004). In the forestry operation decision problems, there are nearly always different individual objects (i.e., agents) that interact with each other and their environment. Often, problems are very complex and a good solution is hard to determine.

Whole-tree cable yarding with processing of the trees at the landing (i.e., forest road) is challenging with limited space in mountainous regions. To avoid running out of space in such operations, timely and well-coordinated transport of the harvested wood is needed. External factors like weather conditions, breakdowns and demand variations or delays in information flows impact the logistics as well and may lead to a standstill for the whole supply chain. About 10 years ago, Heinimann (2007) identified that one future challenge in forest operations would be to support distributed, coordinated decision making through ABS techniques. This study aims to verify if ABS could be an appropriate method to simulate and assess cable yarding and transport operations at the same time and to support decision makers with selecting technology, capacity planning, and yarder and truck scheduling,

The goal of this study is to create an ABS model to simulate yarding and processing whole trees with cable yarders and processors and subsequent the transport of harvested wood to sawmills, paper mills or heating plants. Within case scenarios, different influencing factors and their impact on waiting times of trucks and yarders as well as on costs and the overall performance of the system are analysed. Altogether the simulation should show possible bottlenecks and derive recommendations for an advanced harvest and wood transport planning. In detail within this work the influence of

1. technology change in the harvesting operation,
2. information flows,
3. the number of available trucks and
4. weather conditions

and their impact on waiting times and costs are examined. Beside proofing ABS to be an appropriate tool for simulating harvesting and transport operations, the focus of the attempts aims to provide a training tool for decision makers and students.

2 Material and methods

ABS model creation and implementation happened in the simulation software ‘AnyLogic 8 University 8.3.2’. The statistics software ‘R’ (R Core Team 2018) is used to analyse and plot the output data from the simulation model.

2.1 Simulation model

2.1.1 Basic concepts

The purpose of the model is to simulate the harvesting operation with cable yarder in whole tree method with processing of the trees at the forest road and subsequently transporting the harvested wood to the sawmill, paper mill or heating plant. The initial locations of the different agents and their characteristics like productivity, storage capacity at the forest road, loading capacity of the truck, amount of wood per

yarding line and other yarding line characteristics are set by the user to study the behaviour of the whole system and analyse waiting times for trucks and yarders. By varying the four selected parameters:

- storage capacity at the forest road,
- timing of information flow,
- number of trucks,
- and weather

their influence on waiting times, costs and overall performance can be determined. The following steps summarize the process workflow of the simulation model:

1. According to the input variables, yarding lines, yarders, trucks and sawmills are placed in a spatial model environment.
2. Yarders move to yarding lines to harvest wood.
3. Trucks move to the storage at the forest road to load the harvested wood.
4. Depending on the assortment, trucks transport the wood to the sawmill, paper mill or heating plant.

As it is nearly impossible to create a model that will exactly represent the system under investigation, assumptions must be made and boundaries set. So contrary to real world, trucks are always fully loaded with exactly the same amount. Weight restrictions and road blocks are not considered. Furthermore, delays resulting from heavy traffic are excluded. There is no temporary storage site for the wood available except at the yarder landing. Mandatory legal breaks and sickness rates for truck drivers and forest workers are not considered. Breakdowns of machines are also not included within the current simulation model.

2.1.2 Agents, scales and model initialization

Agents and objects can be nested in the model environment. So, eight agents as well as a spatial model environment based on Open Street Map are placed within the top level agent (i.e., 'Main') (Figure 1). Agents are either defined as single agents or as a population of agents (Table 1). 'Trucks' are associated with the 'HomeTruck' agent who assigns truck orders (dispatcher). 'Yarders' are associated with the 'HomeYarder' agent (head of harvesting operations) who dispatches the 'Yarders' to the 'YardingLines'.



Figure 1: Example for different agents placed inside the spatial model environment

Table 1: Overview of the individual agents with their description and size

Agent	Description	Size
Main	Top level agent	Single
HomeTruck	This agent is the owner of the trucks. It is the home location for the trucks and takes the role of truck order assignment (the dispatcher).	Single
Trucks	Each agent of this population represents a single truck. A single agent within this population is called 'Truck'.	Population
HomeYarder	This agent is the owner of the yarders. It is the home location for the yarders and assigns the yarding lines to them.	Single
Yarders	Each agent of this population represents a single yarder. A single agent within this population is called 'Yarder'.	Population
YardingLines	Each agent of this population represents a single yarding line. A single agent within this population is called 'YardingLine'.	Population
Sawmill	This agent represents a sawmill, to which all round wood is transported.	Single
Papermill	This agent represents a paper mill, to which all industry wood is transported.	Single
HeatingPlant	This agent represents a heating plant, to which all energy wood is transported.	Single

The start date for the simulation is defined as April 1, 2016. Minute-based time steps are chosen for the simulation model, and no fixed time horizon is defined. The end of the simulation is reached if all of the wood is harvested and transported. Agents' positions and characteristics can be set in a spreadsheet, which is read in at the initialization of the simulation environment. 'Trucks' and 'Yarders' can move in the GIS-Environment. At the beginning, 'Trucks' and 'Yarders' are placed at the location of their owners ('HomeTruck', 'HomeYarder').

2.1.3 Scenario analysis and parameter variation

Testing the model's functionality and the effects of parameter changes were carried out using conceived harvesting data. The assumptions made for the input data are based on personal experience, common information and published literature. One-hundred and fifty yarding lines on 65 different stands were randomly distributed spatially over the state Carinthia in Austria. In total, about 52,470 m3 of wood were supposed to be harvested on this 150 yarding lines with 4 yarders. The average volume per yarding line is 350 m^3. The productivity was calculated according to Ghaffariyan et al. (2009), where 90% of the values are between 6.7 m^3/PSH_{15} and 10.5 m^3/PSH_{15}. The mean corridor length is about 360 m, and 90% of the storage capacity at road values are between 82 m^3 and 136.7 m^3. Round wood averaged the highest for the share of the assortments at 70%, followed by industrial wood at 25% and energy wood at 5% (Table 2).

Table 2: Descriptive statistics of selected input data for the 'YardingLines'

Variable	5th Quantile	Mean	Median	95th Quantile	SD	N	Unit
volume	131.75	349.80	332.25	635.45	158.40	150	m^3
treeVolume	0.61	1.08	1.04	1.59	0.32	150	m^3
productivity	6.66	8.61	8.67	10.49	1.20	150	m^3/PSH_{15}
corridorLengths	147.95	358.63	351.5	565.10	126.23	150	m
capacityAtRoad	81.74	109.97	109.14	136.73	16.97	150	m^3
roundWood	61.00	70.00	69.00	79.00	5.90	150	%
industrialWood	14.00	25.00	25.00	36.00	6.80	150	%
energyWood	0.00	5.00	5.00	10.00	3.20	150	%

Four parameters (Table 3), which ca be changed by the user, are added to determine their impact on waiting times and costs. The 'capacityRoadFactor' parameter modifies the available storage capacity for yarders at the forest road. Most cable yarders are combined with processors. This means that the crane with the processor is mounted on the yarder's carriage platform and is not detachable. The ability to store processed timber is therefore limited by the boom reach. Alternatively, mounting the processor on a separate machine like an excavator increases storage capacity at the forest road as it not limited by the boom reach and can move during the operation. The 'shareForCallingTruck' parameter is used to adjust the timing of the truck order. For example, a value of 0.5 means that a truck order is sent as soon as 50 % of the storage capacity

at the forest road is reached. The 'numberOfTrucks' parameter allows changing the number of available trucks. For defining whether weather data are included, the 'unfavourableWeather' parameter is used.

Table 3: Parameters for creating different scenarios with description and necessary data type

Parameter	Description	Data Type
capacityRoadFactor	Modifies capacity available at the landing (forest road) for storing the harvested wood	Double
shareForCallingTruck	Defines at what amount of wood at the forest road a truck should be ordered to transport the harvested wood	Double
numberOfTrucks	Modifies number of trucks, available to transport the harvested wood	Integer
unfavourableWeather	Defines if there is unfavourable weather (1) or no unfavourable weather (0)	Integer

By varying the four parameters (Table 4), 440 different scenarios were created and analysed. For each scenario, 50 replications were carried out, which resulted in 22,000 simulation runs. For each simulation run, waiting times for the yarders and waiting times for the trucks were recorded and exported to a spreadsheet.

Table 4: Minimum, maximum and step size for parameter variation

Parameter	Minimum	Maximum	Step Size
capacityRoadFactor	1.0	2.0	0.1
shareCallingTruck	0.5	0.9	0.1
numberOfTrucks	3.0	6.0	1.0
unfavourableWeather	0.0	1.0	1.0

3. Results

3.1 Waiting times

Waiting times for 'Yarders' are lowest with six trucks at a doubled storage capacity at the forest road (capacityRoadFactor = 2) and with an early information flow (shareCallingTruck = 0.5). In this best-case scenario, unfavourable weather is not included (unfavourableWeather = 0). The mean waiting time for 'Yarders' for the best-case scenario over the 50 replications is 23.3 h with a standard deviation of 4.3 h. For the best-case scenario, 90% of the waiting times for 'Yarders'are between 16.3 h and 29.4 h. The worst-case scenario for waiting times is with three trucks, with no increased storage capacity at the forest road, late truck ordering behaviour and unfavourable weather. The mean waiting time for 'Yarders' in the worst-case scenario is 2937 h with a standard deviation of 71.1 h. For the worst-case scenario, 90% of waiting times for 'Yarders' are between 2844 h and 3064 h (Table 5).

Table 5: Descriptive statistics for waiting times (h) for 'Yarders' for best- and worst-case scenarios and associated parameters

Scenario	unfavourable Weather	number Of Trucks	share Calling Truck	capacity Road Factor	5th Quantile	Mean	SD	95th Quantile
Best-case	0	6	0.5	2.0	16.3	23.3	4.3	29.4
Worst-case	1	3	0.9	1.0	2844.0	2937.0	71.1	3063.8

The best-case scenario for waiting times for 'Trucks' is with four trucks, early information flow (shareCallingTruck = 0.6) and an almost doubled storage capacity at the forest road (capactiyRoadFactor = 1.9). The mean waiting time for 'Trucks' for the best-case scenario is 151.1 h with a standard deviation of 12.1 h, and 90% of the values in 50 replications are between 133.8 h and 171.1 h. For the worst-case scenario, the average waiting time for 'Trucks' is 4978.3 h with a standard deviation of 45.1 h. The worst-case scenario is with six trucks, late information flow (shareCallingTruck = 0.9) and standard storage capacity at the forest road (capacityRoadFactor = 1) (Table 6)

Table 6: Descriptive statistics for waiting times (h) for 'Trucks' for best- and worst-case scenarios and associated parameters

Scenario	unfavourable Weather	number Of Trucks	share Calling Truck	capacity Road Factor	5th Quantile	Mean	SD	95th Quantile
Best-case	0	4	0.6	1.9	133.8	151.1	12.1	171.1
Worst-case	1	6	0.9	1	4885.2	4978.3	45.1	5038.5

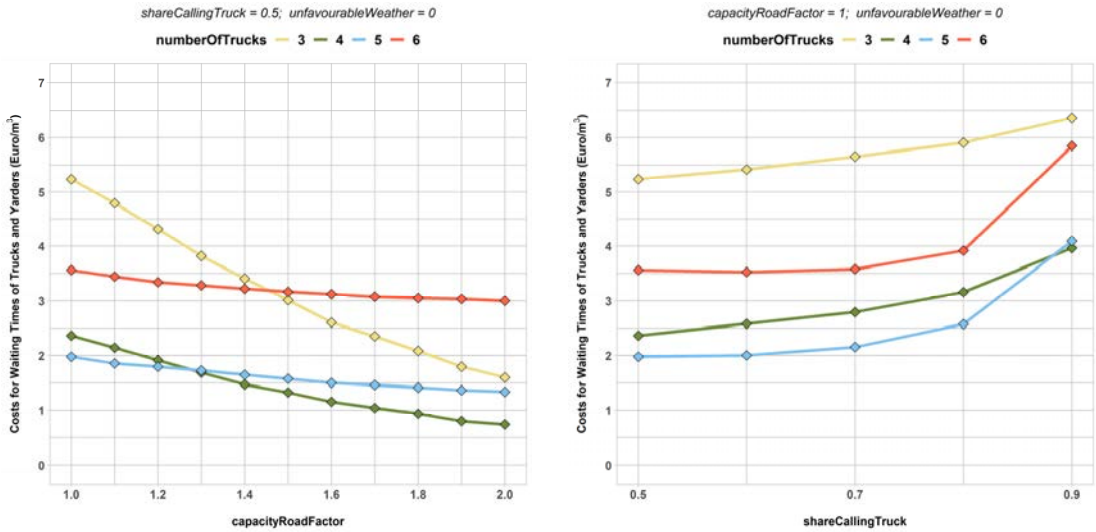
3.2 Costs for Waiting Times

System costs of 196 €/PSH_{15} are calculated for 'Yarders' and system costs of 98.4 €/PSH_{15} for 'Trucks'. To determine only the costs for waiting times, fixed costs are used from the cost calculation. These fix costs, which are 141.1 €/PSH_{15} for 'Yarders' and 64.3 €/PSH_{15} for 'Trucks', are then multiplied by the waiting times. This shows which combination of parameters keeps the costs lowest. In the best-case scenario with four trucks, early truck order behaviour (shareCallingTruck = 0.5) and doubled storage capacity at the forest road (capacityRoadFactor = 2), the average costs for waiting times are 0.74 €/m^3. Over all 50 replications in the best-case scenario, 90% of the values are between 0.68 €/m^3 and 0.81 €/m^3. The worst-case scenario shows up when there is unfavourable weather considered, truck orders are placed very late (shareCallingTruck = 0.9), the capacity at the forest road is not increased (capacityRoadFactor = 1) and only three trucks are available. The worst-case scenario costs on average 9.47 €/m^3. Over 50 replications for the worst-case scenario, 90% of the values are between 9.23 €/m^3 and 9.80 €/m^3 (Table 7)

Table 7: Descriptive statistics for the costs of waiting times for 'Trucks' and 'Yarders' (€/m^3) for the best- and worst-case scenarios and associated parameters

Scenario	unfavourable Weather	number Of Trucks	share calling Truck	capacity Road Factor	5th Quantile	Mean	SD	95th Quantile
Best-case	0	4	0.5	2	0.68	0.74	0.04	0.81
Worst-case	1	3	0.9	1	9.23	9.47	0.19	9.80

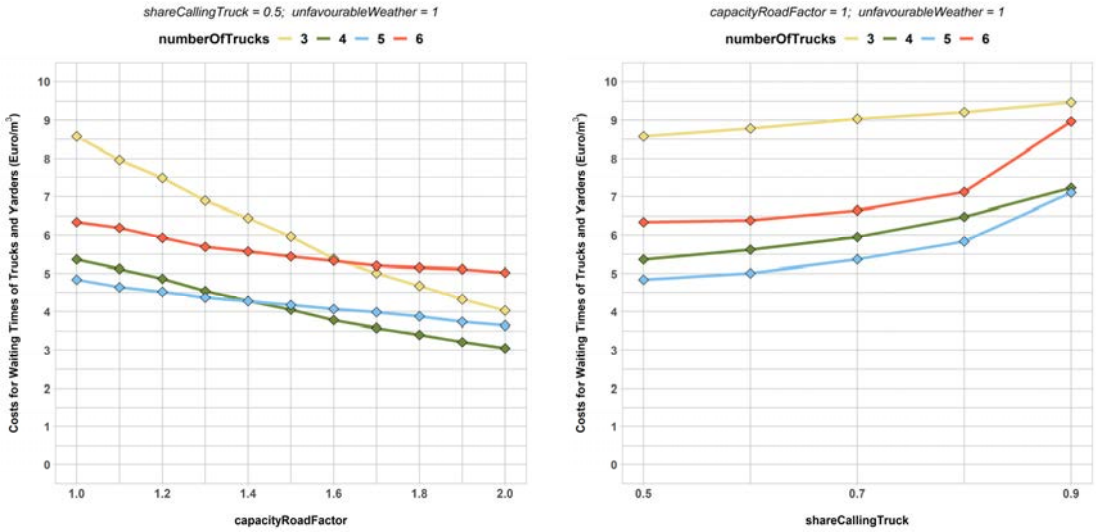
Costs for waiting times can be significantly decreased by increasing the storage capacity at the forest road. Especially with only three trucks, costs can be decreased by about 3.75 €/m^3 by doubling the storage capacity at the forest road. With five or six, an increase in the storage capacity at the forest road does not have such a strong impact on cost (Figure 2a). Early truck ordering always helps keep costs down. Depending on the number of trucks, late truck ordering can increase costs by 1 €/m^3 up to 2 €/m^3 if only the standard storage capacity at the forest road is available (Figure 2b).



(a) (b)

Figure 2: Costs for waiting times for 'Trucks' and 'Yarders' depending on the number of trucks and storage capacity at the forest road (a) and costs for waiting times for 'Trucks' and 'Yarders' depending on the number of trucks and timing of truck orders (b) – unfavourable weather is not included

Including unfavourable weather in the simulation does not have a substantial impact on the progression of the cost curves. There are only some small differences. For example, the curve for three 'Trucks' cuts the curve for six 'Trucks' slightly later (capacityRoadFactor = 1.6) than the curves without unfavourable weather data (Figure 3a). Also with 'shareCallingTruck', unfavourable weather does not change the progression of the curves (Figure 3b). However, costs are on a higher level when unfavourable weather is included.

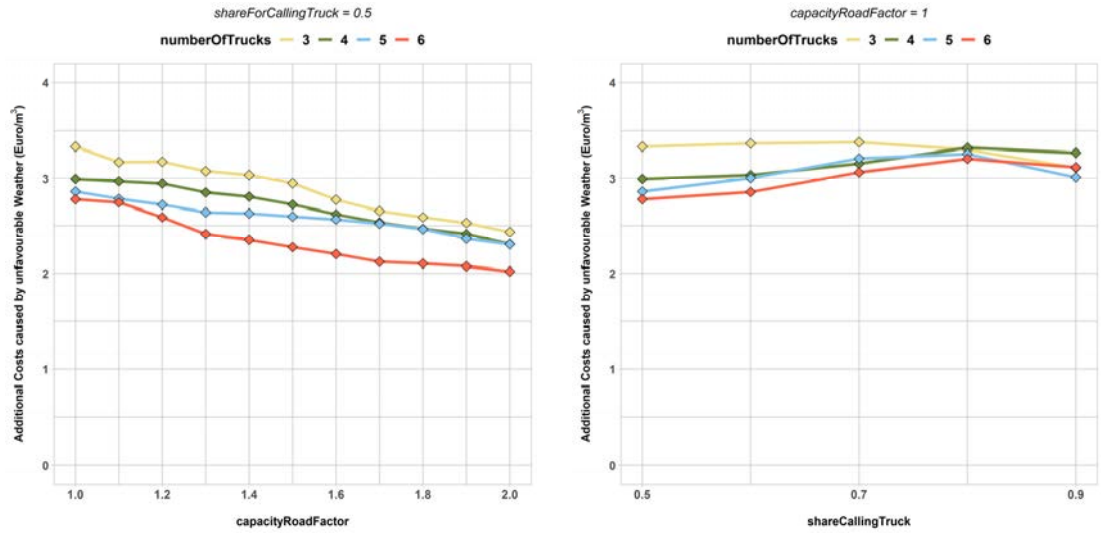


(a) (b)

Figure 3: Costs for waiting times for 'Trucks' and 'Yarders' depending on the number of trucks and storage capacity at the forest road (a) and costs for waiting times for 'Trucks' and 'Yarders' depending on the number of trucks and timing of truck orders (b) – unfavourable weather is included

Depending on the scenario, unfavourable weather can cause additional costs between 2 €/m^3 and 3.5 €/m^3. Increased storage capacity at the forest road can minimize the influence of unfavourable weather on costs

(Figure 4a). Earlier timing of truck orders (e.g., shareCallingTruck = 0.5) minimizes the influence of unfavourable weather on costs only slightly (Figure 4b).



(a) (b)

Figure 4: Influence of unfavourable weather on costs of waiting times for 'Trucks' and 'Yarders' depending on storage capacity at the forest road (a) and influence of unfavourable weather on costs of waiting times for 'Trucks' and 'Yarders' depending on timing of truck orders (b)

4 Conclusion

An ABS model was created using the simulation software 'AnyLogic 8 University 8.3.2'. This model simulates the harvesting operation with cable yarder in whole tree method with processing the trees on the forest road and transporting the wood harvested to the industry (i.e., sawmill, paper mill or heating plant). In total, 150 different yarding lines were supposed to be harvested with four cable yarders on 65 different stands with 52,470 m^3 wood randomly distributed over the state of Carinthia, Austria. Other necessary data to be input in the simulation model are based on assumptions, personal knowledge, common information and published literature. Based on the conceived data, the model functionality was tested and the effect of four different parameters was analysed regarding waiting times of yarders and trucks, operation times and costs. The study shows that it is possible to use ABS to simulate harvesting and transporting processes in the forestry sector.

In particular, a technological change in the harvesting equipment, the availability of different numbers of trucks, varied timing of information flows and the influence of unfavourable weather were analysed. The results show that all four parameters can influence waiting times and costs.

To test the model, 440 different scenarios were created. For each scenario, 50 simulation runs were carried out. Waiting times for yarders were found to be lowest at 23.3 h when there were six trucks, doubled storage capacity at forest road, no unfavourable weather and early information flow. The lowest waiting times for trucks was 151.1 h when there were four trucks, doubled storage capacity at the forest road, no unfavourable weather and early information flow.

As costs for waiting time differ between machines, analysing waiting time only falls to short. Therefore, fixed costs for trucks and yarders were multiplied by the waiting times to make statements about the entire system costs. The simulation showed that the lowest costs for waiting times of yarders and trucks were 0.74 €/m^3, while in the worst-case scenario, costs of up to 9.47 €/m^3 can occur. In the best-case scenario, there are four trucks, doubled storage capacity at the forest road and early information flow. Of course, unfavourable weather is not included in the best-case scenario. When including weather conditions, costs

increase up to 3 €/m^3. This means that unfavourable weather causes additional costs of about 2.25 €/m^3 for the best-case scenario.

In conclusion, ABS is a powerful method for analysing the behaviour of different systems. Much more can be examined than was done in this study. The quality of the input data is important for the results of simulation studies. Therefore, future studies should not only focus on modelling such systems, but also on collecting reliable input data.

References

Aalto M., Korpinen OJ., Loukola J., Ranta T. (2018). Achieving a smooth flow of fuel deliveries by truck to an urban biomass power plant in Helsinki, Finland – an agent-based simulation approach. International Journal of Forest Engineering. 29(1):21-30.

Asikainen A. 2010. Simulation of stump crushing and truck transport of chips. Scandinavian Journal of Forest Research. 25(3):245-250.

Borshchev A., Filippov A. 2004. From system dynamics and discrete event to practical agent based modelling: reasons, techniques, tools. In Proceedings of the 22nd International Conference of the System Dynamics Society, July 25-29, Oxford (ENG).

Eriksson A., Eliasson L., Sikanen L., Hansson PA., Jirjis R. 2017. Evaluation of delivery strategies for forest fuels applying a model for Weather-driven Analysis of Forest Fuel Systems (WAFFS). Applied energy. 188:420-430.

Ghaffariyan MR., Stampfer K., Sessions J. 2009. Production equations for tower yarders in Austria. International Journal of Forest Engineering. 20(1):17-21.

Gould EM., O'Regan WG. 1965. Simulation: A step toward better forest planning. Harvard University, Harvard Forest. 86.

Gronalt M., Rauch P. 2018. Analyzing railroad terminal performance in the timber industry supply chain–a simulation study. International Journal of Forest Engineering. 29(3):162-170.

Heinimann HR. 2007. Forest operations engineering and management–the ways behind and ahead of a scientific discipline. Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering. 28(1):107-121.

Holm S., Hilty LM., Lemm R., Thees O. 2018. Empirical validation of an agent-based model of wood markets in Switzerland. PloS one. 13(1):e0190605.

Huff ES., Leahy JE., Hiebeler D., Weiskittel AR., Noblet CL. 2015. An agent-based model of private woodland owner management behavior using social interactions, information flow, and peer-to-peer networks. PloS one. 10(11):e0142453.

Johnson LR., Fisher EL. 1978. Costing forest residue recovery through simulation. In Proceedings of the 10th conference on Winter simulation - Volume 2, December 01, Miami Beach (FL).

Korpinen OJ., Aalto M., Venäläinen P., Ranta T. 2019. Impacts of a high-capacity truck transportation system on the economy and traffic intensity of pulpwood supply in southeast Finland. Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering. 40(1):89-105.

Kostadinov F., Steubing B., Holm S. 2012. Vorgehen zur agentenbasierten Modellierung eines schweizerischen Waldenergieholzmarktes. Schweizerische Zeitschrift fur Forstwesen. 163(10):422-431.

Pelz DR. 1977. Simulation models of forest resource management. In Proceedings of the 9th conference on Winter simulation - Volume 2, December 05-07, Gaithersburg (MD).

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. URL https://www.R-project.org/.

She J., Chung W., Kim D. 2018. Discrete-event simulation of ground-based timber harvesting operations. Forests. 9(11):683.

Väätäinen K., Asikainen A., Eronen J. 2005. Improving the logistics of biofuel reception at the power plant of Kuopio city. International Journal of Forest Engineering. 16(1):51-64.

Windisch J., Väätäinen K., Anttila P., Nivala M., Laitila J., Asikainen A., Sikanen L. 2015. Discrete-event simulation of an information-based raw material allocation process for increasing the efficiency of an energy wood supply chain. Applied Energy. 149:315-325.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

OPTIMAL TRANSPORT SCHEDULING: DEMONSTRATION OF SOFTWARE CAPABILITY AND POTENTIAL GAINS

Mauricio Acuna [1], Glen Murphy [2]
[1] University of the Sunshine Coast, Hobart, Australia; [2] GE Murphy & Associates Ltd, Rotorua, New Zealand
macuna@usc.edu.au

Abstract: *FastTRUCK, a heuristic optimization truck scheduling tool was used to evaluate four sets of transport scenarios relating to trucking activity in two regions of New Zealand. The purpose of the evaluations was to compare actual with predicted performance metrics for a typical day and to demonstrate the versatility of the truck scheduling tool. The scenarios included a base case scenario similar to trucking activity on a representative day, a scenario with fewer trucks, a scenario with additional night-and-day trucks, and a scenario with additional trucks based in one of the regions. Solution times were generally obtained within 5 to 7 minutes, once the scenarios were set up.*

The validity of time data supplied by a forest company and used in the model was first undertaken. FastTRUCK predicted average waiting times of up to 64 minutes per day per truck. Under these predicted conditions the 173 tasks could not be completed. Modelling the scenarios with shorter load and unload times, and no waiting at customer sites yielded solutions that would complete all 173 tasks with 54 or 55 trucks.

Adding extra night-and-day trucks, or locating extra trucks at one of the regions led to increases in the number of tasks completed (i.e., loads delivered) and the predicted run loaded percent for those scenarios where waiting time was included. However, when no waiting time at customer sites was assumed, the extra trucks did not lead to improvements in task completion or run loaded percent.

A number of recommendations were made to improve the utility of FastTRUCK for use by the forest company.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

INNOVATION IN THE FIELD OF WOOD TRANSPORT IN FRANCE

Thomas CARRETTE, Christophe GINET
Technology Institute for the French forest-based sector – FCBA
Primary processing and supply unit
Allée de Boutaut – BP 227
33028 BORDEAUX CEDEX – FRANCE
thomas.carrette@fcba.fr

Abstract: *Actors of the French wood transport sector are working together on a common forest roads database project. France is indeed confronted to a complex context in this field: specific and non-uniform regulation on the territory, no national database that would allow to share information between public and private stakeholders and would serve as a reference for the calculation of transport distance...*

Over the last decade, several regions created local forest roads databases. These disconnected initiatives sought to respond to local needs (mountain areas, fire protection, etc.) but did not address interoperability imperatives for their future use. A national project, gathering forest companies, wood transporters, public operators and data managers, was launched in 2018 by FCBA and the French National Geographic Institute. Thanks to a methodology based on stakeholders' engagement, exchanges, case study of existing experiences and bibliography, a data standard is now published[1].

A collaborative tool has been released in July 2019. It serves 3 purposes: updating forest roads data, sharing and collecting feedback. This tool includes several modules, to access the database but also to report inconsistencies on the network or the very existence of un-characterized forest roads in a certain area. In the future, other types of tools could be developed and added to the national dynamic, some of which have already been tested on French territory, such as "qualification by use".

This "qualification by use" principle was tested in the French Alps by FCBA. This approach makes it possible to collect a large amount of information about a road thanks to the installation of GPS in the trucks. An automatic process has been created and tested to analyze the data. Results demonstrate it is possible to digitalize the infrastructure and qualify each road segment in terms of speed, status, problems (bottlenecks, infrastructure inconsistencies…) or frequency of use. All these outputs and the collaborative national approach are a first in this field in France and represent a major step forward for the improvement of wood transport and logistics for the national forest-based sector.

Keywords: transport, forest-road database, standard, qualification

[1] Standard can be downloaded here: http://cnig.gouv.fr/?page_id=18535

1. Introduction

Forest roads are a strategic infrastructure for the development of the forest-based sector. Accessing forests is essential to implement sustainable forest management and valorization (forestry work, logging, etc.), hence securing the supply of renewable raw material (wood material and biomass) and enabling the renewal of forests. In France, it is estimated that more than 900 companies (in 2015) operate in the field of roundwood transportation. These companies, mostly SMEs of less than 20 employees, transport more than 95% of roundwood volume in France with an average supply radius of 95 km (on the rise during the recent years). However, despite the strategic importance of this link in the chain, there is no shared database describing the road network. Both industry and public authorities are missing a centralized reliable reference.

Over the last decade, many initiatives arose at regional levels but the lack of consultation resulted in the different communities coexisting as silos. In some areas those initiatives produced operational tools, other prototypes were not updated and phased out. Some approaches rely on experts' opinions to qualify and describe the network, others are based upon observation of uses. All these initiatives and their limitations kept highlighting the need to set up a long-term national tool with all stakeholders in the sector. In 2017, a common project was launched to meet that goal at the national level. Based on a collaborative dimension and the co-development of new information and communication technologies, this project also learns from similar experience in neighboring countries.

2. The construction of a national dynamic

For several years, a community of different users and actors of forest roads database has been in place in France. Gathering both public and private forest stakeholders, geographic data provider, service providers and public authorities, this group works on solutions to structure and mutualized information.

In 2012, work was carried out by IGN (French National Institute of Geographical and Forest Information) and FCBA to define common specifications. A collaborative platform prototype was developed and tested in Lorraine with 15 local actors of the round wood transport sector. This first national project demonstrated the benefits of association between the mapping and database expertise (IGN on the one part) and industrial and business expertise (FCBA on the other part). A market study helped describe the specific needs of stakeholders for a tool with:

- Secure access.
- Fast and intuitive use.
- Responsive design (can be used on mobile, on tablet or smartphone).
- Operational in offline mode.
- Provide navigable instruction.
- Updated regularly.
- Interoperable for organizations (data can be integrated in local GIS).
- Collaborative approach for users to :
    - Consult different layers of data (roads, orthophoto, topo map, equipment, physical constraints)
    - Draw on maps and generate plans.
    - Carry out surveys in the field, and be able to make entries to report information on the service.

In 2017 a major step was taken when four organizations[2] (public and private) decided to pursue with a joint national project. The first phase, co-coordinated by FCBA and IGN aims at coproducing the shared and collaborative national database.

[2] MAA (Ministry of Food & Agriculture), COPACEL (French Union of Cardboard, Paper and Cellulose Industries), FBF (National Inter-professional association of the forest-wood sector) and CODIFAB (Professional Committee for the Development of French Furnishing Industries)

An overview of all pre-existing regional initiatives was completed: both still on-going ones and past major initiatives from which pitfalls needed to be understood. One important output was the up-to-date, accurate, detailed and homogenized inventory of pre-existing forest roads databases in the different regions. This provided a first base for standardization discussions. 16 local initiatives were studied, including 2 international approach (Switzerland and Germany). For each of them a detailed report described technical information (data collected, area covered, qualification and digitalization methods…) and general information (financers, contributors, data managers, governance, conditions of access, centralization process, services offered…) was shared with all the partners in the volunteer community.

Based on all the data collected in the first step, a special working group was gathered under the legitimate umbrella of the French National Geographic Information Council (CNIG). The mission of this group was to establish a common standard to describe all information needed in a forest roads database. The specifications were confronted with this group of users in order to validate a data model consistent with the contexts of use and expected levels of precision. More than 30 people, representing 20 different organizations took part in the 3 different meetings. At the end of this unique collaborative approach, all the users agreed on a standard (http://cnig.gouv.fr/?page_id=18535) to describe two types of roads:

1. Roads authorized by prefectural decree for the transport of roundwood.

Generally, on the national road network, the authorized gross vehicle weight (AGVW) is limited to 44 tonnes, excluding specific limitation. The maximum length is 16.5 m for articulated vehicles. A specific law, allows by derogation to increase the AGVW up to 48 or 57 tonnes under certain conditions of equipment (number of axles) and some roads.

2. Roads connecting to the storage places in forests (forest roads).

The standard also makes it possible to characterize the equipment related to the transport of wood (storage place, turnaround, etc.) as well as traffic constraints (steep slope, height restrictions related to a work of art, etc.).

The standard is divided in three themes: Road Section (42 attributes, including 31 mandatory ones), Equipment (13 attributes, including 8 mandatory ones) and Stress Point (25 attributes, including 15 mandatory ones).

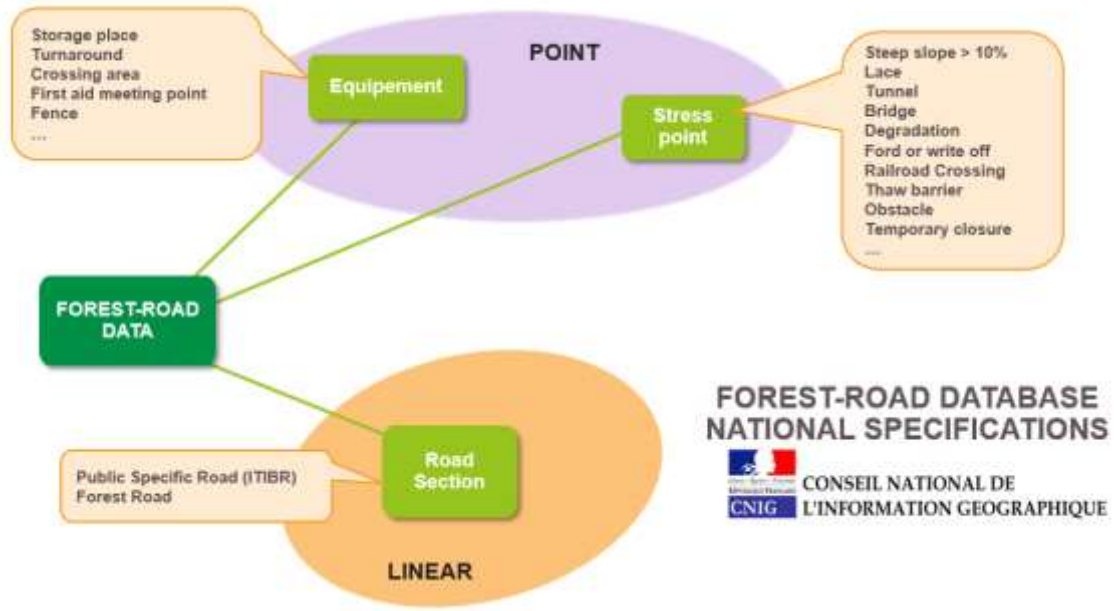


Figure 1 Structure of the national specification regarding forest-road database

In order to collect and share this information on a national level, an online web-tool has been developped. The latter provides an environment where the data model can be implemented, on the geometry of the RGE[3], in order to initialize the national forest-roads database.
As to August 2019, this work by IGN is still in acceptance testing. By December 2019, the tool will be online with all information regarding the specific public roads (authorized by prefectural decree). The forest roads part will be implemented in a collaborative way by and through the contributions all the users during the second phase of the project (2020 – 2021).

3. Exploring the qualification by use

With a common standard and a central database defined at national level, all actors can now carry out the qualification of the network. This collaborative approach can possibly be undertaken in many different ways and the online web-tool is one of the solutions. In order to study different possibilities, FCBA ran some tests with a group of transportation companies in the French Alps.

This approach is based on the monitoring of uses and practices. One significant advantage is that it does not require time or direct actions on the part of carriers. Sensors monitor the activities of a truck (one GPS beacon with data transmission and an embedded video recorder) and feed the system with information derived from the use the vehicule makes of the network. This approach provides information on: stress point, accessibility class of the roads, travel times, average speeds over a given road segment... However, such system would generate a considerable amount of data, hence requiring a methodology and a treatment process.

Processing was broken down into 3 phases: the design of the computer processing (taking into account all possible case studies), the implementation of this code and the detection of measurement errors by analyzing position of the point and speed profile of the data.
The tests used a data set transmitted by 7 different trucks during 11 months in 2017.
At the end of the test period, more than 5 million GPS points were recorded or about 524 days of activity. The majority of carriers have left the beacon plugged-in continuously. No complaint was filed by the carriers about the feeling of "big brother". The beacon was quickly integrated into their environment and routine.

More than 550,000 measurement points were located within the study area (less than 25 m from a forest) and resulted in the qualification of approximately 10,000 sections of road. In total, after this first experiment, 1,250 km of service were qualified over the 25,000 km that included the database serving input. Thus, 5% of the network could be qualified with a fleet of 7 vehicles operating for a total of 524 working days. Sections with less than 10 measurement points were not included in these figures.

This qualification progressed quickly, ¾ of these 1,250 km were mapped and characterized for the first time within less than 3 months of monitoring. Subsequently, one enters a slower phase or the continuous network to be qualified, but where unmeasured section discovery is less frequent. The graph below clearly shows these two phases of "discovery" and then of complementary "collection".

[3] RGE = french large scale repository databases (including orthophotographic, topographic and altimetric data)

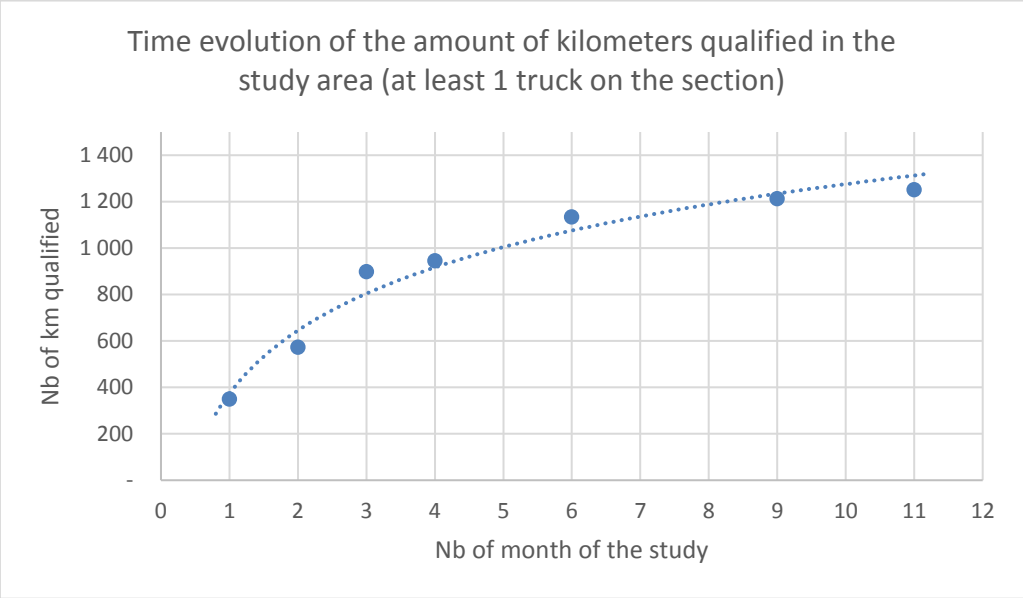


Figure 2 Amount of kilometers qualified over time

The approach is all the more significant when we focuses on a specific geographic area. It turns out that half of the beacons had for main sector of intervention: the massif of Chablais (Haute-Savoie, France). In this sector, 3 beacons have been active for 11 months. It has been possible to qualify 810 km representing 30% of the network.

Data collected about the speed also provides very useful information for planning and route analysis. These measurements allow us to obtain a precise travel time for each section of the database and thus guarantee a reliable estimate for business applications such as the optimization of transport orders or GPS guidance.

4. Conclusion and next step in the French community.

Collaborative work carried out at the national level is good fortune for further development in France. A network of active and participative actors is now in place, guaranteeing progress in the future. Some aspects have yet to be studied within the community to reach a consensus: the long term business model of the national base is still under discussion; access to open source data raises concerns about the hypothetical misuse of the database for recreational purposes or against the wishes of private forest owners…

However, the regional initiatives and the opportunities presented by new approaches, such as the qualification by use, suggest positive ways to implement the national base. Next septs will be to carry on the deployment of the first tools and support the regional approach in a dynamic of sharing and collaboration.

S07 Wood transportation & New technologies
Roll on

HANDLING LABOUR SHORTAGE BY EFFICIENT SUPPLY CHAIN SOLUTIONS - CONTAINER TERMINAL
Robert I Radics, Carel Bezuidenhout, Ginny Christians
Scion Forest Research, New Zealand

LOADING RATES AND COMPACTION FACTORS FOR WOODCHIP VESSELS VISITING AUSTRALIAN PORTS
Glen Murphy [1,2], Mauricio Acuna [2], Michael Berry [2], Rick Mitchell [2]
[1] GE Murphy & Associates, New Zealand; [2] University of the Sunshine Coast, Australia

WIRELESS CRANE SCALE TO IMPROVE ROUND WOOD TRANSPORT EFFICIENCY
Franz Holzleitner, Christoph Santner, Christian Kanzian
Institute of Forest Engineering, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences, Vienna, Austria

HOW TO DEAL WITH AN UPCOMING SHORTAGE OF WOOD TRANSPORTING CAPACITY IN GERMANY?
Herbert Borchert, Sebastian Gößwein, Marina Schusser
Bavarian State Institute of Forestry (LWF), Freising, Germany

LOGISTICS OF SUPPLING WOODY BIOMASS LONG DISTANCE USING RAILROAD TRANSPORTATION
Jeff Halbrook, Han-Sup Han
Ecological Restoration Institute, Northern Arizona University, Flagstaff, AZ, USA

OPERATIONAL EVALUATION OF A TIMBER TRAILER WITH THE HYBRID DRIVE
Tomáš Zemánek [1], Jindřich Neruda [1], Radomír Ulrich [1], Ondřej Vítek [2], Petr Procházka [2]
[1] Department of Engineering, Faculty of Forestry and Wood Technology, Mendel University in Brno, Czech Republic [2] Department of Power Electrical and Electronic Engineering, Faculty of Electrical Engineering and Communication, Brno University of Technology, Czech Republic

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

HANDLING LABOUR SHORTAGE BY EFFICIENT SUPPLY CHAIN SOLUTIONS

Robert I Radics, Carel Bezuidenhout, Ginny Christians
Scion Forest Research
10 Kyle Street, Riccarton, Christchurch 8014 New Zealand
Robert.Radics@scionresearch.com

Abstract:

"Wall of Wood" is the name of the most significant supply chain stress for the forestry industry in this decade in New Zealand. The volume of the harvestable timber doubles from 2016 to 2026. Among all the logistics problems the lack of labour is the most significant one. The issue is current; sometimes, trucks cannot leave the yards because of lack of drivers. The general unemployment rate is low. Besides, the expertise, availability and the need do not meet. New Zealand is the largest log exporter in the world, and about 50% of the timber sold without further domestic processing. The government targeted higher value-added forestry industry that also needs new solutions.
Our study suggested a container terminal investment that would take off 18 thousand trucks off the roads annually, improve safety, and reduce the transportation costs in the Bay of Plenty Region. Discrete event simulation and economic analyses were combined to define the recommended technology, and the cost and benefits of the suggested solution. Uncertainty and sensitivity analyses were used to identify the risks and the most critical factors of a successful project.
Based on the study the Kawarau container terminal project got financed, and the new supply chain will be established.
The presentation includes the problem description, the applied methods, the conclusion, and most importantly the collaboration with the different industries and stakeholders like local government and Maori.

Keywords: Labour shortage, Supply chain, Logistics, Container terminal

1. Introduction

The logistics implications of the inclusion of a container packing and rail transhipment terminal in Kawerau were assessed in this study. The project conducted a field survey on container logistics in the Eastern Bay of Plenty and developed discrete event simulation modelling tools to simulate different scenarios.

The majority of exporters currently have no access to rail services for containers and operate in a relatively fragmented fashion to move their products to the port in the Bay of Plenty. Currently many exporters transport their products by road to storage areas at Mount Maunganui where it is containerised and then trucked to Sulphur Point's container wharf. Alternatively, exporters transport empty containers by road to their manufacturing site, pack the container on site and then truck it back to Sulphur Point. This comes at a significant cost and time expense for exporters. It also contributes to an increased number of heavy truck movements on State Highway 2, which has negative social and environmental impacts.

The baseline model was used to run a series of scenarios aimed at examining the impact of various levels of container volumes through the terminal. The results indicate the need for several key clients to commit towards the terminal's operation before its establishment could be justified. There is potential for a moderately significant seasonal volume of products to use the terminal, which will have waiting time implications for terminal users during certain peak times of the year.

2. Materials and Methods

2.1. Data Collection

Following an initialisation meeting exporters who had previously expressed an interest in using the proposed terminal were invited to participate in a questionnaire survey. Exporters were asked to complete the questionnaire and to participate in a discussion concerning their organisation's operations and requirements. In total 18 exporters were invited to participate, 17 responded and 14 completed the data collection. Non-participating exporters were not completely disregarded and best-estimate volumes were assumed in some of the modelled scenarios.

Kiwirail, Port of Tauranga, Port of Auckland, some shipping lines and trucking companies were also engaged in order to gather further information and data.

2.2. Model development

A baseline discrete event simulation model was developed in ExtendSim® in order to represent the logistics system in the region. The model was tested against the opinions of exporters and other stakeholders who are familiar to the current operations. This was an iterative process that continued until all the major problems in the model were eliminated. The model was also used to perform sensitivity analyses. The sensitivity testing was presented during a stakeholder meeting and feedback was further incorporated into the model. This baseline model makes many assumptions (see below). Not all the assumptions are reported.

2.3. Sensitivity Analyses

The model was tested for sensitivity to the following changes in variables:

- Cost changes in Packing
- Cost changes in Storage
- Cost changes in Rail freight
- Cost changes in Road freight
- Number of exporters packing at Kawerau
- Truck size and/or weight limits
- Number of wagons per train limits
- Number of Trains available to the terminal

2.4. Important Model Assumptions

The model makes a number of assumptions and requires a number of variables to be fixed. The results should be read with these assumptions in mind. A comprehensive outline of the model's cost assumptions can be found in Appendix A, the major system assumptions are outlined below

- Exporters either use trucks or the terminal to pack and tranship their containers (i.e. no combination of operations per exporter was simulated).
- The model did not consider common costs, such as marshalling and stevedoring that apply regardless of the container's pathway.
- A free storage period of 7 days at the container terminal was assumed, after which a nominal daily fee is charged for each container in storage.
- The cost of the train is underwritten by the terminal.
- Rail freight prices were based on Kiwirail provided data, as per agreement with Kiwirail the details are not disclosed.
- Assumed costs are conservative and where possible include a profit margin for intermediate parties.

2.5. Scenario Descriptions

The model was used to examine 13 scenarios. The model is stochastic and each scenario simulation was replicated 20 times. A simulation is representative of a three month period. Initial conditions for each run was randomly seeded. All results should be interpreted while considering the model assumptions, simplifications summarised and sensitivities reported in Appendix A and B. Table 1 outlines the specific scenarios that were examined.

Table 1: Scenarios explained and detailed outline

Scenario Name	Explanation	Annualised Volume (~ containers)	Weekly Train information	Packing %
Best Case	This scenario represents all 18 exporters fully utilising the terminal	33,147	10 full trains	21%
Most Likely Case	This scenario represents the more likely scenario with 15 out of 18 exporters utilising the terminal	18,454	7 full trains	21%
Worst Case Premium	This scenario represents a low use scenario 12 out of 18 exporters using the terminal. This scenario models a premium in order to maintain a daily train service	10,092	5 light trains	21%
Worst Case	This scenario represents a low use scenario 12 out of 18 exporters using the terminal. This scenario models a move to an alternative day train service with no price premium	10,092	3 full trains	21%
Winter	This scenario represents the seasonal impact of the July – September Quarter	19608	7 full trains	21%
Spring	This scenario represents the seasonal impact of the October - December Quarter	17696	7 full trains	21%
Summer	This scenario represents the seasonal impact of the January - March Quarter	17247	7 full trains	21%
Autumn	This scenario represents the seasonal impact of the May - June Quarter	21,089	8 full trains	21%
Light Packing	This scenario represents the most likely scenario volume with 8 out of 15 exporters packing at the terminal	18,454	6 full trains	32%
Moderate Packing	This scenario represents the most likely scenario volume with 11 out of 15 exporters packing at the terminal	18,454	7 full trains	80%
Heavy Packing	This scenario represents the most likely scenario volume with 14 out of 15 exporters packing at the terminal	18,454	7 full trains	87%
Auckland Weekly	This scenario represents the more likely scenario with 15 out of 18 exporters utilising the terminal	18,454 20% volume to Auckland	5 Full trains Tauranga 1 full Train Auckland	21%
Auckland Fortnightly	This scenario represents the more likely scenario with 15 out of 18 exporters utilising the terminal	18,454 8% volume to Auckland	6 Full trains Tauranga 1 full Train Auckland – biweekly	21%

3. Results and Discussion

Figure 1 illustrates the number of containers shipped during a quarter from each exporter across all 13 scenarios. Two thirds of the 18 exporters maintain a relatively stable throughput over the 13 examined scenarios. Figure 2 displays an annualised total number of containers moved through the terminal for each of the scenarios. Figure 3 shows the proportion of each container type handled at the terminal.

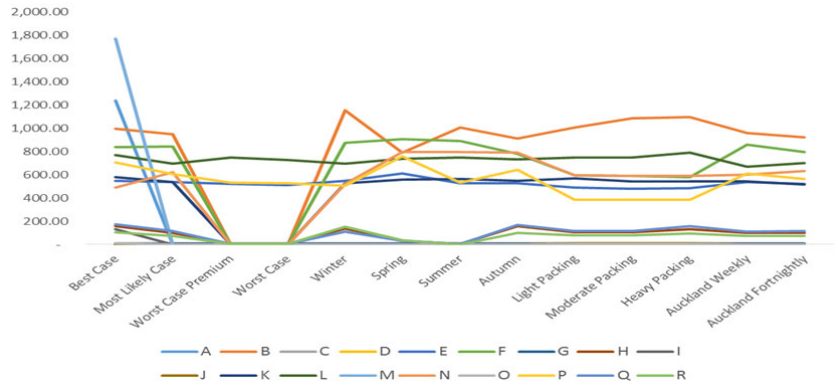


Figure 1: Total number of containers by modelled terminal user for each of the scenarios

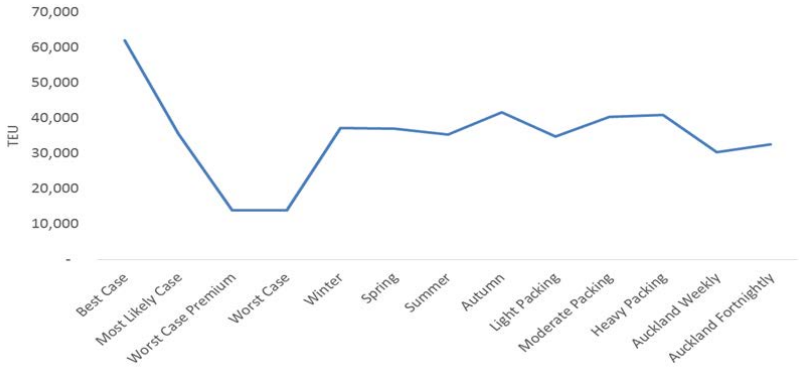


Figure 2: Annualised number of containers for each of the scenarios

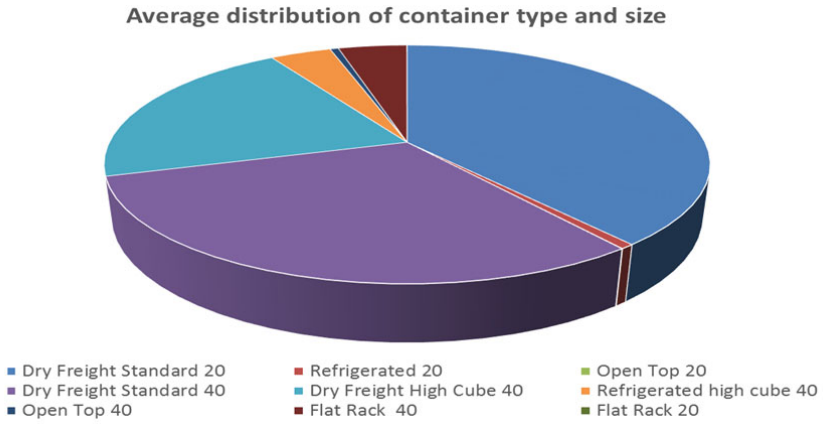


Figure 3: Average distribution of containers moved in all scenarios by type and size.

3.1. Social Impacts

Figure 4 shows the primary route from Kawerau to the Port of Tauranga. The social metrics tracked in the model relate primarily to the reduction in truck traffic on State Highway 2.

This route is frequently travelled by visitors to New Zealand and residents commuting to and from the Eastern and Western Bay of Plenty areas. Significant volumes of heavy trucks on this route have social impacts. Heavy vehicles are involved in 8% of serious injury and 18% fatal accidents in New Zealand, 82% of these fatal crashes involving trucks occur on the open road (Ministry of Transport, 2016a).

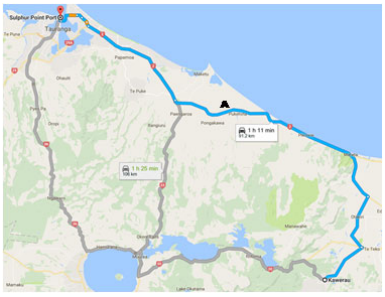


Figure 4: The most common route for heavy traffic moving from the Kawerau end of the Eastern Bay of Plenty to Tauranga

A total of 284,611 heavy vehicles travelled through the Ohinepanea Telemetry Site on State Highway 2 (Point A in Figure 4) in the 12 months from August 2015 to July 2016. This represents 13.8% of all vehicles recorded at this site (NZ Transport Agency, 2016). Heavy vehicle traffic causes two to four times more road surface damage compared to light vehicles (Arnold, Steven, Alabaster, & Fussell, 2005).

Figure 5 shows the number of heavy vehicle trips that will be avoided on State Highway 2 as a result of the container terminal. Figure 6 shows the amount of road kilometres that will be avoided under different scenarios and Figure 7 outlines the potential fuel savings that could be obtained by the use of the Kawerau Container terminal across the 13 examined scenarios. In all cases a significant number of heavy vehicle journeys (>10 000 per annum) could be mitigated by the container terminal, reducing the total heavy vehicle traveling distance on Easterm Bay of Plenty roads by as much as 3 million kilometres per year.

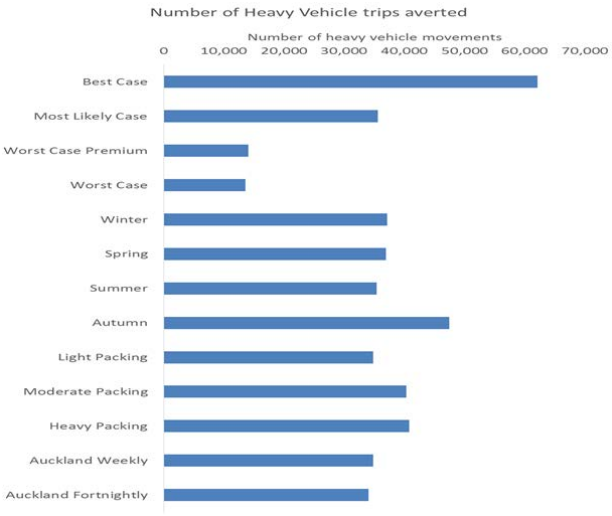


Figure 5: Number of heavy vehicle movements that could be reduced on State Highway 2 on an annual basis.

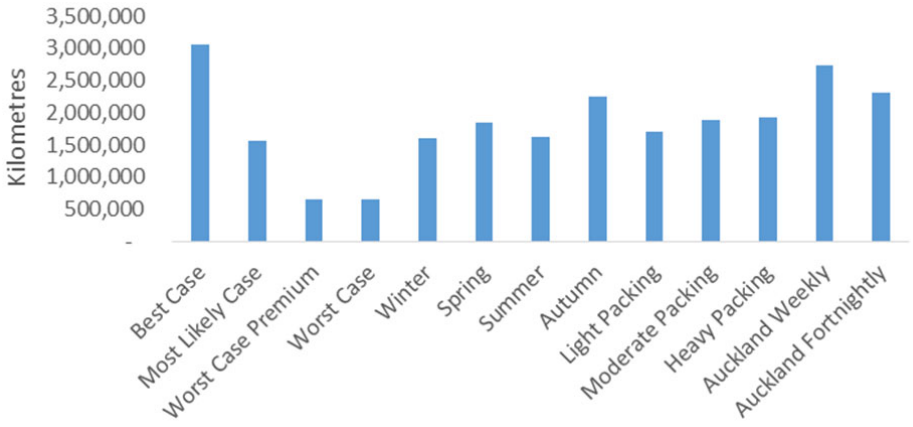


Figure 6: Amount of heavy vehicle kilometers reduced on State Highway 2.

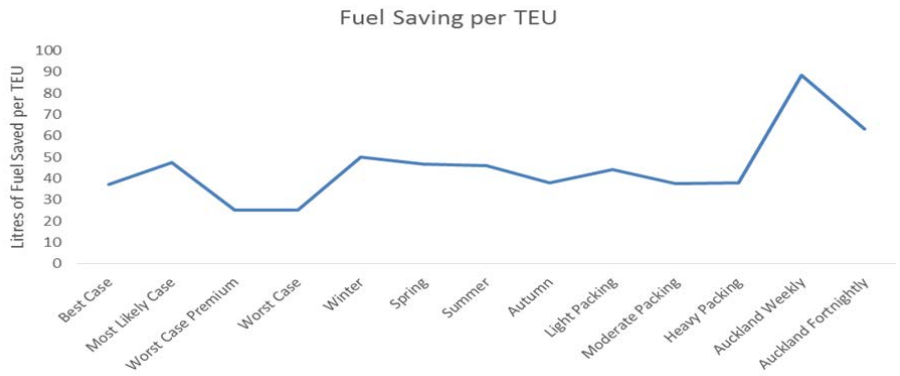


Figure 7: Litres of fuel savings per TEU as a result of the container terminal.

3.2. Environmental Impacts

Transport sector related emissions are estimated at 20% of New Zealand's total Greenhouse gas bill. This represents 40% of emissions from the energy sector (Ministry of Transport, 2017). Transport his a significant contributor to the rise in greenhouse gas emissions in NZ since 1990 (Ministry for the Environment, 2016). The model estimated carbon dioxide (CO_2), oxides of nitrogen (NO_x), hydrofluorocarbons (HFC) and particle matter (PM10) emitted by trucks and trains. Model coefficients for trucks were derived from the Vehicle Emission Prediction Model, which correlate with the NZ guidelines for voluntary, corporate greenhouse gas reporting (Ministry for the Environment, 2015). Rail emission coefficients were obtained from the European Union Commission Directive 2012/46/EU for the DL class locomotive with engine type MTU 20V 4000R43 2700kW (Official Journal of the European Union, 2012).

Figure 8 shows the likely ranges of total CO_2 savings per quarter for each scenario as a result of the container terminal. Figures 9 shows the average potential reductions in NO_x, HFL and Particle Matter (PM10) emissions for the different scenarios simulated. In the best case scenario and based on the emissions trading scheme (ETS), these emissions equate to more than half a million dollars a year.

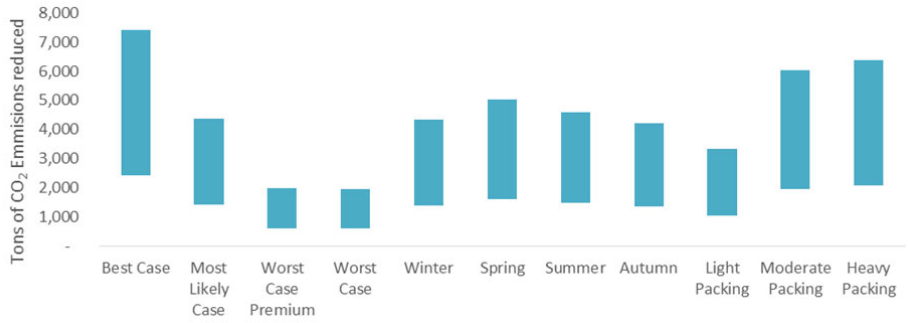


Figure 8: Range of estimated CO_2 savings per scenario.

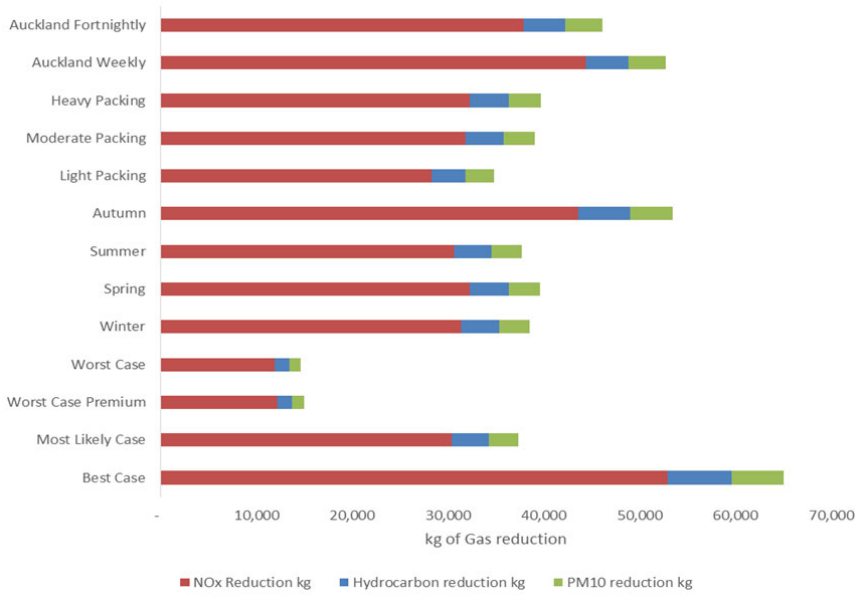


Figure 9: Volume of potential harmful emissions avoided per quarter.

3.3. Economic Impacts

The model calculated operational savings per container, which is the difference between the operating cost of a highway based solution and the operating cost of the Kawerau Container Terminal rail based solution. Positive values are indicative of savings associated with the container terminal. It should be noted that these costs do not include the capital required to establish the infrastructure.

Figure 10 shows the average potential savings per container, per scenario. It is evident that on average all the scenarios simulated yielded a more profitable solution with the container terminal compared to the state highway scenario. The Auckland scenarios (grey shared) are not comparable to the other scenarios and further investigations are required to assess the viability of containers to move to Auckland by train.

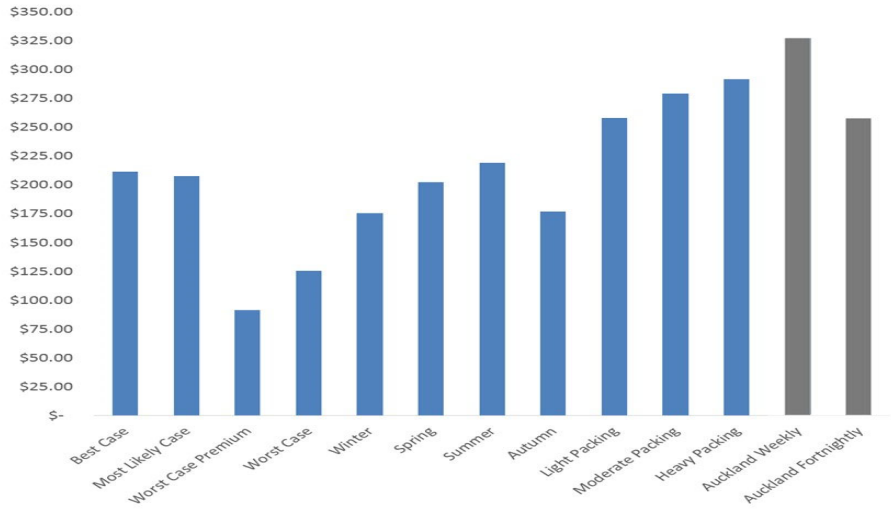


Figure 10: Average savings per container generated as a result of the container terminal.

Figure 11 shows the returns and costs for the terminal operator. This is important since the terminal underwrites the trains and need to show a viable business in itself before the solution could be rolled out to exporters in the region.

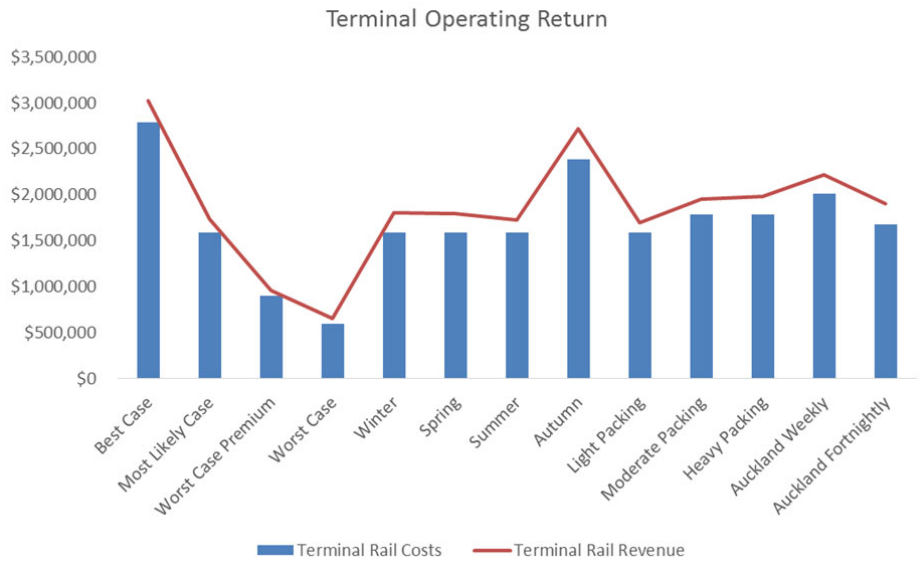


Figure 11: Total cost of trains and rail revenue generated by the terminal. The gap demonstrates the profit margin on the rail resource.

4. Conclusion and Recommendations

It is estimated that the Eastern Bay of Plenty exports more than 33 000 containers per annum (>60 000 TUEs). Some of these containers are already moved by rail to Mount Maunganui. Currently no containers from this region are delivered by rail directly to the container port at Sulphur Point. A rail service of ten trains per week would be required to handle the full complement of containers in the region. Based on a survey among different exporters, it is estimated under favourable conditions that approximately 18,500 containers that are currently transported via State Highway 2 could be transferred to rail at Kawerau. This would require more than one train a day. Approximately 20% of these containers may even be packed at Kawerau, reducing the need for empty container logistics to different production sites in the region. Several producers in the region have seasonal outputs and the proposed container terminal is likely to see a 15% rise in container volumes from March to August. Autumn may be a challenging period for the container terminal with high volumes and a demand for efficient operations. Many simplifications and assumptions were made during this study and a comprehensive due diligence and further conversations with exporters and other stakeholders is required. Several containers may transfer to shipping lines that operate from Ports of Auckland and containers destined to domestic markets could influence the results. Given the current information available it appears that containers destined to the Port of Tauranga could be transported at a considerable reduced rate, while containers destined to Auckland are more questionable. Further research is required to determine the exact number of containers that may move directly from Kawerau to Auckland.

The Kawerau container terminal is likely to reduce the number of heavy vehicles on State Highway 2 by more than 18,000 consignments per year. This amounts to more than eighty trucks a day and releases the infrastructure of an estimated 1.5 million kilometres of heavy vehicle travelling per annum. This does not only reduce the fuel bill, but also potentially reduces carbon emissions by as much as five to six thousand tons per annum. Other harmful emissions are also avoided.

Conservative estimates predict that the container terminal is likely to reduce transfer costs by an average of at least $100 to $150 per container, while the container terminal as a business in itself generates viable returns. These estimates, however, exclude capital and the costs to develop the infrastructure need to be considered in addition to these results. Likewise, the costs to acquire new rail rolling stock were not considered in this study.

While some containers may be more difficult and expensive to handle and while many different ways to establish the terminal could be considered, at least 88% of all containers that will move through the terminal are likely to result in substantial cost savings compared to the conventional state highway solution.

It is recommended that the establishment of the container terminal is investigated further and that a detailed due diligence should be carried out in the future. It is also recommended that the off-loading logistics at the Port of Tauranga is considered since the models used in this study did not research off-loading in detail. While packing containers on the terminal was simulated as a viable enterprise, many exporters expressed concerns in this type of operation and further engagement with the potential customers of the terminal should be considered.

5. Acknowledgements

The authors would like to especially acknowledge the input from the various exporters who agreed to give their time to be interviewed for this project. Acknowledgement and appreciation is expressed towards for the support, direction and guidance from the funders and their representatives, namely: Bay of Plenty Regional Council, Kawerau District Council, Whakatāne District Council, the Ministry of Business, Innovation and Employment, Kawerau Industrial Symbiosis, Ōpōtiki District Council and Toi-EDA. Graham West, a former colleague who left Scion during the course of the project, is thanked for his inputs into the study.

References

Arnold, G., Steven, B., Alabaster, D., & Fussell, A. (2005). Effect on pavement wear of increased mass limits for heavy vehicles– Concluding report (281). Retrieved from Land Transport New Zealand Research Report website: www.nzta.govt.nz/assets/resources/research/reports/281/docs/281.pdf

Ministry for the Environment. (2015). Guidance for voluntary corporate greenhouse gas reporting - 2015: Data and methods for the 2013 calendar year (ME 1194). Retrieved from http://www.mfe.govt.nz/publications/climate-change/guidance-voluntary-corporate-greenhouse-gas-reporting-2015

Ministry for the Environment. (2016). New Zealand greenhouse gas inventory 1990–2014 snapshot (INFO 758). Retrieved from http://www.mfe.govt.nz/publications/climate-change/new-zealands-greenhouse-gas-inventory-1990%E2%80%932014-snapshot

Ministry of Transport. (2016). Trucks 2016. Retrieved from http://www.transport.govt.nz/assets/Uploads/Research/Documents/Trucks-2016.pdf

Ministry of Transport. (2016). Rail safety statistics: Six monthly statistics for the period ended 31 December 2015. Retrieved from http://www.transport.govt.nz/assets/Uploads/Research/Documents/Rail-Safety-Statistics-31December2015.pdf

Ministry of Transport. (2017, January 10). Climate Change and Energy. Retrieved from http://www.transport.govt.nz/ourwork/climatechange/

NZ Transport Agency. (2013). Vehicle emissions prediction model VEPM 5.1. Retrieved from https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/air-quality-climate/planning-and-assessment/vehicle-emissions-prediction-model/

NZ Transport Agency. (2016). Traffic volumes monthly report: July 2016. Retrieved from https://www.nzta.govt.nz/resources/state-highway-traffic-growth/

Official Journal of the European Union. (2012). Commission Directive 2012/46/EU of 6 December 2012 amending Directive 97/68/EC of the European Parliament and of the Council on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery. Official Journal of the European Union, 353(80). Retrieved from http://data.europa.eu/eli/dir/2012/46/oj

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

LOADING RATES AND COMPACTION FACTORS FOR WOODCHIP VESSELS VISITING AUSTRALIAN PORTS

Glen Murphy [1,2], Mauricio Acuna [2], Michael Berry [2], Rick Mitchell [2]
[1] GE Murphy & Associates, New Zealand; [2] University of the Sunshine Coast, Australia
gemurphy.nz@gmail.com

Abstract: *Australia is the world's 4th largest producer of woodchips. Shipping and port costs account for about 60% of the cost of sales of woodchips to Asian markets. Past studies have identified that the rate at which a terminal is able to load or unload a woodchip vessel and the amount of material that can be loaded onto a vessel are two of the four most decisive factors affecting shipping costs.*
Loading rates and compaction factors (relative measures of the amount of material loaded) were quantified via surveys for Australian woodchip exporting ports. Opportunities were identified for improving loading rates and compaction factors through (a) interviews with woodchip exporting companies, (b) analyses of data for over 500 ship or partial ship loads, and (c) literature reviews.
Maximum potential load rates at Australian ports ranged from 670 to 1200 green metric tons per hour. Net loading rates were on average 30% slower - for load compaction reasons - than the maximum potential loading rates. Gross loading rates, which include delays, averaged 86% of net loading rates or about 60% of maximum potential load rates.
Compaction factors at Australian ports ranged from 137 to 170 ft3 per bone dry metric ton.
Factors found to affect loading rates and compaction factors included: the type of shore-to-ship delivery system (e.g., mobile vs fixed conveyors, multi-product vs woodchip only systems), the tree species being loaded, conveyor rates, use of deflector plates on jet slingers, use of dozers in the hold for chip re-distribution and compaction, layering of the chips within the ship's holds, and the order in which holds were loaded.
Other companies commented that loading rates and compaction factors were affected by the loading pattern (e.g. 80% fill followed by 20% top-off), the skill of the loader operator, the wood chips specifications, and the moisture content of the woodchips.
Each 1% improvement in compaction factor is worth US$25,000 to US$40,000 in additional income per vessel for the exporter. This study provides information that should help decision makers to select the work methods and equipment which will lead to the greatest net returns for the exporter.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

WIRELESS CRANE SCALE TO IMPROVE ROUND WOOD TRANSPORT EFFICIENCY

***Franz Holzleitner[1], Christoph Santner[2], Christian Kanzian[1]**
[1]Institute of Forest Engineering
Department of Forest- and Soil Sciences
University of Natural Resources and Life Sciences Vienna
Peter-Jordan-Strasse 82/3, A-1190 Vienna, Austria
franz.holzleitner@boku.ac.at
christian.kanzian@boku.ac.at
[2]EPSILON KRAN GMBH
Christophorusstraße 30, 5061 Elsbethen-Glasenbach, Austria
ch.santner@palfinger.com

Abstract: *In round wood transport the driver is responsible for keeping the load limits according to legal regulations and technical limits. Currently this is mostly done by the driver during loading just by visual estimates. To prevent overloading or even low transporting efficiency due to lower payloads accurate estimating of payloads in round wood transport is an essential requirement.*
The objective of this study was to analyze a wireless crane scale in timber transport in terms of its accuracy, loading efficiency and costs. The studied wireless crane scale is a prototype of Epsilon Kran GmbH (Austria) developed in cooperation with the Swedish company Tamtron Timber.
Overall, 69 loads were studied with the installed crane scale and 36 loads could be compared to data from customers weighing systems. Weighed loads compared to weighing data from calibrated weighbridges showed an average deviation of 3.44%. Loading efficiency before and after the installation of the wireless crane scale showed no significant differences.

Keywords: wireless crane scale, round wood transport, transport efficiency, transport costs

1. Introduction

In roundwood transport, the driver is responsible for keeping the load limits according to legal regulations. Currently the driver mostly does this during loading process just by visual estimates. However, permanently changing operating conditions make it difficult to estimate payloads accurate enough. An essential reason for this is that round wood as a natural product has different qualities and characteristics. It is not comparable to standardized transport goods.

To prevent overloading or even low transporting efficiency due to lower payloads accurate estimating of payloads in round wood transport is an essential requirement. Additionally, an EU directive 2015/719, which should ensure undistorted competition within the transport business, is forcing to estimate payloads of transporting vehicles on the roads. This includes also the transport sector for round wood from the forest to the mill.

The objective of this study is to analyze a wireless crane scale in timber transport in terms of its accuracy, loading efficiency and costs. In addition, a literature review on alternative systems for determining load weights in round wood transport is carried out.

2. Material and methods

The studied transport unit consisted of a Mercedes Benz Actros 3346 truck with 6x6 drive, equipped with a loading crane M120 Z 96 from Epsilon and a tandem trailer for round wood transport. Altogether, the truck and trailer unit including the mounted crane weighs 21.9 tons.

The studied wireless crane scale is a prototype of Epsilon Kran GmbH (Austria) developed in cooperation with the Swedish company Tamtron Timber. The applied sensing technology uses an extra hydraulic circuit, integrated in the joint, which is not connected with the main hydraulics of the crane. The sensor is transmitting calculated single weights to the receiver unit with a display for the operator. Single grapple loads are automatically summarized by the onboard unit and shown on the display during loading. Thus, the operator is able to check the actual load weight. The installed software also offer to set different load limits for carriers or even axles.

Weighing data from the crane scale were compared with data from calibrated weighbridges at customer sites. Internal repeatability of the crane scale was analyze during a simulated loading using a single grapple load with a known weight of 825 kg which was loaded 30 times. Time consumption for defined work phases including driving distances were captured with a detailed time-and-motion study.

3. Results

Before installing the wireless crane scale, 59 loads with an average load size of 24 m³ were recorded during 77 hours time-motion studies. Thereby calibrated weighbridges at the customer capture 27 payloads. Overall, 69 loads were studied with the installed crane scale and 36 loads could be compared to data from customers weighing systems. Weighed loads compared to weighing data from calibrated weighbridges installed at costumers showed an average deviation of 820 kg (3.44%). The mean difference during the simulated loading was 3.1 kg (0.38%). Loading efficiency before and after the installation of the wireless crane scale showed no significant differences (Santner, 2018).

Acknowledgements

This publication is a part of the national funded project “Use of a wireless crane scale in round wood transport – A detailed process and performance analysis”. The research project has received funding from the Federal Ministry for Sustainability and Tourism, the cooperation platform of Forst Holz Papier (FHP) and the Austrian Federal Forests. The authors want to thank the entrepreneur Int. Transporte Gruber GmbH & Co KG (Salzburg, Austria) and Epsilon Kran GmbH (Salzburg, Austria) for supporting the study.

References

RICHTLINIE (EU) 2015/719 DES EUROPÄISCHEN PARLAMENTS UND DES RATES, vom 29. April 2015, zur Änderung der Richtlinie 96/53/EG des Rates zur Festlegung der höchstzulässigen Abmessungen für bestimmte Straßenfahrzeuge im innerstaatlichen und grenzüberschreitenden Verkehr in der Gemeinschaft sowie zur Festlegung der höchstzulässigen Gewichte im grenzüberschreitenden Verkehr.

Santner, Ch. (2018): Einsatz einer Wireless-Kranlastwaage im Rundholztransport - Prozess- und Einsatzanalyse. Masterarbeit am Institut für Forsttechnik.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

HOW TO DEAL WITH AN UPCOMING SHORTAGE OF WOOD TRANSPORTING CAPACITY IN GERMANY?

Herbert Borchert, Sebastian Gößwein, Marina Schusser
Bavarian State Institute of Forestry (LWF)
Hans-Carl-von-Carlowitz-Platz 1, 85354 Freising, Germany
Herbert.Borchert@lwf.bayern.de

Abstract: *From time to time, windthrows or bark beetle outbreaks cause excessive timber harvesting in Germany. In this case the transport of wood by trucks often is the bottleneck within the process chain. The transporting capacity is not sufficient and the flow of the wood stalls. Regularly, the timber industry claims exceptions from the admissible total weight of trucks (40 tons). In the meantime truck companies face a lack of truck drivers. An upcoming shortage of transporting capacity during periods of normal timber harvesting is not unlikely. How can the transporting capacity be maintained? Is it possible to use the limited capacity more efficient? We conducted a written survey of truck companies operating in Bavaria and semi-structured interviews with experts from truck companies, from the wood processing industry and from forestry. We wanted to know, which measures the companies already practice to deal with the challenge. One option is the transport of logs by trucks and semi-trailers without a crane. Thus the payload can be raised, the purchase price is lower and truck drivers can be deployed who have not the skill to handle a crane. Waiting times on arrival at the plant are an ongoing problem. What is being done to reduce these delays? Can the processes and the communication between the participants be improved in order to save time when collecting the wood in the forests? What is the state of the art regarding route optimization? To what extend are foreigners, women and part-time workers deployed as truck drivers? The results indicate that except of periods of calamities there is rather on overcapacity of log transport services. The existing transport capacity can be used more efficient if waiting times at the mills are reduced, payloads increase and empty runs decrease. Delays within the supply chain can be reduced if the data will be exchanged between all participants in a digital format that enables an automatically further processing. A significant reduction of empty runs can be achieved by more collaboration between trucking companies or by a consolidation in the branch. A remarkable reduction of working times and nevertheless a payment of an appropriate salary would make the job more attractive. A more severe truck driver shortage might also be avoided when women are attracted for this job.*

Keywords: logistic, truck driver shortage, log transport capacity

1. Introduction

In case of unplanned excessive timber harvesting due to windthrows or bark beetle outbreaks foresters and agents from the timber industry in Germany complain a lack of log transport capacity. Regularly, they claim exceptions from the admissible total weight of trucks. In the meantime representatives from truck companies report a lack of truck drivers. A shortage of truck drivers seems to be a future challenge for all truck companies in Germany. The main reason is the demographic structure of the population. In total 555,010 truck drivers were deployed in Germany 2016 (BAG, 2017). About 154,000 truck drivers (28 %) were older than 55 years. Between 2010 and 2016 1,529 new truck drivers finished the apprenticeship per year. If there is a need to replace all retiring truck drivers, but the low rate of new truck drivers continues, a gap of about 139,000 drivers will arise in 2026. This calculation doesn't consider the increasing transport demand which some studies forecast (e. g. INTRAPLAN Consult, 2018). The German Federal Ministry of Transport and Digital Infrastructure expects an increase of transport services by 39 % until 2030 (BMVI, 2014). Thus a shortage of log transport capacity might become the bottleneck of the wood supply chain not only in periods of calamities. Witte (2019) reports complaints about a

shortage of log truck drivers also in other European countries. A shortage of truck drivers is even reported from the United States (Costello and Karickhoff (2019), Conrad, 2018). The objectives of our study were (1) to assess the current log transporting capacity, (2) to identify possible measures for keeping the existing capacity and (3) to detect how the limited capacity can be used more efficient.

2. Method

We conducted a written survey of truck companies operating in Bavaria referring to 2017. We tried to reach all trucking companies transporting logs of Bavarian origin. Our address pool comprised 480 companies based in Bavaria and the surrounding federal states. Three large saw mills and the Bavarian state forest enterprise also sent the questionnaire to the trucking companies operating for them. Two of the sawmills are processing softwood the other is processing beech. The questionnaire comprised questions regarding

- the volume of transported roundwood and the share of wood of Bavarian origin
- the number of employees
- the number and type of vehicles (trucks and trailers)
- the deployable radius
- the kind of customers
- the use of navigation devices, which allow a routing within the forest
- the use of software for disposal of the orders
- further business areas of the company
- the plan of carrying capacity changes
- the three most pressing problems and an
- open question about the trends and challenges.

In addition, the Bavarian ministry of transport disposed an enquiry of the vehicle licensing offices in Bavaria. The licensing offices reported the number of log trucking companies within their district, the number of truck and the size of these companies according to the number of trucks.
At two sawmills we recorded the time of truck arrivals over a whole day, the type of trucks and the gender of the truck drivers. We also conducted semi-structured interviews with experts from six truck companies, from six mills of the wood processing industry and from two forest organizations that manage the log transport themselves so that they are clients for the trucking companies.

3. Results and discussion

Some of the Bavarian district licensing offices (12 of 96) were not able to deliver data. We fitted this gaps with the mean of the data that we received by the reporting districts. The enquiry of the vehicle licensing offices revealed 278 log truck companies which have licensed their trucks in Bavaria. We received 97 questionnaires from log trucking companies. Table 1 shows the share of the participating companies according to the number of trucks.

Table 1: The number and sizes of truck companies transporting logs according to both surveys. The share of companies refers to those with assignable numbers of trucks.

Fleet size (number of trucks)	Survey of					
	vehicle licensing offices		log trucking companies			
			all answers		based in Bavaria	
	No. companies	share	No. companies	share	No. companies	share
Total	278		97		73	
1 truck	92	36%	23	24%	17	24%
2-3 trucks	74	29%	29	30%	22	31%
4-8 trucks	49	19%	28	29%	21	29%
9 and more	38	15%	16	17%	12	17%
not assignable	25		1		1	

The size structure of all participating companies and of only those based in Bavaria (73) is identical. The survey of the vehicle licensing companies shows a greater proportion of very small companies owing only one truck and a smaller proportion of big companies. This difference is plausible. In companies with only one truck the owner is mostly driving the truck himself. He is often bounded by the day-to-day business and might less likely response to surveys. Therefore we extrapolate our questionnaire results by company size groups using the number and distribution of the survey by the vehicle licensing offices. The licensing offices reported 1,009 trucks. The companies that responded to our questionnaire owned 417 trucks. The extrapolation by the number of companies in different size groups according to the survey of the licensing offices delivered a total of 1,025 trucks. Thus, both surveys nearly get to the same result. Nevertheless, the accuracy should not be overestimated. The vehicle licensing offices have neither a list about the kind of service the truck owner's offer nor a list that assigns the trucks explicitly as log trucks. Thus, the data is mainly based on their practical knowledge.

3.1 The capacity for log transport by trucks

3.1.1 Results from the survey

First we will estimate the volume of roundwood transported by Bavarian companies 2017.We will compare this volume with the removals. Then we will show the carrying capacity changes planned by the companies. We will report the assessment of the experts who we have interviewed. We will look at the freight rates. The price level can indicate if a shortage exists.

90 companies reported both, the amount of roundwood, which they transported 2017 and the number of trucks. We treated one company as an outlier because the amount of wood transported per truck seemed to be unrealistic. With 70,000 m³ it was almost the double of the second highest value. The considered companies transported a total of 5.9 million m³. Assuming that all roundwood was transported by trucks owned by each company the mean volume of roundwood is 15,466 m³ per truck. The amount of roundwood per truck declined with increasing company size (table 2). The smallest companies transported considerable more wood per truck than the others.

Table 2: The roundwood transported by companies of different size and the amount per truck.

Fleet size	Companies	Roundwood (m³)	Trucks	m³/truck	Difference to mean
1 truck	22	441,300	22	20,059	30%
2-3 trucks	28	1,100,000	66	16,667	8%
4-8 trucks	24	1,971,000	133	14,820	-4%
9 and more	15	2,411,000	162	14,883	-4%
Total	89	5,923,300	383	15,466	0%

The share of roundwood from Bavarian forest was 89 % of the total roundwood transport volume from Bavarian companies. There was hardly any difference of this proportion between companies of different size (min. 86 %, max. 92 %). An extrapolation of the mean amount of roundwood per company and size class by the number of companies based in Bavaria delivered a volume of 15.8 million m³. The share of wood from Bavaria is 14.0 million. An extrapolation of the mean amount of roundwood per truck and size class by the number of trucks of companies based in Bavaria delivers a volume of 16.1 million m³. The share of wood from Bavaria here is 14.2 million m³. Companies that participated in our survey and are based in neighboring countries transported a volume of 0.28 million m³ roundwood of Bavarian origin. We don't know the amount of roundwood of Bavarian origin that was transported by other companies not based in Bavaria and not participating in our survey. But according to our calculation more than 14 million m³ of Bavarian roundwood must have been transported.

We asked the log trucking companies in the questionnaire about their planning for carrying capacity changes in the next 5 years. Almost all companies (97 %) responded this question. Table 3 shows the extrapolated results, both referring to the share of all companies and to the share of currently owned trucks by the companies. The most companies want to keep their capacity. 6 % are planning to abandon it,

but they hold only 3 % of the trucks. The proportion of companies that are planning capacity reduction is greater than the share of companies willing to increase. The companies that want to reduce the capacity own slightly less trucks than those willing to grow. Because we don't know the intended changes of truck numbers, we can't conclude, if the capacity is going to grow or to decline. But table 3 indicates a process of consolidation. Some respondents commented their decision. One intended to reduce although he doesn't want, because of a lack of drivers. Another wants to maintain, provided he has enough drivers.

Table 3: The plan for carrying capacity changes.

Share of	Transport capacity within the next 5 years			
	increase	maintain	reduce	abandon
companies	9%	70%	22%	6%
owned trucks	11%	71%	18%	3%

The experts from the wood processing industry didn't recognize a shortage of wood transport capacity at the time of the interviews. But they reported from temporarily and regional shortages especially after calamities. One expert from a hardwood sawmill told about seasonal shortages every year in spring. The experts expected a shortage of transport capacity in the future due to a truck driver shortage.

We asked the experts the freight rate for a transport distance of 100 km. They stated a range of 10 to less than 13 €/m³ without reimbursement of toll.

We asked the log trucking companies in the questionnaire about the three most pressing problems they face. We offered the following answers: (1) to low freight rates, (2) lack of qualified employees, (3) cheap competitors because of the EU eastward expansion, (4) weight problem, overload, (5) consolidation process in the wood industry (6) difficulty to pass on cost increases to customers (e. g. toll, diesel price) and (7) others. A quarter of the companies named more than three problems. In these cases we reduced the weight of their designations so that the sum always was three. The most often chosen problem was 'to low freight rates' (78 %) followed by the 'difficulty to pass on cost increases' (74 %). A 'lack of qualified employees' ranged on the fourth place (53 %) after the weight problem (58 %).

3.1.2 Discussion of the transport capacity

In 2017 only 23 % of the removals in German forests were unintended, caused by storm, snow or insect damage. No cross-regional forest calamity occurred. Thus it is plausible that the Bavarian log trucking companies transported to a great share wood from Bavarian origin. The removals of wood in Bavarian forests were 17.9 million m³ in 2017 (Statistisches Bundesamt, 2018). The amount of saw logs and pulpwood was 11.1 million m³. So there is a gap of about 3 million m³ between the amount of saw logs and pulpwood delivered from forests and that transported by truck companies. There are different possible reasons for this gap. Comparisons with results from national inventories in the past indicate that the statistical office doesn't cover all removals. In addition, it might be that also some energy roundwood was transported by log trucks to destinations were it was processed to firewood. Moreover, some of the wood might have been transported twice. If logs are transported to storage yards, e. g. for wet storage by irrigation, they have to be transported a second time when delivering the logs to the mill. But we don't know about large amounts of wood stored in such yards 2017. Another reason might be double counting. We asked in the questionnaire: 'How much roundwood did your company transport 2017?' Some companies might have engaged subcontractors but assigned the wood to their own company. Some companies might have delivered wood by rail. Our question should have been more specific. The largest considered amount of roundwood transported per truck was 36,000 m³. This amount seems to be great but still possible.

Overall, the results indicate that the capacity in Bavaria meets the transport need in years of normal wood removals. But the amount of roundwood transported per year doesn't indicate the performance of the log trucking companies. An indicator of the performance has to consider both, the amount of transported wood and the transport distance. Further surveys in future should also ask the mean transport distances.

The freight rates named by the experts seem to be realistic. Becker (2019) asked for freight rates of log trucking companies. He conducted a written survey of log trucking companies in Germany in 2018. 30

out of 34 participants answered this question. The mean freight rate they named was 12.68 €/m³ for a distance of 100 km. He also asked for a sufficient freight rate. The mean of the adequate rate was 25 % higher than the current rate. The transport tariffs in Germany were deregulated 1994. Since then the freight rates are formed on a free market. Lücke and Weber (1998) reported freight rates of 9,71 €/m³ for a distance of 90 to 100 km and 11,52 €/m³ for 101 to 150 km in Rhineland-Palatinate in 1994. Thus, the freight rates have hardly changed within the last 25 years. This indicates that there is currently rather an over-capacity on the market of log transport services.

3.2 Efficient use of existing transport capacity

3.2.1 Delays at the mills

When log trucks are arriving at big mills, registration and unloading is often delayed. We asked the companies in the questionnaire which additional amount of logs they can transport, when there are no delays at the mills. 81 % of the participating companies answered this question. We deemed two statements as outliers, because they differed far more from the mean than the threefold standard deviation. Extrapolated by the company size classes and transport volume an additional amount of 11 % roundwood could have been transported. The percentage rate in the size classes varied between 11 % and 14 %. The coefficient of variation in the size classes is high (70 % to 94 %).

We recorded the number of unloaded trucks per hour during a whole working day at two big sawmills in the winter 2018/2019. At one sawmill the record could start for safety reasons only with a delay of one hour in the morning. At one mill 110 and at the other 98 trucks were registered. Fig. 1 shows the distribution of the unloading during the day. We can see a peak of unloading early in the morning and at noon. During the late afternoon only few trucks were cleared.

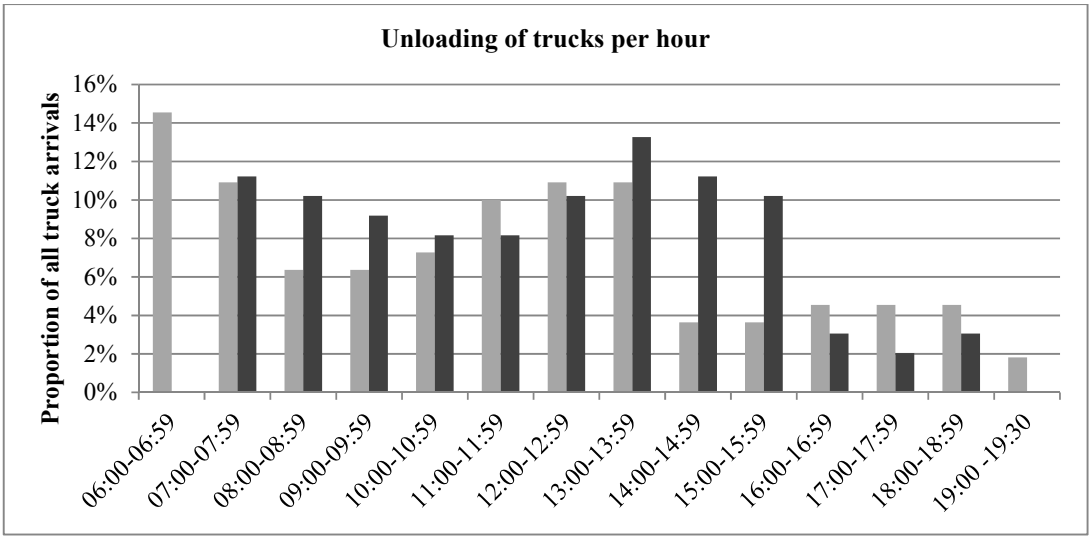


Fig. 1: Distribution of the unloading of trucks during a whole day at two large saw mills in Bavaria. At one sawmill the first hour is missed.

During the truck counting different delay reasons were observed. Due to technical failures no or not enough unloaders could operate. Trucks without their own crane had to wait. Also technical failures at the conveyor band or the sorting facility caused delays. The sawmill staff makes a half an hour break in the morning and in the afternoon. The trucks have to wait so long. An arriving train should be unloaded with priority. Therefore the trucks were restricted to deliver the logs only from one site to the sorting facility.

Experts from the truck companies told us that they try to deliver three loads a day and therefore start very early in the morning. They try to avoid the rush hour traffic around the big cities in the morning. Thus, many trucks arrive when the sawmill opens the gate in the morning. Some experts stated that some sawmills reduced the space of the storage yards at the mills. Instead they built e. g. new facilities for a pellet production. Experts from the mills conceded the delays. Only the experts of a large hardwood

sawmill neglected any delay. There they discount the logs by the measurement of the forest owners. So they don't have to separate the loads for the measurement in the mill and they have plenty space at their storage yard. None of the visited mills have established a system of time slots for the clearance of the trucks although they seem to discuss it from time to time. Due to the dense traffic in Central Europe and the frequent traffic jams the exact time of arrival is often not foreseeable. So far none of the mills tried to distribute the arrivals more evenly by financial incentives (e. g. a freight rate depending on the time of arrival). The experts from the forest organizations declared that the delays are caused by management failings. Some mills have unfavorable conditions like few storage space but are well managed and have therefore little delays. Others have much storage space but are poorly organized and therefore much delays.

Waiting time at the mills can also be reduced by a faster registration. At some mills the truck drivers deliver a hardcopy of the delivery note and the sawmill staff records the data in the EDP system. At other mills the truck drivers have to type at terminals the data by themselves into the system. An online transmission of the delivery note in a format that can be automatically processed further could speed up the registration. Some forest organizations and sawmills are currently trying to establish this data transfer. The German ELDATsmart offers a data format that allows each link in the supply chain the automatically processing of transferred data.

We can conclude that the transport capacity is better exploit to a relevant degree, if delays at the mills decrease.

3.2.2.1 Extending the payload

The legally admissible total weight of trucks inclusive trailers is 40 tones in Germany. The lower the tare weight the bigger can be the payload. Of course, a lightweight construction of trucks and trailers can help to reduce the tare weight. A remarkable reduction can be achieved, if no crane is mounted at the truck.

When asking for the number of trucks we distinguished in the questionnaire between trucks having a mounted log carrier for short logs from cut to length harvesting and truck tractors hauling semi-trailers and trucks for the transport of long logs. The long log trucks can be both, trucks hauling semi-trailers and trucks pulling a dolly. Table 4 shows the number of different trucks in Bavaria according to our questionnaire and extrapolated by the fleet size structure of the companies reported by the licensing offices.

Table 4: The number of trucks in Bavaria grouped by companies of different size and kind of truck.

Fleet size (number of trucks)	Short log trucks	Long log trucks	Truck tractors	Others	Total
1 truck	44	20	12	16	92
2-3 trucks	107	28	31	8	174
4-8 trucks	137	54	77	2	270
9 and more	185	28	185	0	398
not assignable	47	13	30	3	92
Total	519	143	335	28	1,025

The licensing offices reported 521 trucks and 488 truck tractors, overall 1,009 trucks. The licensing offices didn't assign the number of trucks to the size of the companies. Noticeable in table 4 is the greater share of truck tractors in the largest companies (46 %) than in the smaller ones (22 %). The licensing offices reported 636 trailers and 319 semi-trailers. We asked in the questionnaire only for semi-trailers and extrapolated count 466 of them. The largest companies having 9 trucks and more owned 59 % of the semi-trailers.

The kind of truck and trailer combinations recorded during the tuck arrivals at two large sawmills processing softwood of cut-to-length logging is shown in table 5. In total 190 combinations were identified. Trucks with a mounted log carrier and with a trailer dominated by far. Nearly all of these

combinations had a mounted crane. In the combination of truck tractor and semi-trailer only about one fifth had a crane mounted on the truck.

Table 5: The truck and trailer combinations recorded at two softwood processing sawmill.

Truck trailer combination	Share of observations
Truck tractor with crane and semi-trailer	5.3 %
Truck tractor with semi-trailer, but no crane	18.4 %
Truck with a mounted log carrier and crane and with trailer	73.7 %
Truck with a mounted log carrier and trailer, but no crane	0.5 %
Others	2.1 %

According to the information given by the experts there are different ways of loading trucks without a crane. (1) A truck tractor equipped with a crane loads a semi-trailer and parks it at a suitable place in or close to the forest. On this way the total weight is bigger than the admissible load on public roads. A truck tractor without a crane picks the semi-trailer up and brings it to the mill. Usually one truck tractor equipped with a crane supplies some truck tractors without a crane. This combination requires a certain spatial concentration of wood amount. But it ought to be profitable even in case of short transporting distances, e. g. to a railway station. (2) A truck with a mounted crane loads its own log carrier. At a suitable place the truck loads the logs from its carrier to a semi-trailer. This operation requires enough space so that both vehicles can stay side by side. If the crane is mounted at a proper place, both vehicles can also meet backwards on a forest road for reloading. (3) In principle, a forwarder can load a truck too. In this case logging and the transport to the customer are linked operations. So far, this linkage is unusual in German forestry. According to one expert this linkage was tested in a trial at that time. (4) If the logs are concentrated at a storage yard in or close to the forest, the semi-trailers can be loaded by a loader, e. g. an excavator equipped with a gripper.

All experts from the industry and from forestry reported an increasing share of the combination ‘truck tractor without crane and semi-trailers’. Only at one mill they have hardly any deliveries of this kind, because they don’t provide a loader for unloading.

The tare weight of the combination of ‘truck equipped with a crane and trailer’ varies according the expert information between 16 and 22 tones. The combination of a ‘truck tractor without a crane and semi-trailer’ has a tare weight of about 13 tones. Thus the payload can increase by 3 to 9 tones, respectively 12.5 % to 50 %. Other advantages named by experts are reduced purchase prices, reduced fuel consumption and no demand of crane handling skills of the truck driver.

3.2.2.2 Discussion of payload extension

Experts expect a raise in the share of trucks without crane in the future and thus a further extension of payload. Becker (2019) asked in his questionnaire the fleet size of the companies 2012 and 2017. The share of trucks without a crane of all recorded trucks increased from 28 % in 2012 to 29 % in 2017. Thus his data don’t confirm a remarkable increase during the last years. Mainly large companies participated in Becker’s survey. 58 % of the companies had a fleet size of 4 and more trucks. The acquisition of trucks without a crane should be more likely in big companies, because loading can be more easily organized there. Thus it can’t be expected that a greater capture of small companies in his survey would have resulted in a higher share of trucks without a crane. So his results indicate that the rise in share of trucks without a crane took place before 2012 and since then there was no big change anymore. It is difficult to judge, if there is an additional potential for the use of trucks without crane. A further consolidation of the branch might go hand in hand with a growing share of these trucks. But a growing share of these trucks restricts the companies to orders from big mills, because only big mills can provide the machinery for unloading trucks without cranes. Small or medium mills cannot afford these machines.

3.2.3 Reducing empty runs

Empty runs can be reduced by return freights or by round trips. According to the interviewed experts return freights are rarely offered. One expert of a sawmill estimated the proportion of return freights to

5 %. Only some log carrying trucks are suitable for the transport of products of the wood processing industry. The transport of sawn wood requires a mounted platform. In one sawmill they insist on the possibility to take down the stanchions of the truck carrier. Otherwise the risk of damage to the sawn wood is too high. The transport of paper requires a closed truck for safety reasons. Thus paper can't be transported by common log trucks. Empty runs can be reduced by a clever combination of orders. The bundling of log piles to orders and their allocation to trucking companies with the objective of shortening the transport distances and avoiding of empty runs is a classical traveler salesman problem which can be solved by methods of operation research. Of course, only mills with different subsidiaries and forest organizations which deliver wood to different mills can substantially reduce empty runs. All clients of trucking companies told us that they don't apply optimization methods for the purpose of empty run reduction. The most trucking companies work for different clients. So it is for the trucking companies to optimize their routes. The route planning can be supported by tour planning software. The larger the pool of orders of different clients the easier the route can be optimized. The dominance of small scale companies is an obstacle for route optimization. The pool of orders can be extended by both a consolidation of the branch and by cooperation between companies.

We asked the companies in the questionnaire if they use a software for disposal of orders. Weighting the answers by the fleet size structure of the Bavarian companies, 11.5 % of the log trucking companies uses such software. But this result doesn't disclose how sophisticated the software is. Some respondents might have meant even a simple spreadsheet program.

According to the survey of Becker (2019) empty runs have a share of 44 % what has to be deemed as a high proportion. None of the companies participating at Becker's (2019) survey uses a tour planning software. The trucking companies have in the mean 12 different clients. Only 6 from 34 companies (18 %) in his survey cooperate with other trucking companies to avoid empty runs.

3.2.4 Facilitating the loading in the forest

In Germany logs are usually piled along forest roads and not at landings. At each place of loading some work steps have to be done which are independent of the loading amount such as climbing the crane, extending the outriggers and possibly cargo securing. Experts from the trucking companies complained the frequently scattered small log piles. A more concentrated storage of logs (minimum a truck load) would help to reduce the loading times substantially. Sometimes log piles are stored along roads which are not suitable for traffic of heavy trucks. This can extend the travelling time, e. g. salvage of trucks being bogged down, can cause damage to the trucks or cause unnecessary empty runs in case the truck has to return unloaded. They also complained about twigs and branches growing within the crane range and hindering the loading. Forest owners or forest owner associations mostly send the notification about log piles ready for removal by e-mail in a pdf-format or by fax to the mills and the mills hand them over to the trucking companies. In case of a poor data quality searching for the piles can be difficult and cause delays. Even if the position coordinates are given, they can be wrong due to transposed digits if they were manually typed. Here it is important that the coordinates are transmitted directly by the recording device. The forest owners should transmit the notifications of removable piles online in a format that can be automatically processed further. A suitable format already exists (ELDAT-smart). Delays caused by difficult orientation can be avoided if the truck drivers use a navigation system which works also within the forest. We asked in the questionnaire if the trucking companies use a navigation device which can guide the drivers along the forest road to the log piles and we added in brackets `routing by NavLog-data´. NavLog is a German application that classifies forest roads according to the road quality and attributes traffic restrictions like restricted permissible weight for bridges and restricted turn opportunities within the forest. Weighting the answers by the fleet size structure in Bavaria, 26 % of the log trucking companies uses a navigation system which works within the forest. This is more than expected, but there is still a great growth potential.

3.3 Maintain the transport capacity

The last question in our questionnaire was an open question about the trends and challenges which the trucking companies face. 48 % of the companies named an upcoming shortage of truck drivers as a challenge. Freise et al. (2015) asked 122 German log trucking company's number of drivers within different age classes. The companies assigned 1,043 drivers to age classes. Weighting the employees by

the center of their age class the mean age was 45 years. Becker (2019) asked a similar question. There the companies assigned 688 employees to age classes. 68 % of the employees were truck drivers. Weighting the employees by the center of their age class the mean age was 46 years. The mean age of the drivers seems to rise slightly in the course of time. Costello and Karickhoff (2019) also state the demographic structure of the truck drivers in the US as a primary reason for the shortage. There the 'median age of over-the-road truck drivers is 46'.

3.3.1 Exploiting the labor market potential

The national office of freight transport (BAG 2017) recorded that female have a share of 1.7 % of all truck drivers in Germany. During the truck counting in two mills we also recorded the gender of the truck drivers. Due to the short period of daylight in winter we could only recognize the gender from a part of the arriving truck drivers. There were only two female among 131 truck drivers what mean a share of 1.5 %. All experts confirmed that the share of female truck drivers is extremely low. The main reason quoted was the hard work in particular the moving of stanchions and the mounting of snow chains. Witte (2019), a manager of the EGGER group, stated that the log trucking branch is so far excluding half of the labor market, because it does largely without women. Costello and Karickhoff (2019) reported that only 6.6 % of all truck drivers in the US are women. They deem this also as a primary reason for the shortage there.

We also asked the experts about the share of part time workers among truck drivers. They assessed the share as very low. Sometimes, retired persons work part time as truck drivers. In family business sometimes relatives stand in if there is a need. This can also be deemed as a part time work. The national office of freight transport (BAG 2017) states that part time workers have a share of 5.7 % among all truck drivers. The German national statistical office (DESTATIS 2019) reports that 38 % of all employed women worked on a part time basis whereas male had a share of only 5 % part time workers. The offer of part time jobs probably is the key to attract more women for the profession of a log truck driver.

Foreign workers can be a further source of employees. The additional potential of workers from eastern European countries might not be large. Witte (2019) reported that in some eastern European countries the log trucking companies also complain a shortage of truck drivers. The experts from the wood processing industry told us that the share of foreign drivers is greater among trucks that transport the mill products compared to drivers from log trucking companies. Thus, the potential of foreign workers seems to be not completely exploited.

Some experts see a chance to extend the pool of possible drivers by decoupling the loading of logs from the log transport. The labor market comprises much more truck drivers who don't have the skill of handling a crane.

3.3.2 Improving the attractiveness of the log truck driver profession

Witte (2019) reported from a survey of the log trucking companies operating for the European subsidiaries of the EGGER group. According to this survey the hourly wages of the truck drivers are highest in the United Kingdom followed by France. Germany is in the middle range. In Poland, Romania and Russia the hourly wages are significantly lower. The monthly salary in Germany is rather high. Also Burckhardt (2019) reported a high monthly salary of drivers from log trucking companies in Germany. How can the log trucking companies afford high monthly wages although their revenues stagnate for about 25 years? The reason is the long working time of log truck drivers in Germany. The experts from the log trucking companies complained about the many hours they have to put into the job. One expert stated that work shifts of 13 hours a day are usual. According to the survey of Becker (2019) the mean weekly working time of the log truck drivers was 53 hours. Also Witte (2019) confirmed extremely long working times of German truck drivers. According to Witte (2019) the log trucking companies in the United Kingdom complain the least about a truck driver shortage what goes hand in hand with the better payment there. Costello and Karickhoff (2019) name a driver pay increase as a market reaction to the driver shortage in the US. Interestingly, also some experts of the wood processing industry consider a pay rise as necessary. Probably, there is no need for higher monthly salaries of truck drivers. But a significant reduction of the working times to a normal level would make the job more attractive. Keeping the salaries stable and reducing the working time needs increasing freight rates. With respect to the unsymmetrical

market power with a lot of small trucking companies on the one hand and big mills on the other it might be difficult to enforce a freight rate increase.

The attractiveness of a profession also depends on how the staff is treated. The experts from the industry were aware of this aspect and have already taken different actions so that the drivers can feel more comfortable during their stay in the mill. In forestry the acceptance of foreign truck drivers could be improved as well as the behavior when language barriers occur. Costello and Karickhoff (2019) also name a better treatment of truck drivers at shipping and receiving facilities as a mean for improving the job attractiveness. They also count a reduction of wait times to such measures.

4 References

BAG, Bundesamt für Güterverkehr (Hrsg.) (2017): Marktbeobachtung Güterverkehr Auswertung der Arbeitsbedingungen in Güterverkehr und Logistik 2017-I – Fahrerberufe-

Becker, F. (2019): Holztransportgewerbe – Das Nadelöhr zwischen Wald und Werk. Eine Umfrage zur aktuellen Situation der Holztransportunternehmen. Masterthesis an der Fachhochschule Erfurt. 83 S.

BMVI, Bundesministerium für Verkehr und digitale Infrastruktur (2014): Verkehrsprognose 2030 https://www.bmvi.de/SharedDocs/DE/Pressemitteilungen/2014/044-dobrindt-verkehrsprognose2030.html clicked on 04.03.2019

Burckhardt, M. (2019): Managing director of the national association of log trucking companies in Germany: Oral statement.

Conrad, J. L. (2018): Costs and challenges of log truck transportation in Georgia. Forests 9(10), 650. https://doi.org/10.3390/f9100650

Costello, B.; Karickhoff, A. (2019): Truck driver shortage analysis 2019. American trucking association. 16 p.

DESTATIS, Statistisches Bundesamt (2019): Kernerwerbstätige in unterschiedlichen Erwerbsformen (atypisch Beschäftigte) nach soziodemografischen Merkmalen und Wirtschaftsabschnitten. https://www.destatis.de/DE/Themen/Arbeit/Arbeitsmarkt/Erwerbstaetigkeit/Tabellen/atypische-beschaeftigung.html clicked on 12.04.2019

INTRAPLAN Consult GmbH (2018): Gleitende Mittelfristprognose für den Güter- und Personenverkehr - Kurzfristprognose Sommer 2018, München /Köln, September 2018

Lückge, F.-J.; Weber, H. (1998): Ökonomische und ökologische Optimierung von Rundholztransporten - dargestellt am Beispiel der Holzvermarktung der Landesforstverwaltung Rheinland-Pfalz im Forstwirtschaftsjahr 1994. Allg. forst- u. J.-Ztg., 169 (1), S. 1-4

Freise, L.; Ohnesorge, D.; Prawdzik, P.; Kopetzky, M.; Degen, J. (2015): Optimierung des Holztransports in Baden-Württemberg – Ergebnisse einer Umfrage zur Wettbewerbsfähigkeit des Holztransportgewerbes. Bericht, Ehingen, Freiburg und Berlin.

Statistisches Bundesamt (2019): Forstwirtschaftliche Bodennutzung – Holzeinschlagsstatistik Fachserie 3 Reihe 3.3.1

Witte, C. (2019): Sicherung der Rohstoffversorgung – Herausforderungen, Lösungsansätze und Maßnahmen der Holzindustrie. Vortrag auf der Tagung „Ressource Holz“ des Fraunhofer Instituts für Fabrikbetrieb und –automatisierung am 4.04.2019 in Hundisburg.

5 Acknowledgments

This study was funded by the Bavarian State Ministry of Food, Agriculture and Forestry.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

LOGISTICS OF SUPPLING WOODY BIOMASS LONG DISTANCE USING RAILROAD TRANSPORTATION

Jeff Halbrook, Han-Sup Han
Ecological Restoration Institute, Northern Arizona University, Flagstaff, AZ, USA
Jeffrey.Halbrook@nau.edu

Abstract: *Northern Arizona, similar to many states in the western US, is threatened by catastrophic wildfire and the impacts of subsequent flooding that follows. Without a local forest products industry, the economics of utilizing woody materials is poor and forest restoration and fuel reduction thinning activities are being delayed. Truck and trailer combinations are the predominant method of transporting woody biomass from the woods to a manufacturing facility. There are however, several issues associated with truck transportation such as availability of workers, fuel use, traffic, and weight limits that make this mode of transportation economically challenging; particularly as transportation distances increase. These are significant challenges as truck transportation often accounts for more than 50% of the total forest biomass supply cost (stump-to-facility). Railroad transportation may be a solution. Rail transportation is three times more fuel efficient compared to trucks, and each train can remove more than 280 long haul trucks from roadways. Northern Arizona is traversed by the Burlington Northern Santa Fe (BNSF) Transcontinental Railway; a rail system that connects much of the US to the 2nd largest shipping container port in the US. A pilot project is underway to explore the logistics associated with chipping and shipping 2300 tons of wood chips from Arizona to South Korea utilizing intermodal (commonly called "Shipping") containers. Logistics include transporting logs from forest restoration treatment sites to Camp Navajo, a local Arizona Army National Guard facility, with an extensive rail spur network. Logs will be chipped and loaded into bottom dumping coal cars and transported to Long Beach, CA where they will be loaded into intermodal containers and shipped via marine transportation to South Korea. Basic economic statistics associated with the operation (cost to haul, chip, load, transport by rail and fill containers) will be collected which will assist managers seek alternatives such as increasing rail car capacity, changing container loading sites, and exploring delivery logistics that improve economics. By increasing access to Asian markets through rail transportation, communities across the western US may find uses for an overabundant woody supply thus decreasing the risk of catastrophic wildfire.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanization of the Future
6-9 October, 2019 - Sopron, Hungary

OPERATIONAL EVALUATION OF A TIMBER TRAILER WITH THE HYBRID DRIVE

Tomáš Zemánek*, Jindřich Neruda, Radomír Ulrich
Department of Engineering
Faculty of Forestry and Wood Technology
Mendel University in Brno
Zemědělská 3, 613 00 Brno, Czech Republic
tomas.zemanek@mendelu.cz

Ondřej Vítek*, Petr Procházka
Department of Power Electrical and Electronic Engineering
Faculty of Electrical Engineering and Communication
Brno University of Technology
Technická 12, 616 00 Brno, Czech Republic
viteko@feec.vutbr.cz

Abstract: *This paper deals with the operational evaluation of a timber transport unit equipped with a hybrid drive. The front wheels of a twin axle trailer with a payload of 10 tons was driven by a system consisting of a hydraulic motor and hydraulic pump powered by an electric engine supplied from a system of accumulators. The accumulators were recharged from the energy of non-intensive operational machine modes by an electric generator powered by the hydraulic system of the tractor. We studied the influence of the hybrid drive on the trailer in regards to the energy intensity of travel, the tensile force of the machine, the slip of the chassis wheels and fuel consumption. The electric drive of the axle on a loaded trailer was capable of boosting the machine performance by nearly 18 kW. While travelling up a slope and switching on the trailer's electric drive, we recorded that the prime mover's fuel consumption decreased by 35 % and the wheel slip decreased by 85 %.*

Keywords: tractor**,** timber trailer, hybrid drive

1. Introduction

A tractor and trailer timber transport unit is used for chokerless skidding by hauling in short-length logging operations. The tractor and trailer unit for timber transport combines an agricultural tractor as the prime vehicle and the trailer as the cargo space. The required engine performance of an agricultural tractor is from 50 kW to 110 kW in relation to the trailer size. The trailer has mostly a mechanically or hydraulically powered twin axle. Lower payload trailers can even be equipped with an unpowered twin axle. In the case of a hydraulic drive, the hydraulic motors are typically situated in the wheels of the twin axle. For short-time use (overcoming uneven terrain), an auxiliary hydraulic drive can be applied, with traction rollers (so-called Robson drive) introduced after activation in the tire tread pattern. A trailer's dead load usually ranges from 1 to 6.5 tons and a payload is 7 – 15 tons.

Basically, any vehicle power train is required to develop a sufficient power to meet the demands of the vehicle's performance, to carry sufficient energy onboard to support the vehicle travelling a sufficient range, to demonstrate high efficiency, and to emit few environmental pollutants (Ehsani et al., 2004). New solutions were sought for vehicle driving systems with respect to the diminishing crude oil supplies in the world, the growing price of fuels, increasing environmental pollution, global warming, and hence

the pressure on reducing the exhaust emissions. In modern history, the concept of the hybrid electric vehicles started to develop in the 1990s namely in passenger cars.

Electric drives are already quite common in application with it heavily converted into electric energy. The regenerated energy is stored in the capacitor and can be used to swing, or vehicles (Ponomarev et al., 2014; Pohlandt, Geimer, 2015). The main motivation is to reduce the fuel consumption, plus to enhance short-time machine's performance or possibly also to use a smaller engine. Furthermore - the use of a downsized engine will possibly result in a more compact machine layout and for example better visibility and agility of the machine as well as in a reduction of noise and vibration levels at the operator's station (Einola, 2013). One of the first applications of the hybrid drives was implemented in the construction machinery, namely in excavators. In the Komatsu excavator hybrid system, the electric swing motor-generator captures and regenerates energy as the upper structure slows down and by the use of the generator-motor helps the engine accelerate (Komatsu, 2017). Ishida and Higurashi (2015) described the mode of using the hybrid drive in Hitachi wheel loaders. Two traction motors are driven by electric power from the generator, which in turn is driven by the engine. Traction motors are used as generators during deceleration to store the regenerative energy as electrical energy in the capacitor so that it can be reused when accelerating. Minav et al. (2010) theoretically estimated the possibilities of energy recovery in the main cylinder of a forwarder boom based on forklift data. According to their findings, the energy efficiency of the whole system could be improved by 10 %.

One who has extensive experience in the development of the hybrid systems in forestry is the Swedish company Elforest Technologies. They currently offer a complete system design with customized energy storages based on batteries or super capacitors. Elforest Technologies developed and manufactured the first forwarder in the world with the electro hybrid system for the drive transmission and boom. The Company's electric hybrid system merchandized as Elturbo was tested also on the Ponsse Ergo harvester. Elturbo technology assists the diesel engine during sudden and high loads. An electric motor can, in contrast to diesel engines, change its torque very quickly. Elforest's Elturbo, which is mounted on the outgoing shaft of the diesel engine, reacts to the smallest deviations in RPM and instantly adds torque to help maintain the RPM until the diesel engine can handle the load by itself. The result is a very even RPM even when loads are high and sudden (Elforest Technologies, 2015). The Elforest Technologies hybrid systems are used in heavy forestry machinery also by EDILOG and Engbergs loghandlers.

A Finnish company LOGSET OY offers two models of harvesters with the hybrid system based on the electric motor and super capacitators used for energy storage. When the engine load is normal, the electric motor functions as a generator charging the supercapacitors. For a peak engine load, the electric motor discharges surplus energy to provide additional torque to pumps. The engine load is kept constant, which reduces emissions per felled cubic meter (LOGSET OY, 2019).

The utilization of the electric drive in the doubled car axis allows immediately the increase in the maximum power of the whole drive in extreme conditions. The auxiliary hybrid drives are not commonly used in timber trailers. There are several hybrid solutions mainly focused on the lifting or chipper function of the trailer, where the hybrid drive is used to reduce the total dimensions and weight of the hydraulic components as well as the total fuel consumption (Minav et al., 2010) and (Prinz, 2018). Our hybrid solution is focused on the auxiliary hybrid drive to provide additional energy during the timber movement and is based on the standard hybrid architecture discussed in Fig. 1. The duty cycle of a forwarder or vehicle train consists of several operations whose representation differs in relation to the operator's skills, cargo space size, parameters of logs, their concentration and hauling distance. A non-negligible share of time in the forwarder duty cycle is spent on the work of the hydraulic crane on loading and unloading logs. In the literature, information is given about a wide range of these values from ca. 48 % (Sánchez-García et al., 2016) up to 80 % (Ghaffariyan et al., 2012). During this operation, the diesel engine is usually loaded by the way not allowing passive regeneration of the solid particles filter, which reduces its service life. These are exactly the moments when the hybrid drive concept presented by us uses the free performance capacity of the diesel engine to recharge the system of the accumulators. Thus, the optimization of the operational load on the diesel engine during the machine duty cycle allows the passive regeneration of the solid particles filter and hence a longer service life for it. Other expected benefits of forwarders with trailers equipped with the hybrid drive include the possibility for using a

prime vehicle with the lower engine power. A fact that will favourably reflect in the machine purchasing costs, and the positive affect at the same time the fuel consumption, too. The lower consumption of fuel then entails also the lower production on emissions.

2. Material and methods

The hybrid drive was installed into a trailer with the payload of 10 tons, a width of 2400 mm and a twin axle with tires 500/45 R22.5. The total load on the wheels of the front axle of an unloaded trailer was 2500 kg; the total load on the wheels of the rear axle was 2600 kg. The basic principle block diagram of an electric timber trailer drive is shown in Fig 1. The electric drive can be split into the control and power part. The power part consists of an electric source (lithium accumulator (2)), which is able to feed the electric drive as well as to store electric energy during the braking of the trailer. The battery is kept in an almost fully charged state by using the electric generator (1), which is driven by a hydraulic motor fed by the tractor's hydraulic pump. The battery is charged during the reduced power demands on the tractor's power (drive with an empty trailer, wood loading). The battery consists of 60 LiFePO4 CALB L135F172 cells connected in a series and a parallel combination (three parallel sections consist of 20 cells in series connection). The battery voltage is 73.6 V with a total capacity 216 Ah (ca 16 kWh). The generator and two electric motors (7, 8) are chosen as a three phase induction machines. The three phase DC/AC inverters (2, 5, 6) ensure proper control of electric motors and the generator in all operational modes (motor/generator mode). The whole power circuit is protected by the power fuse. Simultaneously, it is possible to disconnect the electrical source (accumulator) from the electric drive by the power circuit breaker. The control part consists of the main microcontroller, which controls all the power parts and sensors of the electric drive together and cooperates with the higher control system of the timber trailer.

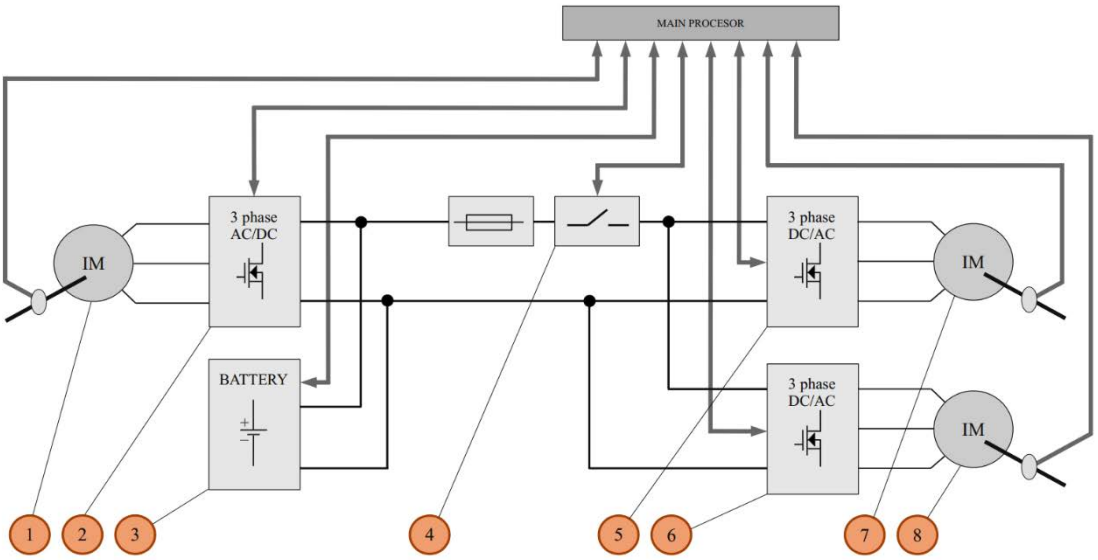


Fig. 1 Block diagram of the hybrid trailer drive

The chosen three phase DC/AC inverter is based on the low voltage MOSFET semiconductor technology; its parameters and the parameters of the induction machines are summarized in Table 1.

The prime vehicle was an agricultural tractor (engine power 97 kW) with the switched-off front axle drive. After the connection of the unloaded trailer, the load on the front axle with the 14.9-28 tires was 3600 kg and the load on the rear axle with the 18.4-38 tires was 5400 kg. For indicative determination on the average fuel consumption in *l/hr* we used data from the on-board computer of the tractor.

Table 1 - Motor and three phase DC/AC inverter parameters

Motor parameters 1AY132M-4		Three phase DC/AC inverter parameters.	
Power	15 kW	Minimum operational voltage	18 V DC
Voltage	48 V	Maximum operational voltage	84 V DC
Frequency	100 Hz	Nominal power	24500 W
Nominal current	275 A	Current	340 A
No load current	169 A	Peak power (10 sec)	28800 W
cos ϕ	0.72	Peak current (10 sec)	500 A

The effect of the trailer hybrid drive on the energy intensity of travel, tensile force of the machine, slip of chassis wheels and fuel consumption was studied during field measurements on polygons test on the premises of Masaryk Forest Training Forest Enterprise operated by Mendel University in Brno. The measurements were taken on the private paved (asphalt macadam) road with the gradient of 6.2°. The trailer was loaded with fir roundwood (length 4 m) and the cargo weight was 5700 kg. The vehicle's train weight was determined by weighing the load of individual vehicle train wheels on a Haeni ramp scale with the measuring range of 0 – 5 tons. The energy intensity of the travel of the forwarder with the trailer hybrid drive was calculated based on the values of hydraulic fluid pressure and flow. Pressure sensors HT-PD ISDS (0 - 600 bar) and flow sensors (turbine ISDS, 9 – 300 l/min) were placed between the hydraulic pump and hydraulic motor in three hydraulic circuits (electric generator, and driven wheels of the left and right parts of the trailer's twin axle). The sensors were interconnected with the MultiHandy 3010 recording unit. The data was evaluated in the Hydrocom programme. Mean values of hydraulic fluid pressures and flows were used to calculate (see Equation 1) power input values provided to the hydraulic motors on the trailer chassis wheels and to the hydraulic motor of the electric generators in individual situations. The manufacturer of the used hydraulic system claims its efficiency to be 85 % and the symmetrical distribution of losses between the pump and the motor.

$$P = pQ\eta \qquad (1)$$

where: P is power input transmitted by the hydraulic fluid *[W]*, p means hydraulic fluid pressure *[Pa]*, Q means the hydraulic fluid through-flow $[m^3.s^{-1}]$ and η is efficiency *[%]*

Variables in the forwarder travel modes at measuring hydraulic fluid pressures and through-flows were cargo space load (with and without cargo) and the adjustment of potentiometer controlling the input power of the trailer's hybrid drive (75 % and 100 %).

In the case of the tensile tests, traction force for the forwarder train travel was not induced by the wheels of the attached tractor but by the pulling movement of another separate tractor. This separate tractor was connected with the forwarder train tractor by means of chokers. Between the chokers, an instrument measuring tensile force – an linear hydraulic motor (hydraulic cylinder) was fitted, into the inlet opening on which the hydraulic fluid is supplied under the piston, a HySense PR 100 electronic pressure sensor with the range from 0 – 600 bar was built in. The pressure sensor was then interconnected via a cable with a MultiHandy 3010 measuring and recording unit, which recorded changes in the hydraulic fluid pressure, which occurred due to changes in the tensile stress transmitted from the chokers inside the hydraulic cylinder. The data was evaluated in the Hydrocom programme. By knowing the parameters of the hydraulic cylinder: D = 80 mm, d = 40 mm (D - internal diameter of the cylinder, d – piston rod), we can determine the tensile force transmitted from the chokers onto the rectilinear hydraulic motor by using Pascal's law as follows (2):

$$F = pS10 \qquad (2)$$

where: F is tensile force *[N]*, p is hydraulic fluid pressure in the cylinder *[bar]*, S is effective area of piston $[cm^2]$

All measurements were taken with the forwarder train movement up a slope in the following travel modes:

- Separate tractor + tractor of forwarder train without a trailer in order to establish traction demands in the forwarder train tractor travel
- Separate tractor + tractor of forwarder train with loaded trailer, travelling without the drive of the trailer wheels
- Separate tractor + tractor of the forwarder train with loaded trailer, travelling with the drive of the trailer wheels, and with the potentiometer controlling the input power of the hybrid drive on the trailer gradually set to 25 %, 50 % and 75 %

For the calculation of slip and shoot of the machine wheels, we used modified Voltcraft mechanical counters to register RPMs of the tractor's rear driving wheel and RPMs of front (driven) and rear (non-driven) wheels of the trailer's twin axle. Circumferential length of the rear non-driven trailer wheel (that only rolls and has no slips) was used as a standard (actual distance travelled), to which circumferential lengths of the driven trailer wheel and rear tractor driving wheel were compared. Through the ratio of these values we determined the wheel slip or shoot in percentages.

3. Results

A model (Fig. 2) of a timber trailer drive for the estimation of the electrical drive parameters (mechanical and electrical) according to the chosen drive profile was designed in the MATLAB/Simulink programme. The tractor was also considered in the simulation model.

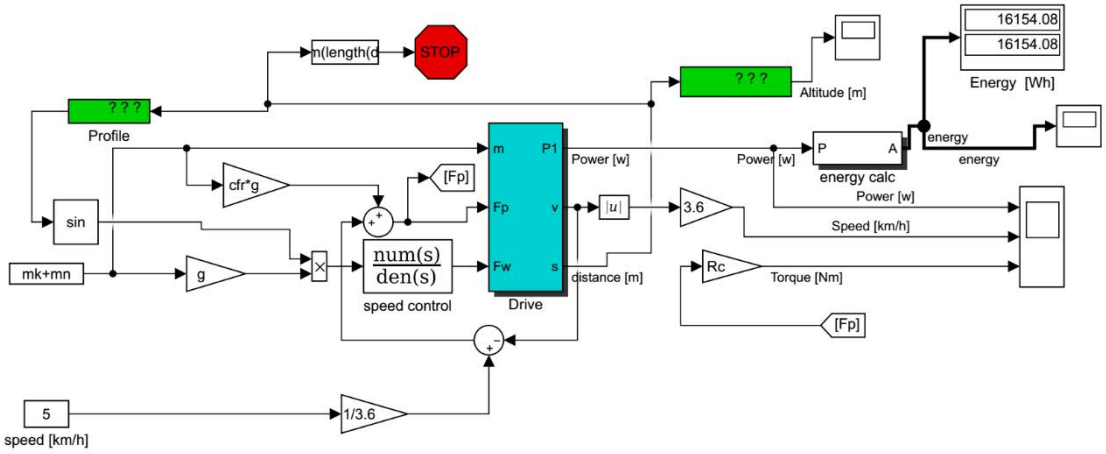


Fig. 2 A basic model of the trailer's electrical drive realized in MATLAB/Simulink.

Parameters of the simulation models were chosen according to real forwarder parameters together with the defined speed demands. Two drive profiles were taken into account according to Fig. 3.

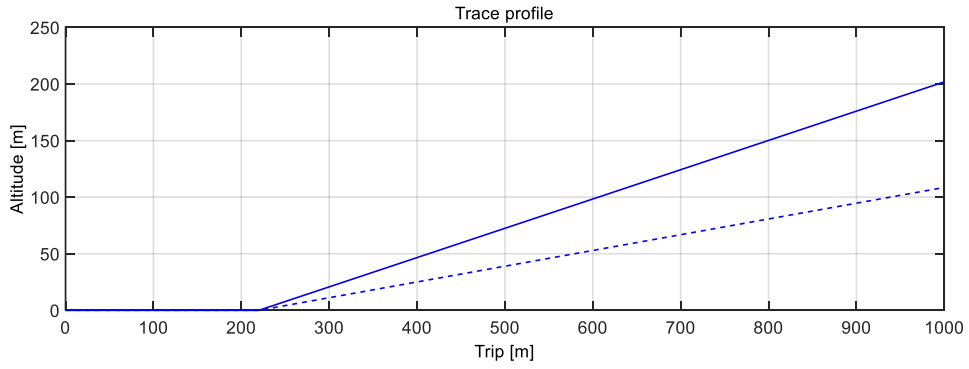


Fig. 3 - Two drive profiles P1 and P2 (dashed line) chosen for the electrical drive design

Thanks to the designed simulation model, it was possible to estimate the required torque, power and energy consumption during the drive profile. Results of the simulation are summarized in Tab. 3. There were two drive profiles chosen for the hybrid drive system design. These two profiles (P1 and P2, see Fig. 3) are defined by a different slope trace and different surface (letter "a" denotes the column where a solid terrain with a friction coefficient of about 0.001was taken into account, letter "b" denotes the column with a less solid surface with a friction coefficient of about 0.05). The number of drive cycles was counted for a battery with a defined capacity of 16 kWh. The energy covered by the accumulator was calculated considering the chosen tractor. The tractor power is placed into round brackets in Table 2.

Table 2 - Simulation results

Terrain type	**Maximum Torque** [Nm]	**Motor power** [W]	**Maximum slope** [deg]	**Velocity** [km/hr]	**Battery capacity** [Wh]	**Number of cycles** (16 kWh)
P1a	3000	143000	15	7	4920 (110 kW)	90
P1b	6500	150000	15	7	6255 (110 kW)	79
P2a	3300	78500	8	7	1117 (70 kW)	214
P2b	4000	84000	8	7	1993 (70 kW)	150

Results summarized in Table 2 show that the chosen battery total capacity (ca 16 kW) is sufficient for the chosen drive profiles at the maximum allowable forwarder's weight and speed. In the heavy terrain (unpaved road steep trace profile slope), it is possible to realize up to 3 traces. If an easier terrain is expected, it is possible to pass 8 traces. Therefore, the battery is acceptable with a sufficient energy reserve e.g. for battery charging, etc.

Some basic measurements have already been taken on a built prototype to verify the model based designs. During the harvester operation cycle, the measured battery current and voltage (Fig. 5) show satisfactory compliance with the simulated data (Fig. 4). The differences in current and voltage waveform are given by the battery inner resistance, which was neglected in the simulation model.

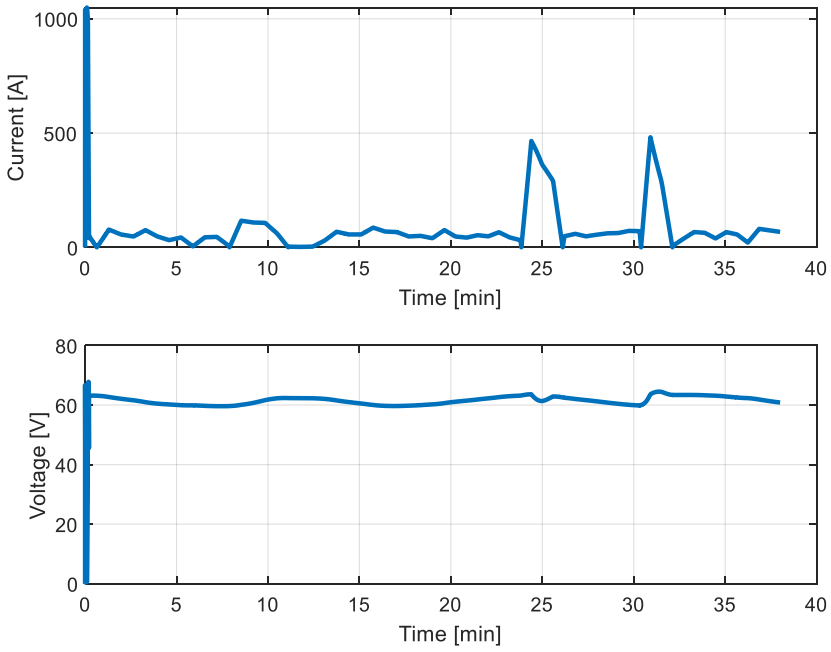


Fig. 4 - Simulated data of the battery current and voltage during the trailer operation cycle

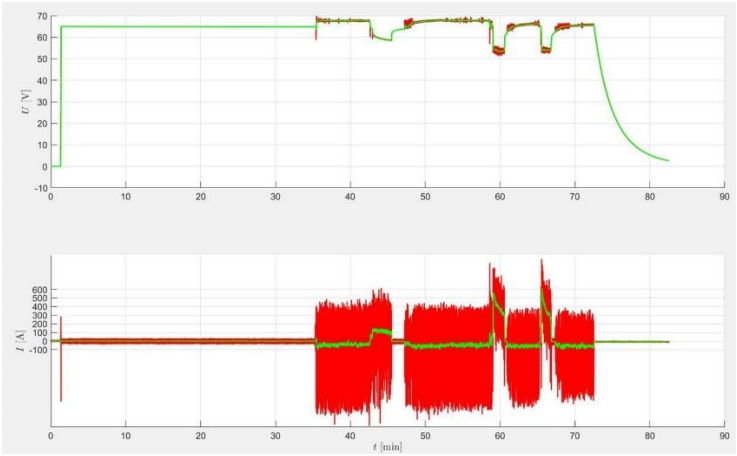


Fig. 5 - Battery current and voltage measured during the trailer operation cycle

The mean values of the pulling force required for the forward movement of the tractor and loaded trailer on the paved road with a gradient of 6.2° in the defined operational modes are presented in Tab. 3.

Tab. 3 – Mean values of the pulling force in defined operational modes of tractor and loaded trailer

Operational mode	**Travel speed** [km/hr]	**Wheel slip intensity in separate tractor** [%]	**Mean value of pulling *(pushing *)* force F** [N]
Forwarder train tractor without trailer	4.5	< 5	10566
Trailer without wheels drive	1.5	> 30	15074
Trailer with wheels drive, potentiometer 25 %	2.5	< 10	9792
Trailer with wheels drive, potentiometer 50 %	3.0	< 5	*4157* *
Trailer with wheels drive, potentiometer 75 %	3.2	0	*5665* *

Table 3 indicates that the mean value of the pulling force required by the forwarder train tractor without the trailer for moving forward was 10566 N in the given conditions. Under the same conditions, the separate trailer with a cargo of 5700 kg without the wheels drive required a pulling force of 15074 N. The required pulling force was reduced by 35 % already by setting the potentiometer controlling the input power of the trailer hybrid drive to 25 %. The potentiometer adjustment to 50 % fully covered the pulling force requirements of a loaded trailer and contributed to the forward movement of the prime tractor of the forwarder train with a mean value of 4157 N pushing force.

Table 4 shows the values of power input and slip of the driven front wheels of the trailer's twin axle during travelling with the load uphill onto the paved surface. The potentiometer controlling the power input of the trailer hybrid drive was set to 75 %, the tractor was in gear A1 and the tractor RPMs were 1800 $n.min^{-1}$.

Tab. 4 – Input power and slip of the front wheels of the trailer's twin axle during travelling with the load up a hill

Cargo [kg]	**Travel speed** [km/hr]	**Slip of tractor rear wheels** [%]	**Slip of trailer front wheels** [%]	**Input power of trailer front wheels** [kW]
0	2.5	1.4	6.4	7.2
5700	2.2	-1.8	3.2	6.5

During the measurements, we recorded negative values of wheel shoot on the rear tractor axle at the potentiometer setting at 75 % and more ranging from -0.7 to -2.4. Negative shoot values were detected also in the front trailer travel wheels upon the drive switch-off, i.e. at the time when the wheels were just rolling over the ground surface. This fact may indicate a negligible but still measurable influence of putting on the brakes of the driving rotational hydraulic motor of the wheels. Upon switching on the drive of the trailer's twin axle travel wheels, the slip rate of the rear driving wheels on the prime tractor decreased. The fact showed namely during the travelling of the tractor with the loaded trailer up the hill a reduction of the slip of the wheels from about 35 % to 0 - 5 %.

According to our findings, the requirement of the electrical generator power supply for charging the system of batteries is 8.3 kW. Power inputs required for lower energy-intensity operational modes, i.e. during the forwarder train travelling down the hill, over a flat terrain or during loading/unloading range from 3 to 9 kW. The maximum value of the power input provided to the driven wheels on the trailer's twin axle during uphill travel and to the potentiometer controlling the power input of the hybrid drive set to 100 % was about 17.7 kW.

The values of the average fuel consumption given by the on-board computer of the forwarder train tractor can be considered indicative only. Despite the fact, an essential difference can be seen between the fuel consumption of a tractor pulling the loaded trailer up the hill without the drive (10.3 l/hr) and with the hybrid drive on the twin axle (6.7 l/hr).

4. Discussion

The above results show that the chosen battery total capacity (ca 16 kW) is sufficient for the chosen drive profiles at the maximum allowable forwarder's weight and speed. In the heavy terrain (unpaved road steep trace profile slope), it is possible to realize up to 3 complete work cycles and about 8 complete work cycles can be implemented if an easier terrain is expected. Therefore, the battery is acceptable with a sufficient energy reserve e.g. for battery charging, etc. Demands on the tractor's power and its fuel consumptions are reduced and the recuperated energy amount is much larger (ca hundreds of kJ) in comparison with the solution discussed in Minav et al. (2010) and Prinz (2018), where the recuperated energy is about tens of kJ during one operating cycle.

In respect to the power input from the electrical drive, tensile force, travel speed and slip of wheels, optimum results in the terrain passage of the forwarder train were achieved with the control potentiometer adjusted to 100 %, A1 tractor gear and tractor engine RPMs of 1800 min^{-1}. In the given case, the loaded forwarder train travel speed up the hill was 3.0 km. The values of electric generator power input for charging the system of batteries and power input for less energy intensive work operations calculated on the basis of actual operational parameters confirm our assumption that batteries can be recharged during the operations in the daily work regime of the forwarder's train.

Values of the pulling force required for the forward movement of the tractor and loaded trailer were determined on the road with a paved surface. It can be presumed that under the same slope conditions of unpaved road, the pulling force demand for the forwarder train tractor will not be so significant thanks to the lower efficiency of tractive force transmission from the wheels onto the ground surface.

Janulevičius and Pupinis (2013) studied the wheel slip of timber transport unit travelling in the rutted track in the flat terrain of a field in relation to the burden of the weight and drive option of the trailer's twin axle wheels. In the situation when the tractor had the front axle drive switched off and the twin axle of the trailer was driven only by the front wheels, during this travel they recorded without a load a wheel shoot on the tractor's rear axle of -0.1 % and a slip of 1.2 % on the front wheel of the trailer's twin axle. Travelling with the load, slip values on the rear tractor axle and on the front wheel of the trailer's twin axle were 7.3 % and 8.5 %, respectively. Despite the differences in our conditions (travelling up the hill along the paved surface and nearly double the weight of the forwarder train), we recorded in accordance with the colleagues a shoot of wheels on the rear tractor axle when the drive of the trailer's twin axle was switched on. Minus the shoot values – 1.8 % on the rear tractor axle were recorded when the loaded

forwarder train travelled with the potentiometer adjusted already to 75 %. Although this is apparently not an optimum situation (indicating that the drives of both the tractor and trailer are not harmonized), it documents at the same time the energy sufficiency of the trailer's hybrid drive.

The use of the hybrid drive in the conditions of a loaded forwarder train travelling up the hill was capable of reducing the fuel consumption by 35 %. Spinelli et. al. (2015) mention an average fuel consumption of 6.3 l/hr for a forwarder train with the tractor of the same performance and trailer with a payload by two tons lower during a 14-month period of standard operation. The use of the hybrid drive in our trailer with a higher payload allowed the reduction of the average fuel consumption measured in the most severe work conditions (loaded trailer travelling up the hill) to a comparable level of 6.7 l/hr.

The following example illustrates the possible fuel savings in specific working conditions. At an average skidding distance of 500 m, six work cycles per shift with an average speed of 2.8 km/hr and 80 % of the forwarder train employment per year, the use of the hybrid drive in those given work conditions would bring a savings of 1123 litres fuel per year.

5. Conclusion

The operational evaluation of timber transport unit with a trailer equipped with the hybrid drive corroborated the system functionality in harsh operational conditions. In operations of lower energy intensity, energy can be stored in the system of accumulators and later used to strengthen the trailer's performance in difficult terrains. The use of the electrical drive on the front wheels of the trailer's twin axle reduced the fuel consumption of the prime tractor and improved the forwarder train passage through the terrain by reducing the wheel slip. The fact that the electrical drive strengthens the trailer's performance in difficult working conditions allows the use of a tractor with a downsized engine, which will favourably reflect in the investment costs as well as in the economy of a forwarder's train operation.

Acknowledgements

This paper uses results from the solution of Project TA CR no. TH02010115 Forwarder with the hybrid chassis drive for timber transport.

6. References

Ehsani, M., Gao, Y., Gay, S.E. and Emadi, A. (2004) Modern electric, hybrid electric, and fuel cell vehicles: Fundamentals, theory, and design, pp. 1-396.

Einola, K. (2013) "Prestudy on Power Management of a Cut-To-Length Forest Harvester with a Hydraulic Hybrid System" in Krus, P., Sethson, M., and Ericson, L. (Eds.). 13th Scandinavian International Conference on Fluid Power, June 3-5, 2013, Linköping, Sweden.

Elforest Technologies, Ponsse Ergo with Elturbo [online]. Arnäsvall. Published 2/2015 (cited 12.7.2019) Available at: http://elforest.se/eng/news.php?id=17

Ghaffariyan, M.R., Sessions, J. and Brown, M. (2012) Machine productivity and residual harvesting residues associated with a cut-to-length harvest system in southern Tasmania, Southern Forests, 74 (4), pp. 229-235.

Ishida, K and Higurashi, M. (2015) Hybrid wheel loaders incorporating power electronics. 64. 398-402.

Janulevičius, A. and Pupinis, G. (2013) Power circulation in driveline system when the wheels of tractor and trailer are driven Transport, 28 (3), pp. 313-321.

Komatsu Hybrid Technology. [online]. VILVOORDE. Komatsu Europe International N.V.. Published 9/2017 (cited 12.7.2019) Available at: https://www.komatsu.eu/en/komatsu-hybrid-technology

LOGSET OY, Hybrid technology in forest machines [online]. Koivulahti. Published 3/2019 (cited 12.7.2019) Available at: https://www.logset.com/harvesters/logset-8h-gte-hybrid

Minav, T., Laurila, L. and Pyrhönen, J. (2010) "Energy recovery efficiency comparison in an electro-hydraulic forklift and in a diesel hybrid heavy forwarder", SPEEDAM 2010, Pisa, pp. 574-579.

Pohlandt, C. and Geimer, M. (2015) "Variable DC-link voltage powertrain for electrified mobile work machines", International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles (ESARS), Aachen, pp. 1-5.

Ponomarev, P., Åman, R., Handroos, H., Immonen, P., Pyrhönen, J. and Laurila, J. (2014) "High power density integrated electro-hydraulic energy converter for heavy hybrid off-highway working vehicles," in IET Electrical Systems in Transportation, vol. 4, no. 4, pp. 114-121.

Prinz, R., Laitila, J., Eliasson, L., Routa, J., Järviö, N. and Asikainen, A. (2018) Hybrid solutions as a measure to increase energy efficiency – study of a prototype of a hybrid technology chipper, International Journal of Forest Engineering, 29:3, 151-161.

Sánchez-García, S., Canga, E., Tolosana, E. and Majada, J. (2016) Analysis of productivity and cost of forwarding bundles of eucalyptus logging residues on steep terrain, Croatian Journal of Forest Engineering, 37 (2), pp. 241-249.

Spinelli, R., Magagnotti, N., Pari, L. and De Francesco, F. (2015) A comparison of tractor-trailer units and high-speed forwarders used in Alpine forestry, Scandinavian Journal of Forest Research, 30 (5), pp. 470-477.

S08 Trafficability
Can we get over it?

INNOVATIVE FOREST WHEEL DESIGN FOR LOW INFLATION PRESSURE
Felix zu Hohenlohe
HSM Hohenloher Spezial-Maschinenbau GmbH

RUTTING ON SKID TRAILS - STATIC AND DYNAMIC PRESSURE ALLOCATION
Bastian Hinte, Katharina Meyer-Schulz
Georg-August-Universität, Göttingen, Germany

MEASURING OF WHEEL RUTS DEPTH IN FOREST TERRAIN WITH DRONE AND DIGITAL STEREO PHOTOGRAMMETRY
Tomas Nordfjell, Rasmus Wictorsson
[1] *Swedish University of Agricultural Sciences, Department of Forest Biomaterials and Technology, Umeå, Sweden*

OPERATIONS PROTOCOL FOR ASSESSING TRAFFICABILITY PRIOR TO LOGGING OPERATIONS – KEY FINDINGS FROM THE EFFORTE PROJECT
Jori Uusitalo
Natural Resources Institute Finland (Luke), Tampere, Finland

EVALUATION OF A (THE HSM) TRIPLE BOGIE SYSTEM FOR FORWARDERS
Michael Starke [1], Felix Heubaum [2], Martin Ziesak [1]
[1] *Bern University of Applied Sciences (BFH) – School of Agricultural, Forest and Food Sciences (HAFL), Bern, Switzerland* [2] *Public enterprise Sachsenforst, Pirna, Germany*

COMPARISON OF DIFFERENT ESTIMATION METHODS TO WHEEL RUTS AND SOIL COMPACTION DURING HARVESTING OPERATIONS.
Elena Marra [1], Martina Cambi [1], Andrea Laschi [1], Fabio Fabiano [1], Francesco Neri [1], Cristiano Foderi [1], Enrico Marchi [1], Tomas Nordfjell [2]
[1] *Dipartimento di Gestione dei Sistemi Agrari, Alimentari e Forestali (GESAAF), Università di Firenze, Firenze, Italy;* [2] *Department of Forest Biomaterials and Technology (SLU), Swedish University of Agricultural Sciences, Skogsmarksgränd, Umeå, Sweden*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

FOREST WHEEL DESIGN FOR LOW INFLATION PRESSURE

Felix zu Hohenlohe
Hohenloher Spezial-Maschinenbau GmbH & Co. KG
Im Greut 10, D-74635 Neu-Kupfer, Germany
info@hsm-forest.com

Abstract: *Wheeled forest machines, such as skidders, forwarders and harvesters, transfer their weight and wheel forces over the footprint of their tyres.*
The larger the area of these footprints is, the higher the traction force transmitted and the lower the resulting rut depth will be.
Besides soil condition, wheel loads and tyre dimensions, tyre inflation pressure plays the main role in determining the footprint area.
The minimum inflation pressure confirmed by the tyre manufacturers for a specific wheel depends on wheel load, maximum driving speed and characteristics of the terrain. The forest tyre industry has recently developed extra low inflation tyres.
Technically, often a higher inflation pressure is used to avoid the wheel sliding on the rim, which often results in a puncture unless it is a tubeless specification. Also, obstacles may push the tyre off the rim hub, and pieces of wood may enter between rim and tyre.
In this report, a wheel design new to the Central European market will be introduced, which will avoid both problems and thus will enable using the full potential of low inflation forest tyres.

Keywords: forwarder, inflation pressure, rutting, traction, driving efficiency, bead-lock.

1. Introduction

The forest tyre and its footprint are important for the performance of a wheeled forest machine.

At a given wheel load and pulling force, it has a major influence on

- floatation (rutting, trafficability)
- traction (gross and net pulling force)
- driving efficiency (slip, rolling resistance)
- vibration insulation (driving comfort, on- and off-road)

In the last years, manufacturers have developed forest tyres which allow driving with a reduced inflation pressure. At the forest machine show Euroforest in France (June 21-23, 2018), the forest tyre manufacturer Alliance presented the first members of the new ELIT-program (Engineered Low Inflation Tyre).

The following paper discusses the influence of a lowered inflation pressure and describes an innovative wheel design, which solves some limiting problems when using forest tyres at the lowest pressure acceptable.

The paper covers wheeled forest machines such as skidders, forwarders and harvesters in the size dominating in professional timber harvesting in Europe. The design can be 4WD, or, with bogie axles, 6WD or 8WD.
The use of bogie tracks to increase floatation and / or traction is not covered, nor is arctic timber harvest at deep frost and / or massive snow.

2. Impact of low inflation pressure on the interaction of soil and forest tyre

The behavior of tyres is depending on the inflation pressure.

M. Saarilahti [Saarilahti 2002] gives a comprehensive overview of the known models describing the soil interaction of forest tyres. Most of the models are based on the WES-method.

As the inflation pressure determines the deflection of a specific forest tyre at a specific wheel load, all diagrams and equations mentioning the deflection also give the tendency for the inflation pressure.

There is a numerical value equation to calculate the deflection of a forest tyre from the inflation pressure [Saarilahti 2002]:

$$\delta = 0.008 + 0.001 \cdot \left(0.365 + \frac{170}{p_i}\right) \cdot W \qquad (1)$$

where

δ	is	deflection, m
p_i		inflation pressure, kPa
W		wheel load, kN

With the help of this equation, the results of the research based on the WES-method can be used concerning the wheel performance depending on the inflation pressure. The WES-method was developed in the Waterways Experiment Station in Vicksburg, Mississippi, a United States Army Corps of Engineers research facility. It is based on semi-empiric modelling of wheel performance and on measuring soil penetration resistance by a standardized cone penetrometer.

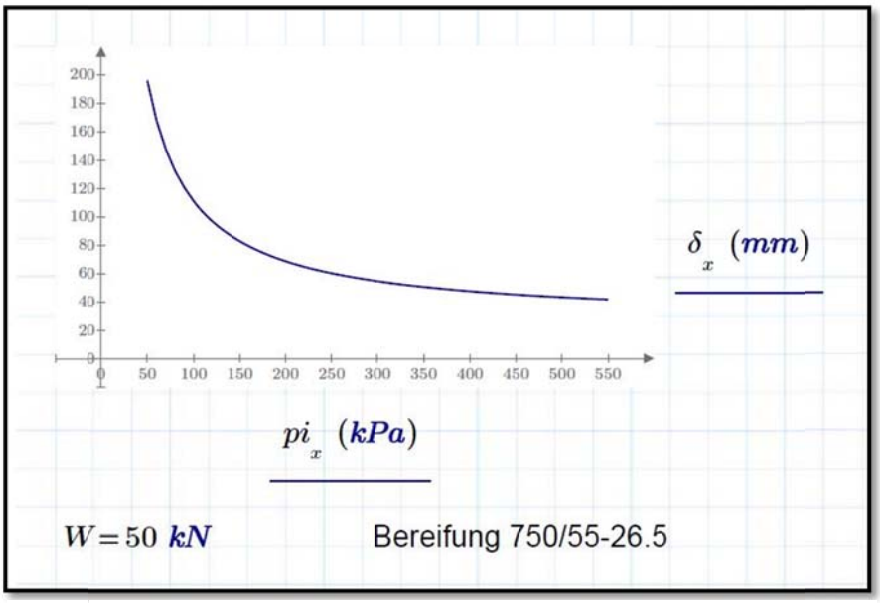


Fig 1: Deflection over inflation pressure, calculated according to Eq.(1)

Examples for results based on WES are [Wijekoon et al. 2012], [Saarilahti and Anttila, 1999] and [Marusiak and Neruda, 2018].

Ebel (2006) quotes numerous authors as follows:
"… by reducing the inflation pressure, the tyre's deflection increases and the wheel load is distributed over a bigger footprint, thus reducing the contact pressure and soil penetration. In this context, additional advantages of reduced inflation pressure are mentioned:

- reduced soil compaction,
- reduced rut depth
- reduced rolling resistance,
- improved pulling force transmission and improved driving efficiency at less slip,
- lower fuel consumption
- higher driving comfort due to vibration insulation for the operator
- less dependency on the weather

and

- better self-cleaning of the tyres."

The test machine for this article is a 14 ton forwarder with eight wheels 750/55-26.5. The recommended inflation pressure for using bogie tracks is between 550 and 600 kPa. With the experimental tyres adapted for an extra low inflation pressure, the front tyres (wheel load 33 kN loaded) were filled with 140 kPa and the rear tyres (50 kN loaded) were filled with 240 kPa.

HSM 208F14 (Forwarder2020)			
	Front Axle	Rear Axle	total
	[kN]	[kN]	[kN]
empty	110,0	80,0	190,0
Load	20,0	120,0	140,0
loaded	130,0	200,0	330,0
wheel load	32,5	50,0	

Fig 2: Wheel loads of the test forwarder

Saarilahti (2002) quotes a field observation of Löfgren (1992) measuring the rut depths of a forwarder travelling with ½, ¾ and full load and with inflation pressures of 100, 240 and 380 kPa. At full load, the reduction in rut depth was 26.5% between 380 kPa and 240kPa and 51% between 380 kPa and 100 kPa.

In another test under Swedish conditions, the rut depth resulting under a 8WD forwarder was not changing significantly between 300 kPa, 450 kPa and 600 kPa (Eliasson 2005).

Also under Swedish conditions, tests showed a reduction in rut depth after 10 passes of the loaded forwarder of approx. 35% at an inflation pressure of 450 kPa instead of 600 kPa (Wijekoon et al. 2012, Figure 6). This is unexpected because the deflection of the tyre and its footprint are not changing massively between these two high pressure settings.

By lowering the inflation pressure from 300 kPa to 120 kPa, the contact area was reported to be enlarged by 29% (Tobisch 2001).

Backhaus (1994) has tested skidder tyres with very low inflation pressure settings. Standard pressure was 220 kPa; the footprint was increased by 23% at 100 kPa and 39% at 60kPa. The use of this low pressure setting was only possible with the BLS safety rim, which locks the bead to the rim with 6 rim-lock devices.

The increase in tractive effort has been reported as high as 10% to 14% by lowering the inflation pressure from 300 kPa to 100 kPa. This was tested on claylike-sandy silt with a humus layer with and without a brush-mat and at 20% and 40% water content. Also the slip was altered from maximum force to a reasonable value of 20% (Jacke und Drewes, 2004).

In another report, the tractive effort was increased by 22.8% on a skid trail by lowering the inflation pressure from 300 kPa to 120 kPa (Tobisch 2001).

On a skidder, Stoilov (2007) reports an increase of the net traction of 6.8% by reducing the inflation pressure from 230 to 190 kPa.

A reduction in fuel consumption was published as high as 8% on a skid trail on a 5% slope downhill with a brush-mat and 14.9% on a 5% Slope uphill without a brush-mat. The inflation pressure was altered from 370 kPa to130 kPa (Burk und Weise, 2005). The reduced fuel consumption is a product of reduced rolling resistance and reduced slip.

Bloch et al. (1992) are reporting significantly lower full body vibrations during work with a skidder without wheel suspension. Reducing the inflation pressure from 150 kPa to 100 kPa results in a reduction of the vibrations between 20% and 30%, especially in vertical direction.

3. Limitations of Lowering the Inflation Pressure

3.1 Tyre Design

Depending on the tyre design and dimensions, the wheel load, the travel speed and the classification of the terrain, the manufacturer requests a minimum inflation pressure. These parameters are concluded by a committee of tyre manufacturers, but exceptions for purpose-built low inflation tyres have been made lately.



Fig 3: Cracks caused by low inflation pressure

If a tyre is running for a longer time with an inflation pressure which is too low, damages may occur. Typically, there are radial cracks in the area off the shoulder of the tyre, see Fig. 3.

When the deflection exceeds a critical value too often and at higher speed, radial cracks such as those above may occur. Also when equipped with a tube, excessive deflection will increase the wear on the tube massively and reduce the lifetime significantly.

The design of forest tyres – radial or bias design – will be a compromise between low inflation pressure abilities and robustness, reliability and endurance.

This is indeed a challenge for the designer of low inflation pressure tyres.

3.2 Torque Transmission

Standard forwarder tyres are mounted on "AG" type rims with a seat angle of 15° and a low rim flange.

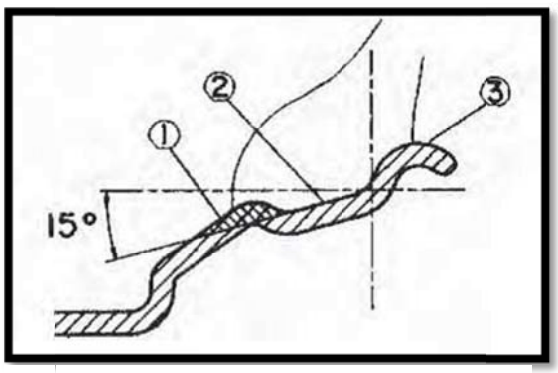


Fig 4: Tyre bead on a hump rim AG, Trelleborg (2018).

Fig. 4 illustrates the contact area between the hump (1), the bead seat (2) and rim flange (3). For the forwarder tyres, up to 500 kPa of inflation pressure is used during fitting on 15° rims (Trelleborg 2018).

Tyre slippage on the rim is a major problem in connection with lowering the inflation pressure.

Already with the standard inflation pressure settings, the effort of the manufacturers for the precision of the preload and the stiffness of the bead is high. At higher inflation pressures, the bead is pressed against the bead seat and this normal force increases the friction force, thus enabling higher

torque between the rim and the tyre to be transmitted. The knurling on the bead seat crucial and it is best not painted.



Fig 5: Knurling on the bead seat, Nokian (2019)

A slipping wheel on the rim will destroy the tube by tearing off the inflation valve. Even in the tubeless version, intense wheel slip will wear out the contact area of the tyre bead and therefore further reduce the torque transmitted between rim and tyre.

3.3 Obstacles pushing the tyre off the rim's hump

Due to side sliding of the wheel during cornering and on side slopes, obstacles such as pieces of wood or branches can slide between the rim flange and the tyre, see Fig. 6. Especially wooden splinters can be pressed with high forces against the rim flanges when the wheel is side sliding against a tree stump. With tubeless mounted wheels, this may lead to a puncture, sometimes rather slowly. Even with a tube, the friction between rim and tyre will be reduced and may lead to a puncture due to a torn off inflation valve.



Fig 6: Wooden splinters entering due to low inflation pressure.

Fig. 4 illustrates the hump (1), which is meant to support the bead towards the inside against side forces from the outside against the tyre. With the extra support of a higher inflation pressure, this system works reliably.

4. Forest Wheel Design

In the forest, often the inflation pressure is set to values between 450 and 600 kPa for driving with bogie tracks. Trelleborg (2018) requests 600 kPa and Nokian (2019) recommends 550 kPa when using bogie tracks for the typical tyres used on bogie axles.
External or onboard devices for rapid adjusting of the inflation pressure during mounting and demounting the bogie-tracks are not common. In Central Europe, the tracks are mounted and demounted frequently, often several times per week. Therefore most of the forwarders will operate with a higher inflation pressure than necessary when driving without tracks.

A solution to the problem of wheel slippage (see 3.2) and wooden splinters entering between rim and wheel (see 3.3) is described by Backhaus (1994). The rim design with six bead-lock devices (BLS rim = Bead Lock Safety by Trelleborg) enabled reliably the use of a very low inflation pressure (down to 60 kPa) with a rather small skidder (wheel load 17.4 kN and 21.3 kN). There were no problems anymore reported as above after using the new rim design delivered by Trelleborg.
The same rim design was used for the tests concerning full body vibrations and very low inflation pressure (Bloch et al. 1992).



Fig 7: Test forwarder with bead-lock rims

The forwarder to test the new low inflation pressure wheels has the following technical specification:

- HSM 208F 14 ton (payload), 8WD, weight empty 19 tons, loaded 33 tons
- max gross pulling force 195 kN
- 8 tyres 750/55-26.5, modification for low inflation pressure, 750mm wide, diam. 1465 mm
- bead-lock rim design

- wheel load front 32.5 kN loaded, p_i = 140 kPa
- wheel load rear 50.0 kN loaded, pi = 240 kPa
- max speed 20 km/h (limited for onroad regulation)

Although the forwarder has eight wheels, the wheel loads are more than the wheel loads of Backhaus (1994) and Bloch et al. (1992).

In the relevant literature, there are very few remarks made in the meantime concerning rims allowing the lowering of the inflation pressure, especially not in connection with bogie axles.

Fig. 8 shows the new rim design with bead-lock. Two outer rings with a 15° bead seat are bolted against the wheel. The rim centers the ring and has a counterpart for the rim flange. Between these two, the bead is locked with the force from the bolts, which is significantly higher than the side force on the bead created by an inflation pressure suitable for track use, > 500 kPa.

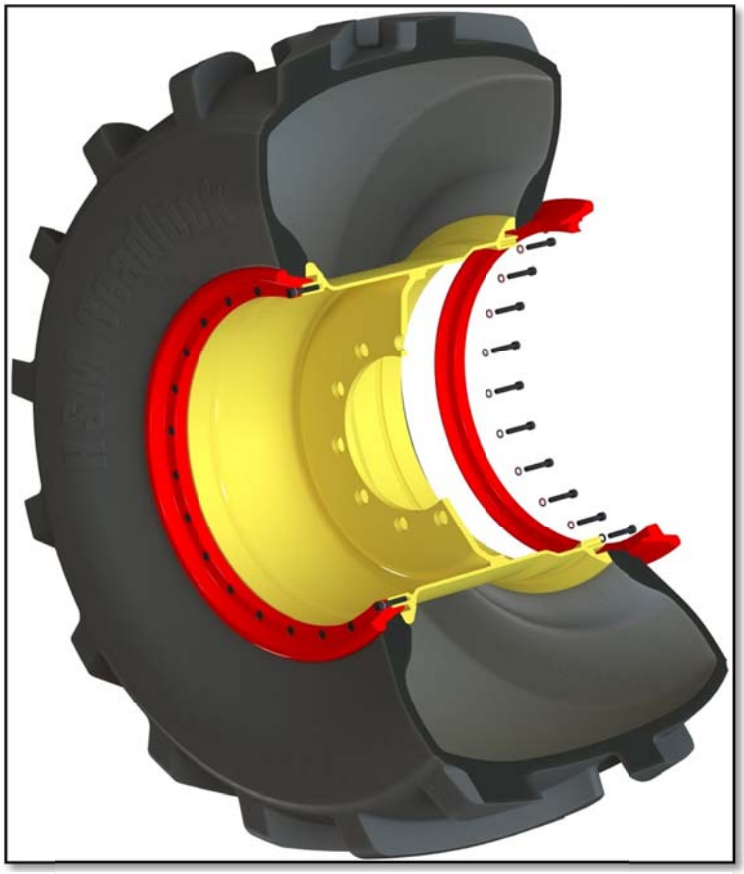


Fig 8: Bead-lock rim

The inflation pressure increases the side normal force on the outside contact area, while decreasing it on the inside.

For the tubeless use, a minimum preload must be reserved to ensure the sealing on the inner side contact.

For very low inflation pressure settings, the tubeless version will avoid the high wear of tubes due to the strong deflection.

The fitting of the tyre and the tube on the rim did not show any problems on a standard tyre changer. The fitting of the rings and the tightening of the bolts with a ¾" electric impact driver was time-consuming and there seems to be potential left for improvement.

During the first hundreds of hours of testing, there were no problems with deformed rings or loosened bolts occurring. From the cost side, this project looks critical compared to standard rims.

The corners of the bead are being compressed, even more than with a hump rim. The design allows for a certain tolerance of the width of the bead. This will be necessary to adapt to different tyres and brands.

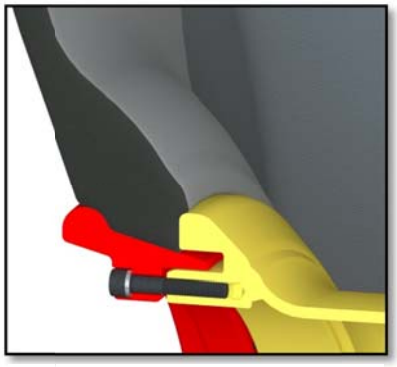


Fig 9: Detail of bead-lock

Depending on the preload created by the bolt forces and the inflation pressure applied, the design should be suitable for tubeless use as well.

With standard rims the bead is more flexible to deform elastically at high deflections of the tyre. The first reaction of the engineers developing the forest tyres was positive about this design. They

assumed an advantage for the tyre design if there was a reliable bead-lock.
Depending on the bogie axles, -- rather with the portal- than with the planetary-end drives -- the space next to the inside of the ring is very limited. It is clear that planetary end drives will be an advantage for these rims. Though, as the prototype rims proved, the use with portal bogies is also possible.
The presented rim design is in prototype status. From the health and safety point, multipiece rims need to be handled with extra care by the operator and service technician. A failure can result in violent separation and the explosive release of pressurized air. It must be absolute clear to anybody involved, that the bolts fastening the rings to the rim must not be unscrewed before the inflation pressure is completely released.

5. Conclusion and Further Development

The use of a lower inflation pressure for forwarder tyres concerning floatation, traction, reducing wheel slip and insulating vibrations from the ground to the chassis is very evident in the scientific literature.
Among the tyre manufacturers, there is a trend to develop tyres for low inflation pressure and higher deflections. To enable the use of the benefits of this development, wheel slippage on the rim and entering of wooden splinters must be avoided. This can be done with the use of a rim with a bead-lock, as proposed in this article.
Every standard forwarder driving without tracks can benefit from this development. For mixed operations with and without bogie tracks there will be a need for a quick adaption of the tyre pressures during mounting and demounting of the tracks. Powerful compressors, external or integrated in the forwarder, are available.
The best effect is obtained by over-specifying the tyre dimensions and then using a lower inflation pressure due to the low wheel load.
There seems to be quite some potential for both soil conservation and increased performance in this development. The development will be driven rather by market demand than by technical advantages.

6. Acknowledgements

The tests were carried out in connection with other technical innovations in connection with Forwarder2020, a research program under EC's Horizon 2020. As the tests of the innovative tyre – rim combination did not show any problems, the tests did not influence each other. The author and HSM wish to express their thanks for this opportunity to participate in the field tests, especially in the Carpathian Mountains in Romania in spring/summer of 2019.

7. References

Alliance (2018): Alliance F344 ELIT (Low Pressure): The world's first low inflation forestry tyre to make its debut at Euroforest in France. Press Release of ATG tire Amsterdam

Backhaus, G. (1994). Konsequenzen für die Bereifung von Forstmaschinen bei verstellbarem Reifenluftdruck. In: Forst & Technik 12/1994, pp 12 – 17.

Backhaus, G. (1993). Reifendruckverstellanlagen und ihr Nutzen beim Forstmaschineneinsatz. In: AFZ – Der Wald 15/1993, pp 761 – 763.

Bloch, G.W., Gerdsen, G.; Zietsch, R. (1992). Belastung und Beanspruchung durch Ganzkörperschwingungen beim Rücken mit unterschiedlichen Reifeninnendrücken. In: Forsttechnische Informationen, Nr. 6/7, Juni/Juli 1992, pp 45 – 48.

Burk, J.; Weise, G. (2005): Einfluss von Reifendruckregelanlagen auf den Kraftstoffverbrauch von Trag-schleppern. In: Forsttechnische Informationen, Heft 4 / 2005

Ebel, A., (2006): Druckverteilung auf Kontaktflächen unter Forstreifen. Dissertation. Georg-August Universität Göttingen

Eliasson, L. (2005). Effects of forwarder tyre pressure on rut formation and soil compaction.
Silva Fennica 39(4): 549–557.

Heubaum, F. (2015): Bodenscherfestigkeit auf Rückegassen. In: Forst & Technik 8 / 2015, pp 18 – 22.

Jacke, H.; Drewes, D. (2004): Kräfte, Schlupf und Neigungen – ein Beitrag zur Terramechanik forstlicher Arbeitsmaschinen. In: Forst und Holz, Jg 59, H.6, S.259 – 262.

Marusiak, M. and Neruda, J. (2018): Dynamic Soil Pressures Caused by Travelling Forest Machines.

McDonald, T.P. and Aust, W.M. (1995): Soil Physical Property Changes After Skidder Traffic With Varying Tire Widths.

Nokian, (2019): Nokian Tyres Technical Manual. Heavy Tires | Truck and Bus Tires. Version 6.0.1 updated: July 2019.

Saarilahti, M. (2002): Soil Interaction Model, Development of a protocol for ecoefficient Wood Harvesting on sensitive Sites (ECOWOOD) with appendixes 1 to 8. University of Helsinki, Department of Forest Resource Management, Helsinki.

Saarilahti, M. and Anttila, T. (1999): Rut depth model for timber transport on moraine soils. In: Proceedings of the 9th International Conference of International Society of Terrain-Vehicle Systems, 14th – 17th September 1999, Munich, Germany.

Schwanghart, H. (1991): Measurement of contact area, contact pressure and compaction under tires in soft soil. In: Journal of Terramechanics, Vol 28, No. 4, pp 309 – 318, 1991

Stoilov, S. (2007): Improvement of wheel skidder tractive performance by tire inflation and tire chains. In: Croatian Journal of Forest Engineering 28 (2007) 2.

Tobisch, R. (2001): Weniger Druck ist mehr! In: Forsttechnische Informationen Nr. 1 / 2001, S. 5 - 7.

Trelleborg (2018): Technical Manual. Trelleborg-Wheels-Technical_manual_18_EN.pdf, downloaded from https://www.trelleborg.com/en/wheels/tools-and-ressources/agriculture-and-forestry-tires/technical_information on August 19th, 2019.

Wijekoon, M., Sellgren, U., Pirnazarov, A. and Löfgren, B. (2012): Forest Machine Tire-Soil Interaction. Presented at FORMEC 2012 in Dubrovnik, Croatia on October 8th – 12th, 2012.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

RUTTING ON SKID TRAILS - STATIC AND DYNAMIC PRESSURE ALLOCATION

Bastian Hinte [1], Katharina Meyer-Schulz [2]
Georg-August-Universität, Göttingen, Germany
bastian.hinte@uni-goettingen.de

Abstract: *The usage of bogie tracks on forest machines, especially on harvester and forwarder, has been increased clearly for the last years. There are different reasons which favor the usage of tracks on wheel based forest machines. Firstly there is a possibility to increase the traction and reduce the slip by using tractive tracks. One the other hand it is also possible to improve the floatation and decrease ground disturbance with wide and long chain links for higher amount of contact area between tires and underground. Various manufactures offer different types of bogie tracks for manifold tasks in the forest sector. For these types of tracks steal is the mostly used material. In the project "Soil protecting use of forest machines" the advantages and disadvantages of synthetic tracks (FelastecTM) in comparison with steal tracks and tires will be reviewed with focus on static and dynamic pressure allocation and also the rutting process and the amount of slippage on skidding trails will be compared. So there can be given proposals, whether the usage of tracks is helpful or unnecessary in different environmental conditions.*

Since the start of the project there have been a lot of measurements in the test fields east of Göttingen (rutting on skidding trails) and in the test stand at the campus (PrAllCon – stat-ic/dynamic) with a Rottne F14 Solid forwarder. Methods of data gathering, main results of measurements and final conclusions in recommendation of track usage will be given at the 52th International Symposium on Forestry Mechanization.

Keywords: laser scanning, rutting, soil disturbance, tracks, pressure allocation

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

MEASURING OF WHEEL RUTS DEPTH IN FOREST TERRAIN WITH DRONE AND DIGITAL STEREO PHOTOGRAMMETRY

Tomas Nordfjell*, Rasmus Wictorsson
Department of Forest Biomaterials and Technology
Swedish University of Agricultural Sciences
tomas.nordfjell@slu.se

Soil disturbance due to wheel ruts and compaction of the soil is often evident in machine-operated areas. It is however time consuming to measure and evaluate those soil damages with high accuracy for comparison between different machine configurations. The traditional manual method is to measure the rut profile at fixed intervals (cf. Sakai et al. 2008). Forestry inventory and mapping of forest related damage using aerial photography has been used for many decades (Sylvander 1972). Photogrammetry has been demonstrated for data collection on the surface structure of the soil as early as the 1990s. (cf. Warner 1995). Flying drones have been used in military applications for a long time, but it was around year 2010 that they reached the forestry sector in some notable extent (cf. Turner et al. 2012). Öhman & Asplund (2015) have shown that it is efficient to do inventories with a flying drone in storm-damaged forests to plan the harvesting operation. Pierzchała et al. (2016) have shown that soil damages in steep forest terrain can be evaluated with a flying drone and 3D photogrammetry. Despite this, the technology is still considered new in operative forestry.

The overall purpose with this study was to develop a method for measuring wheel ruts made by forest machines in regeneration-felled areas with a flying drone and digital photogrammetry, and to investigate the accuracy with this method. The detailed aims was to evaluate if the accuracy differs between:

i) a drone flying height of 60 or 120 m.
ii) ruts in the middle of an open clear-cut or close to other stands
iii) deep or shallow ruts

In a field object and a control object, drone photogrammetry measurement from 60 m and 120 m flight height was used, with manual measurements as a reference method. The field object was a 4.5 ha clear cut area recently harvested, and with a rather high concentration of ruts. In total 20 plots with 10 m length, each was manually inventoried. The plots was divided into three groups with the average depth of about 18, 29 and 48 cm respectively. The control object was on a flat agricultural land with simulated ruts of two uniform depths of about 20 and 80 cm. The ruts on control plots were done with a small excavator. The drone photos were taken with 80% overlap to next photo in all directions. Ground control points were done with white color marks. The field object and control object had 10 and 12 Ground control points respectively. The photos was thereafter imported to a 3D point cloud program (Agisoft PhotoScan Professional). Then, the 3D point cloud was exported to the program Quick Terrain Modeler, and the rut depths could be measured (cf, figure 1).

There were no significant differences between manual measurement and the remote measurement from 60 or 120 m height (p-values 0.37 and 0.28). Drone measurement of wheel ruts depth from 60 and 120 m showed similar values, but with a higher standard deviation for the 120 m flight height. A linear regression between manual measured rut depths and drone measured depths gave a R^2 of 0.83 for 60 m flight height and 0.77 for 120 m flight height on the field object. It was however difficult to match the manual and drone measured points exactly on the field object, and this explained part of the variation. On the control object with more homogeny conditions, on the other hand the difference between manual measurements and the remote drone measurements did almost not exist. A similar linear regression between manual measured rut

depths and drone measured depths gave a R^2 of 0.99 for both 60 m and 120 m flight height on the control object.

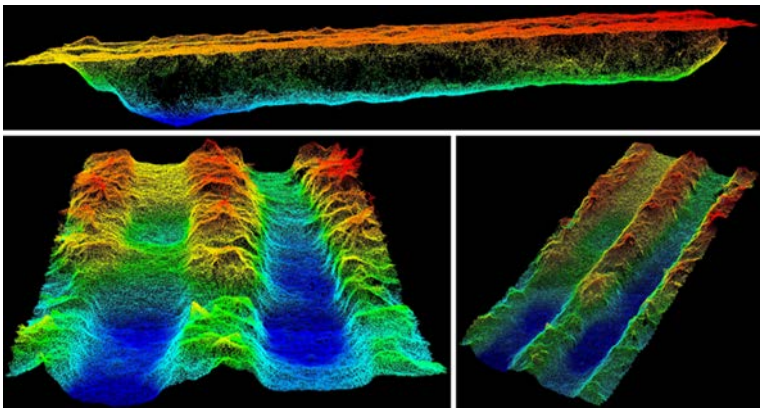


Figure 1. 3D point clouds based on 60 m flight height.

The result was in general equal good if it was deep or shallow ruts to measure. The result was also in general equal good when the rut was close to trees or in the middle of an open area. The only drawback found with photogrammetry was that it is not possible to measure in water-filled ruts. It will then only be a measure down to the water surface. However, it is normally possible to detect that it is a water surface in a rut, since it is shown as a very flat area on the 3D photogrammetry images.

Data collection via aerial photography was shown to be less time-consuming than the manual reference data collection. In research, this methodology can give even more detailed data on rut formation than manual methods normally tend to do. In addition, measures like the rut volume can be estimated with existing algorithms, and this is very time consuming to measure manually. In a practical application, remote measurements with digital stereo photogrammetry can be developed to an operational monitoring of soil damages that covers large areas and gives reliable samples. In practical application, remote drone photogrammetry measurements can contribute to cost savings in operational forest operations.

References

Öhman, M. & Asplund, V. (2015). Inventering och drivningsplanering av stormskadad skog med hjälp av drönare (UAV). SLU, Institutionen för skogens biomaterial och teknologi. Manuscript.

Pierzchała, M., Talbot, B. & Astrup, R. (2016). Measuring wheel ruts with close- range photogrammetry. Forestry 89(4):383–391.

Sakai, H., Nordfjell, T., Suadicani, K., Talbot, B. & Bøllehuus, E. 2008. Soil compaction on forest soils from different kinds of tires and tracks and possibility of accurate estimate. Croat. J. For. Eng. 29:1, 15-27.

Sylvander, R. 1972. Skoglig datainsamling från flygplan: Collection of forest data from slow-flying aircraft. Sveriges lantbruksuniversitet, Avdelningen för skogsuppskattning och skogsindelning. Rapporter och Uppsatser. Nr 1. Umeå.

Turner, D., Lucieer, A. & Watson, C. (2012). An Automated Technique for Generating Georectified Mosaics from Ultra-High Resolution Unmanned Aerial Vehicle (UAV) Imagery, Based on Structure From Motion (SfM) Point Clouds. Remote Sensing. 4, 1392–1410, doi: 10.3390/rs4051392.

Warner, W. (1995). Mapping a three-dimensional soil surface with hand-held 35 mm photography. Soil and Tillage Research 34:187–197.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

OPERATIONS PROTOCOL FOR ASSESSING TRAFFICABILITY PRIOR TO LOGGING OPERATIONS – KEY FINDINGS FROM THE EFFORTE PROJECT

Jori Uusitalo
Natural Resources Institute Finland (Luke), Tampere, Finland
jori.uusitalo@luke.fi

Abstract: *It is generally wetness that makes forest soil loose and soft. However, different soil types react in different ways towards changes of moisture content. In inorganic soils grain size distribution generally controls the magnitude of hydraulic conductivity and the wideness of the scale in which moisture content varies in forest soil. Thickness of organic layer above the inorganic layer and proportion of organic substrate within the inorganic layer has also significant influence on the strength of soil. Topography may to certain extent be benefitted in assessing trafficability of forest soils.*
Based on the key findings in the EFFORTE project, funded by EU, an operations protocol has been compiled. The protocol summarizes the best understanding about trafficability of forest soils. The protocol is meant as a guide for practical operations. The protocol is divided into three parts. The first part classifies forest soils in trafficability classes by wetness, soil type and topography. It is basically meant for areas with insufficient access to exact geographical data sources. The second part presents models that predict strength of soil and the third part enhanced map layers and computational models that may be utilized in predicting trafficability of soil prior to operations.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

EVALUATION OF A (THE HSM) TRIPLE BOGIE SYSTEM FOR FORWARDERS

Michael Starke [1], Felix Heubaum [2], Martin Ziesak [1]
[1] Bern University of Applied Sciences (BFH) – School of Agricultural, Forest and Food Sciences (HAFL), Bern, Switzerland
[2] Public enterprise Sachsenforst, Pirna, Germany
michael.starke@bfh.ch

Abstract: *Within the Forwarder2020 EU-Project, which is headed by "Hohenlohe Spezial Maschinenbau" (HSM), a new bogie axle was designed to especially suite wet and soft soil conditions. The new axle consists of 2x3 driven wheels in the same diameter, which makes the use of specifically designed, wetland bogie tracks possible. Nevertheless, the larger bogie axle with its bigger constructional parts leads to higher machine weight, which increases even more when using those large bogie tracks additionally.*
The aim of research during the field tests in Saxony strived to investigate the soil-related environmental impact of the new technology. The applied methodology is based on Heubaum & Padberg (2014) what is locally used as information database complement to the soil protection guidelines of the Saxonian Forest Commission. Therefor a cumulative multi-pass test was performed on several selected skid-trails with a fully loaded forwarder. In addition to the weight of the machine-setup, the soil shear strength, the soil humidity, topographic characteristics and the relating rut depth development were recorded. Afterwards, the machine was compared towards the existing datasets of the Saxonian Forest Commission regarding the observed soil conditions. Besides the manual rut depth measurements, terrestrial laser scanner (TLS) data were gathered after every second passage to test a potential data-source enhancement of the sample size.
The evaluation of a subset of the manually gathered data show, that especially under those conditions, where the soil bearing capacity is low and drops towards the technical feasibility of ground-based excavation the developed rut depts still do not exceed the 10cm warning threshold of the Saxonian Forest Commission after a defined amount of 90m3 of hauled timber. This superior performance of the triple bogie seems to hold still true with a higher number of passages as found in clear-cut hauling situations.

Keywords: Forwarder2020, triple bogie, soil protection, forest production, wetlands

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

COMPARISON OF DIFFERENT ESTIMATION METHODS TO WHEEL RUTS AND SOIL COMPACTION DURING HARVESTING OPERATIONS.

Elena Marra [1], Martina Cambi [1], Andrea Laschi [1], Fabio Fabiano [1], Francesco Neri [1], Cristiano Foderi [1], Enrico Marchi [1], Tomas Nordfjell [2]
[1] Dipartimento di Gestione dei Sistemi Agrari, Alimentari e Forestali (GESAAF), Università di Firenze, Firenze, Italy; [2] Department of Forest Biomaterials and Technology (SLU), Swedish University of Agricultural Sciences, Skogsmarksgränd, Umeå, Sweden
elena.marra@unifi.it

Abstract: *Forestry operation carried out by heavy machinery may results in substantial, long-lasting, and sometimes irreversible soil damages (increased soil erosion, reduced porosity and water infiltration). The damages extent and severity may be depending of harvesting systems, soil and machine characteristics. Contrasting results have been published about the effect of skidding and forwarding on soil compaction and rut formation. In order to analyses the spatial distribution of soil disturbance more accurately, new methods based on the 3D soil reconstruction have been developed. In this context, the overall objective of this study was compare rutting and soil compaction caused by forwarder and skidder. Innovative and traditional methods were applied for determining soil disturbances: i) manual measurement and 3D soil modelling by close-range photogrammetry and portable laser scanner analysis were used to determine rutting and soil displacement; ii) cone penetration resistance, soil bulk density and soil porosity measurements were used for determining soil compaction. Our findings show a relationship between soil compaction (i.e. cone penetration resistance) and rutting (i.e. total reduction of soil volume) in low moisture soil condition. The shortest data acquisition was observed during the portable laser scanning, while in accuracy rutting estimation was higher in close-range photogrammetry. The comparison of photogrammetric and manually-measured profiles confirmed that Structure For Motion photogrammetry can be an accurate instrument for the modelling of ground morphology and the analysis of soil disturbance after forest logging. Furthermore, the results showed the effect of harvesting systems on soil disturbance. In conclusion, soil disturbances were higher for skidder than for forwarder considering the same wood volume extracted.*

S09 CTL harvesting & Quality improvement
We make it better

RANGING SYSTEM FOR A FORWARDER AND A CUTTING SLOPE OF A LOGGING ROAD FOR AUTONOMOUS DRIVING

Sho Ono [1], Masahiro Iwaoka [2], Takeshi Matsumoto [2], Midori Uenohara [3]
[1] Graduate School of Agriculture, Tokyo University of Agriculture and Technology [2] Institute of Agriculture, Tokyo University of Agriculture and Technology [3] United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology

TOWARDS UNDERSTANDING THE EFFECT OF TREE SIZE UNIFORMITY ON HARVESTER PRODUCTIVITY USING MACHINE STANFORD DATA IN A SOUTH AFRICAN CONTEXT

Simon Ackerman [1], Rasmus Astrup [2], David Drew [1]
[1] University of Stellenbosch, South Africa; [2] The Norwegian Institute of Bioeconomy Research, Ås, Norway

ESTIMATING THE POTENTIAL OF TREE SELECTION TUTORIAL SYSTEM OF HARVESTER OPERATOR IN THINNINGS

Mika Vahtila [1], Kalle Kärhä [2], Heikki Ovaskainen [3], Ville Kankare [1], Timo Melkas [3], Asko Poikela [3], Veli-Pekka Kivinen [1], Markus Holopainen [1], Juha Hyyppä [4], Jarmo Hämäläinen [3]
[1] University of Helsinki, Helsinki, Finland; [2] Stora Enso Wood Supply Finland, Helsinki, Finland; [3] Metsäteho Ltd, Vantaa, Finland; [4] Finnish Geospatial Research Institute at National Land Survey, Helsinki, Finland

HARVESTING HEAD CALIBRATION: EFFORTS AND BENEFITS

Daniel Beaudoin [1,2], Luc LeBel [1,2,3]
[1] Consortium de recherche FORAC, Université Laval, Québec, Canada [2] Département des sciences du bois et de la forêt, Université Laval, Québec, Canada [3] Centre interuniversitaire de recherche sur les réseaux d'entreprise, la logistique et le transport (CIRRELT)

DEVELOPMENT OF A SMALL-SCALE HARVESTER FOR BIOMASS OPERATIONS

Kleydson Diego da Rocha [1], Thomas Gallagher [1], Timothy McDonald [2], Dana Mitchell [3]
[1] School of Forestry and Wildlife Sciences - Auburn University, Auburn, United States; [2] Department of Biosystems Engineering - Auburn University, Auburn, United States; [3] USDA Forest Service - Southern Research Station, Auburn, United States

EVALUATION OF PROCESSING HEAD MEASUREMENT IN MERCHANDIZING SOUTHERN YELLOW PINE IN SOUTHEAST US

Marisa Sitanggang [1], Thomas Gallagher [1], Timothy McDonald [1], Dana Mitchell [2]
[1] Auburn University; [2] US Forest Service

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 -Sopron, Hungary

RANGING SYSTEM FOR A FORWARDER AND A CUTTING SLOPE OF A LOGGING ROAD FOR AUTONOMOUS DRIVING

Sho Ono, Masahiro Iwaoka*, Takeshi Matsumoto and Midori Uenohara
Tokyo University of Agriculture and Technology
3-5-8, Saiwai-cho, Fucu-shi, Tokyo 183-8509, Japan
iwaoka@cc.tuat.ac.jp

Abstract: *Automated and unmanned operations are being investigated to reduce labor load and improve labor safety. This paper suggests running along the cutting slopes of logging roads to keep traveling on the roads, for the autonomous driving of forwarders. This study aims at identifying a suitable ranging sensor along with its mounting height and orientation, clarifying the relationship between the measured distances and actual positions of a forwarder on a logging road, and determining the control parameters for autonomous driving. For this, three types of ranging sensors were compared, and an ultrasonic sensor was chosen. The measurable angle between the incident wave of the sensor and surface normal was 25° with acceptable accuracy. The target distances to control the forwarder were 59.5–83.0 cm.*

Keywords: ultrasonic wave sensor, incident angle to surface normal, ranging accuracy, sensor position, control parameter

1. Introduction

Automated and unmanned operations are being examined to reduce labor load and improve labor safety. Forwarding is one of the typical operations used for such studies in the forests of Japan. This is because forwarders travel through the same path on logging roads that are constructed on steep terrain and connected between loading and unloading points. There have been several studies on autonomous driving of forwarders. Mozuna and Yamaguchi (2000) used permanent magnets and a fiber-optic gyroscope for indicating path and detecting the running direction. Mozuna et al. (2016) used human teaching operations along with the instruments used in the previous study. Shiratori et al. (2009) used stereo cameras for machine vision for road edge detection. Lastly, Usui and Mozuna (2018) used a time-of-flight camera to detect strip roads. However, these systems are currently under development.

This paper presents a new idea of running along cutting slopes of logging roads for autonomous driving of forwarders. The idea was formulated based on the belief that forwarders can continue traveling on logging roads when they maintain a suitable distance from the cutting slopes on logging roads constructed on steep slopes, such as in Japanese forests. There must be cutting slopes on such roads.

This study aims at identifying a suitable ranging sensor between a forwarder and cutting slope along with its mounting height and orientation, clarifying the relationship between the measured distances and actual positions of a forwarder on a logging road, and determining the control parameters for autonomous driving. For this, the features of a few ranging sensors are compared, and measurable angles between the incident wave from the sensor and the surface normal of cutting slopes are determined. Then, the ranging accuracy of actual cutting slope surfaces is clarified, and the control parameters of distances are discussed.

2. Materials and Methods

2.1 Sensor Selection

The parameters of the assumed logging road and a forwarder are shown in Figure 1. The road width $W_r = 3$ m, the forwarder width $W_f = 2$ m, and the angles of cutting slopes are $45 \leq \theta \leq 90°$. Therefore, the distances between the bottom of cutting slopes and forwarder are $0 \leq D_b \leq 1$ m. The distance between a ranging sensor and cutting slopes D_w (m) can be calculated using equation (1).

$$D_w = \frac{\sin\theta + h\cos\theta}{\sin\theta\cos\alpha + \cos\theta\sin\alpha} \quad (1)$$

where θ, h, α are cutting slope angle, mounting height of the ranging sensor, and dip angle of the ranging sensor respectively.

Therefore, D_w takes the minimum value of 0 m when θ is 90°. Further, D_w takes the maximum value of $h + 1$ m when θ is 45° and α is horizontal.

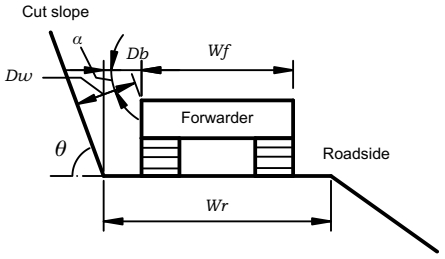


Figure 1 Parameters of logging roads and a forwarder

Ranging sensors need to measure more than the maximum value of D_w, which depends on the mounting height of the sensor. If the mounting height is 2 m at the highest point, ranging sensors would need to measure more than 3 m. Furthermore, ranging sensors need to measure accurately even if they get dusty or dirty as forwarders are used off-road.

The following three types of ranging sensors were used: laser ray, infrared ray, and ultrasonic wave. These are compared in Table 1. All the three types of sensors have enough maximum range distances; however, an infrared ray sensor needs to be confronted with smooth measurement surfaces. Furthermore, a laser ray sensor is weak in terms of resistance toward dust and dirt. Therefore, an ultrasonic wave ranging sensor was chosen. The specifications of an ultrasonic wave ranging sensor, HC-SR04, manufactured by SainSmart, are listed in Table 2.

Table 1. Comparison of characteristics of ranging sensors

Criteria	Laser ray	Infrared ray	Ultrasonic wave
Maximum range distance	More than 10 m	A few meters	A few meters
Direction of measurement surfaces	Accepts some tilt	Facing the sensors	Accepts some tilt
Measurement surfaces	Rough	Smooth	Rough
Resistant to dust and dirt	Weak	Weak	Strong

Table 2. Specifications of ultrasonic wave ranging sensor HC-SR04 (manufactured by SainSmart)

Item	value
Operating voltage	5 V (DC)
Operating current	15 mA
Frequency of ultrasonic wave	40 kHz
Ranging distance	2 – 400 cm
Diffusion angle	15°

The ranging sensor was controlled by a microcontroller board called the Osoyoo UNO Board, which is fully compatible with Arduino UNO Rev3.

2.2 Measurable Angles

An ultrasonic wave ranging sensor cannot measure accurate distances when the incident sonic wave from the sensor is not perpendicular to the measurement surface (Okugumo, 2013). The distances between a metal flat board and the sensor were measured to identify the acceptable angle with which the sensor could measure the exact distance. The point where the board was perpendicular to the incident wave was defined as 0° of the board tilt angle (θ in Figure 2). This angle was increased from 0° in steps of 10 or 1° until a non-accurate distance was measured. The measured distances between the board and the sensor were 10, 20, 40, 60, 80, 100, 125, 150, 175, 200, 225, and 250 cm. Three sets of 35 measurements were repeated for each combination of the distances and angles.

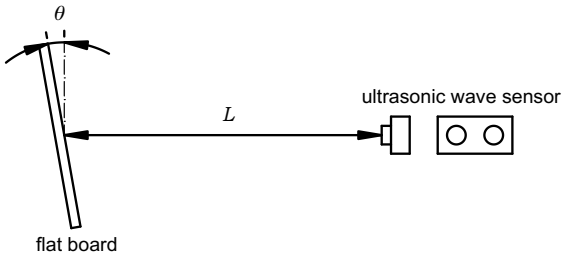


Figure 2 Experiment on measurable angle

2.3 Ranging Accuracy of Actual Cutting slopes

The experiments to clarify the ranging accuracy of actual cutting slope surfaces were conducted in Sano, Tochigi prefecture and Ome, Tokyo, Japan. Nine cutting slopes were used to measure distances between the slope surface and sensor; two slopes were in Sano and the other seven were in Ome.

The actual surface shapes of the cutting slopes were measured, before the experiments, by a staff with the use of a laser rangefinder and slant rules. The staff leaned against the cutting slopes between the top and bottom of the cutting slopes and the leaning angle was measured by using slant rules. The perpendicular distances from the staff to the cutting slope surface were measured by using the laser rangefinder at each 10 cm distance from the bottom of the staff.

The measurements were conducted at horizontal distances of 30, 80, 130, 140, and 200 cm between the bottom of the cutting slopes and the ultrasonic wave ranging sensor (L in Figure 3), and at sensor's ground heights of 55 and 120 cm (H in Figure 3). A set of 35 measurements were conducted for each combination of L and H.

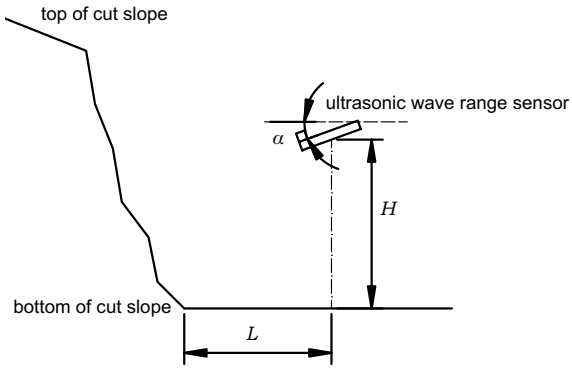


Figure 3 Experiment on ranging accuracy of actual cutting slope

3. Results

3.1 Measurable Angles

The measured distances between the tilted flat board and the sensor at distances of 10, 60, 100, 125, 150, and 175 cm are shown in Figure 4. The dotted lines in the figure indicate theoretical calculated distances. The measured and calculated distances are well-fitted when the tilt angles are smaller than 25°. Therefore, the sensor can measure the exact distances when the angle between the measurement surface and the incident wave is between 75–90°. This implies that the distances to the cutting slopes where the slope angles are between 45 and 90° can be measured accurately using the sensor with a dip angle of 20°.

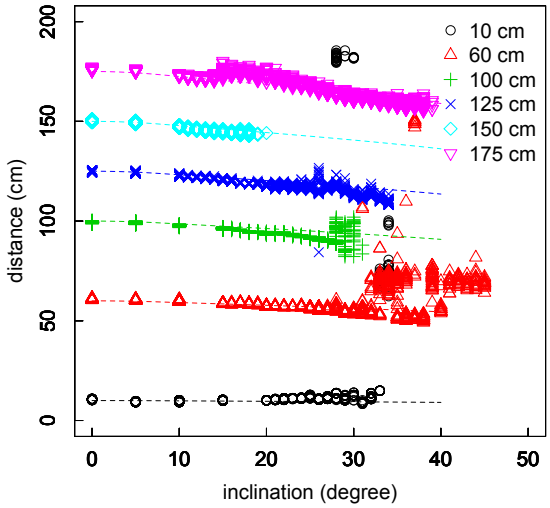


Figure 4 Measured and calculated distances between the tilted flat board and sensor

3.2 Ranging Accuracy of Actual Cutting slopes

From the above results, the dip angle α of the ranging sensor was set to 20°. The measured distances between the actual cutting slopes and the sensor are shown in Figure 5. The horizontal axis indicates the distances calculated from surface shapes of the cutting slopes. The two sets of measured values with large residuals are indicated by "+" and "Δ". The values indicated by "+" are measured with 200 cm of horizontal distance L and 120 cm of height H at the cutting slope 1 in Sano and the values indicated by

"Δ" are measured with 32.3 cm of horizontal distance *L* and 120 cm of height *H* at the cutting slope 12 in Ome. The reason behind these points having such large residuals is unclear, however, the other points have residual standard deviations of minimum 0.27 and maximum 14.94. No significant relationship was observed between the residual standard deviations and the calculated distances.

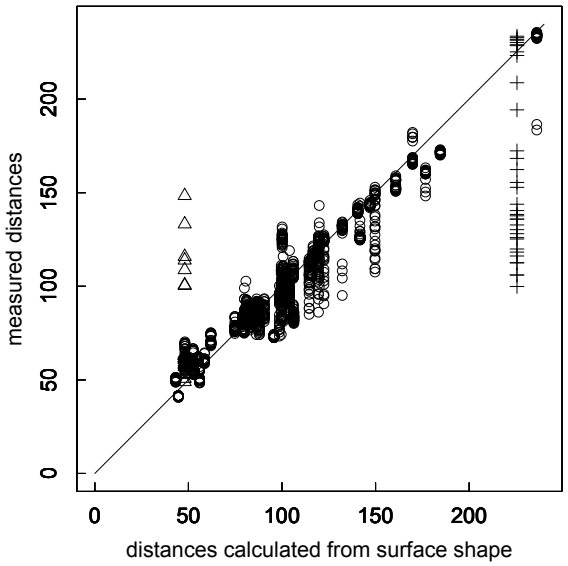


Figure 5 Measured and calculated distances between actual cutting slopes and the sensor

4. Discussion

4.1 Reliability of the Results

The accuracy of the measured distances becomes lower when the angle between the incident wave and measured surface normal becomes greater than 25°. Mataric (1992) reported that the used ultrasonic ranging sensor had a high accuracy for incident angles less than 15° from the surface normal, based on the sensor's handbook. Additionally, Takamura et al. (1996) reported that the used ultrasonic ranging sensor had a high accuracy for incident angle less than 20° from surface normal. On the other hand, Okugumo (2013) measured the incident angles with 100 % success measurements and reported that the angles were approximately 30° and a few degrees from surface normal, when the measured distances were 0.5 and 1.5 m, respectively, using the pulse-echo method. Our low-cost ultrasonic ranging sensor has almost the same or higher robustness to the angles between the incident wave and the surface normal.

Emaru and Tsuchiya (2000) indicated that the chances of a measurement miss increased with surfaces where it was difficult to obtain echoes. Our results from the measurements with actual cutting slopes indicate that a sensor can measure distances to uneven surfaces, although the measured values contain errors.

4.2 Acceptable Observation Values of Control Forwarders

Actual distances can be estimated from observed distances; however, the estimated values include errors because the observations include errors as described in the results. The dotted lines in Figure 6 show 95 % prediction interval for estimated values of actual distances calculated from observed distances excluding the large residual values.

Here, acceptable observation distances for a forwarder to continue traveling on a logging road are estimated when the height and dip angle of the ranging sensor are 55 cm and 20°, respectively. The actual distance D_w, between the sensor and the cutting slope surface, is minimum 0 cm with 90° of cutting slope angle θ and maximum 40.8 cm with 45° of θ when the horizontal distance D_b between the bottom of the cutting slope and the sensor is 0 m. Further, D_w is minimum 102.4 cm with 90° of θ and maximum 114.9 cm with 45° of θ when D_b is 1 m. Therefore, when D_w is between 40.7 and 102.4 cm, a forwarder can keep traveling on a logging road with any θ. When D_w is 40.7 cm, the maximum observed value of 59.5 cm can be calculated using the lower prediction line, as shown in Figure 6. Moreover, when D_w is 102.4 cm, the maximum observed value of 83.0 cm can be calculated using the upper prediction line, as shown in Figure 6. Therefore, a forwarder must be controlled to keep the observation distance between 59.5 and 83.0 cm to continue traveling on a logging road with any cutting slope angle.

Further, using the above procedure, the minimum and maximum height of a sensor to keep a forwarder traveling on a logging road can be calculated as 52.1 and 65.8 cm, respectively.

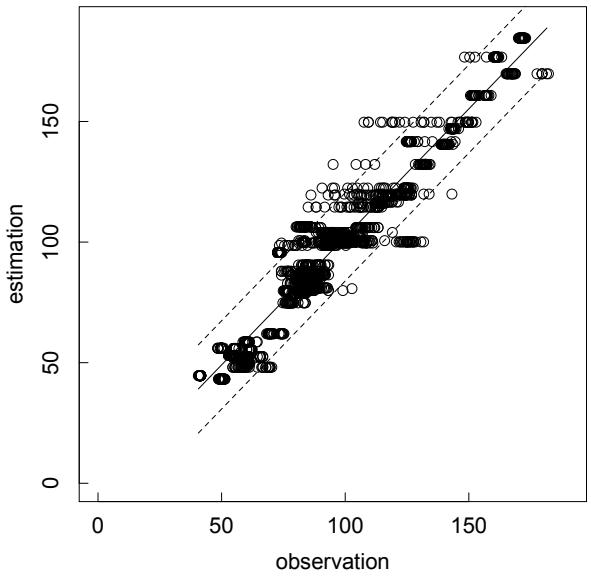


Figure 6 95 % prediction interval for estimation of actual distances from observation

5. Conclusions

In this study, three types of ranging sensors were compared and an ultrasonic wave ranging sensor was chosen for ranging distances between a forwarder and a cutting slope of a logging road for autonomous driving of a forwarder. The sensor's acceptable angle between the incident wave and surface normal was 25°, which is almost same or larger than that of previous studies. When the distances to the actual cutting slopes were measured, the standard deviations of most of the measured residuals were between 0.27 and 14.9. However, some observations contained larger residuals. The reason for this is yet to be identified.

The height of the sensor had to be between 52.1 and 65.8 cm above ground for an assumed forwarder to continue driving on an assumed logging road. The observed distances to the cutting slopes had to be between 59.5 and 83.0 cm when the height and dip angle of the sensor was 55 cm and 20°, respectively. These observed distances become a target value for controlling autonomous driving.

References

Emaru, T., Tsuchiya T. (2000), "Research on Estimating the Smoothed Value and the Differential Value of the Sensor Inputs by Using Sliding Mode System : Application to Ultrasonic Wave Senser". Transactions of the Japan Society of Mechanical Engineers Series C, 66, 3947–3954. doi: 10.1299/kikaic.66.3947

Mataric, M.J. (1992), "Integration of representation into goal-driven behavior-based robots", IEEE Transactions on Robotics and Automation, 8, 304–312. doi: 10.1109/70.143349

Mozuna, M., Yamaguchi, H. (2000), "Development of the autonomous forwarder that used permanent magnets and optical fiber gyro", Journal of The Japan Forest Engineering Society, 15, 197–204. doi: 10.18945/jjfes.KJ00007484813

Mozuna, M., Yamaguchi, H., Ito, T., et al (2016), "Development of operational support technology of a forwarder by remote control and automated travelling function", Bulletin of the Forestry and Forest Products Research Institute, 15, 91–102. doi: 10.20756/ffpri.15.4_91

Okugumo, M. (2013), "Development Research on Ultrasound Sensor System aiming at External Recognition of a car", Research reports of Yonago National College of Technology, 48, 22–26.

Shiratori, R., Mori, Y., Aruga, K., Tasaka, T. (2009), "Research on running route extraction technique for forwarder using stereo image processing", Journal of The Japan Forest Engineering Society, 23, 233–237. doi: 10.18945/jjfes.KJ00005490426

Takamura, S., Nakamura, T., Asada, M. (1996), "Behavior-based map representation for a sonar-based mobile robot by statistical methods", Advanced Robotics, 11, 445–462. doi: 10.1163/156855397x00155

Usui, K., Mozuna, M. (2018), "Strip road detection using TOF camera for autonomous forwarder", Journal of The Japan Forest Engineering Society, 33, 193-198. doi: 10.18945/jjfes.33.193

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

TOWARDS UNDERSTANDING THE EFFECT OF TREE SIZE UNIFORMITY ON HARVESTER PRODUCTIVITY USING MACHINE StanForD DATA, IN A SOUTH AFRICAN CONTEXT

Simon Ackerman, David Drew and Rasmus Astup
Department of Forestry and Wood Science
Faculty of Agri Science
Stellenbosch University
Private Bag X1, Matieland, 7602, South Africa

ackerman@sun.ac.za

Abstract: *Management practices in plantation forestry aim to maximise merchantable timber yield from a timber stand at end of rotation. This is primarily achieved by intensive site preparation, planting stock management, growing stock establishment, post-plant tending and reduced timber waste at harvesting. Uniformity of tree size, stem form, fibre quality and the arrangement of trees spatially has been hypothesised to maximise timber yield per hectare. Furthermore, this stand uniformity has also been suggested to improve harvesting efficiency, particularly in mechanised operations. This has led to the paradigm that forestry management should ensure high levels of uniformity at all cost.*
However, in a supply chain context, the relationship between the cost of achieving optimum uniformity against potential gains in yield and improved harvesting productivity is not fully understood. These increased cost may not be offset by potential higher yield, improved product quality or reduced production costs. To this end there is a need to establish and quantify this relationship.
This investigation aims to understand the effect of tree size uniformity on end of rotation processes (harvesting) by analysing machine on-board-computer StanForD (.stm) files over a period of 12 months. Data were generated by four machines operating in Pinus patula saw timber clear-felling operations. Non-linear least squares functions were fitted. The models were used to describe the effect of DBH, tree volume, the size of the machine and site index (site quality) factors on machine productivity. These functions can be used to predict machine productivity based on the abovementioned factors with the overall aim of developing site (compartment) based harvesting costs. These models and derived costs could contribute to more effective management of the type of machines harvesting timber on different tree diameter distributions for difference site quality classes. The approach of using these machine data for productivity modelling is a first for South African commercial forestry.*
Keywords: Forest engineering, uniformity, productivity, StanForD, modelling, *Pinus patula, saw timber*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

ESTIMATING THE POTENTIAL OF A TREE-SELECTION TUTORIAL SYSTEM FOR HARVESTER OPERATOR IN THINNINGS

Mika Vahtila[1], Kalle Kärhä[2*], Heikki Ovaskainen[3], Ville Kankare[1], Timo Melkas[3], Asko Poikela[3], Veli-Pekka Kivinen[1], Markus Holopainen[1], Juha Hyyppä[4] & Jarmo Hämäläinen[3]

[1] University of Helsinki
Faculty of Agriculture and Forestry
P.O. Box 27, FI-00014 University of Helsinki, Finland
mika.vahtila@gmail.com, ville.kankare@helsinki.fi, veli.kivinen@helsinki.fi,
markus.holopainen@helsinki.fi

[2] Stora Enso
Wood Supply Finland
P.O. Box 309, FI-00101 Helsinki, Finland
kalle.karha@storaenso.com

[3] Metsäteho Ltd
Vernissakatu 1, FI-01300 Vantaa, Finland
heikki.ovaskainen@metsateho.fi, timo.melkas@metsateho.fi, asko.poikela@metsateho.fi,
jarmo.hamalainen@metsateho.fi

[4] Finnish Geospatial Research Institute at National Land Survey
P.O. Box 84, FI-00521 Helsinki, Finland
juha.coelasr@gmail.com

Abstract: *The productivity and quality of cutting work in mechanized thinnings are highly dependent on the harvester operator. Operator tutorial systems can be assessed in terms of their potential to improve the working performance of an operator. Sensor technologies, based on Mobile Laser Scanning, Machine Vision, or a combination of these, enable the development of intelligent operator guidance. This study investigated the potential of tree-selection tutorial systems. Tree-marking was utilized to guide professional operators on trees recommended for removal, the effect of which on the cutting time was clarified by a comparative time study. On the tree-marked time-study plots, the trees to be removed were marked with paint, and the standard thinning work was conducted on the reference study plots. The quality of the trees of growing stock was measured after the cutting tests. Data collected during August-September 2018 in Finland on the first and later thinning stands included participation from four experienced harvester operators who removed 4,825 trees. The results suggested that the tree-marking significantly influences the work phase time boom-out as well as moving the harvester during cutting work. The cutting of tree-marked thinning stems was more than 2% faster than that of the reference stands, making the thinning intensity closer to the forest management recommended target level set by the Finnish Forest Centre. The reduced time for cutting enabled by the tree-marking process does not cover the costs of the tree-selection tutorial system. Therefore, additional impacts of harvester operator tutorial systems on the harvesting costs as well as the ergonomics, wellbeing of the operator and the duration of operator training programs must be considered in feasibility analyses for tree-selection tutorial systems. Acquisition costs of novel sensor systems are expected to be reduced through possibilities for utilizing the technology in other applications, such as forest resource inventory and bucking control.*

Keywords: sensor technology, mobile laser scanning (MLS), machine vision (MV), tree-marking, cutting, time study

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

HARVESTING HEAD CALIBRATION: EFFORTS AND BENEFITS

Daniel Beaudoin [1,2], Luc LeBel [1,2,3]
[1] Consortium de recherche FORAC, Université Laval, Québec, Canada [2] Département des sciences du bois et de la forêt, Université Laval, Québec, Canada [3] Centre interuniversitaire de recherche sur les réseaux d'entreprise, la logistique et le transport (CIRRELT)
daniel.beaudoin@sbf.ulaval.ca

Abstract: *Millions of dollars have been invested in sawmills to improve lumber recovery factor. Sawmills also rely on an incentive systems to be supplied with the logs they desire. About 15 % of a contractor's revenues is subjected to the log compliance rate he achieves. Most contractors do not calibrate the measuring apparatus of their harvesting heads. Some adjust log lengths by modifying the limiting values for the "bucking window" (i.e., the values that the computer uses to determine when to cut a log) rather than by calibrating the system. Because of the lack of control over the measurement errors, log specifications from the sawmills require excessive over length on each logs to reduce the number of under size logs delivered at the sawmill. Despite numerous investments in the mills, the lack of control over the measuring apparatus of the head limits the lumber recovery factor and the value at the sawmills. The main objectives of the project were to: 1) quantify the required effort for the contractor to maintain the measuring apparatus of the head properly calibrated, 2) evaluate the financial gains for the contractor, and 3) evaluate the gain in value at the sawmill.*
Calibration protocols were tested and implemented in the field. Three Ponsse H7 harvesting head were monitored from June 2017 to February 2018. The contractors kept a log book where they recorded the time (machine and men) spent on calibration activities. Discrete-event simulation was used to evaluate the financial gains for the contractors and at the sawmill.
It was found that keeping a harvesting head properly calibrated took in average 0.7 machine-hour and 2.3 man-hour weekly. Implementation of the calibration protocols improved significantly log compliance rate and resulted in an increase of 0.30 $/m3 in revenues for the contractors. The reduction of log over lengths and in bucking errors improved value at the sawmill by 3%.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

DEVELOPMENT OF A SMALL-SCALE HARVESTER FOR BIOMASS OPERATIONS

Kleydson Diego da Rocha*[1], Tom Gallagher[1], Tim McDonald[2], Dana Mitchell[3]
[1]: School of Forestry and Wildlife Sciences
Auburn University, Auburn, Alabama, USA
*: kdd0020@auburn.edu; gallatv@auburn.edu

[2]: Department of Biosystems Engineering
Auburn University, Auburn, Alabama, USA
mcdontp@auburn.edu

[3]: USDA Forest Service
Southern Research Station, Auburn, Alabama, USA
dana.mitchell@usda.gov

Abstract: *Concerns about population growth and the availability of conventional non-renewable sources of energy have sparked lots of emphasis for studies about renewable energies. Biomass is an alternative source of energy that can be very successful in the United States where there is a surplus of growing stock of forests. While very promising, new development in the USA about how to improve this market has been slow to occur. Our objective is to develop a small-scale machine that can be used as a feller-buncher for biomass harvesting. As it is known that most woody biomass availability is in small diameter material, we are going to use a mini hydraulic excavator as a basis for this study, making modifications to its boom, and adding an auxiliary motor that will make the machine more productive and economically feasible while aiming for Timber Stand Improvements (TSI).*

Keywords: biomass, small-scale harvesting, TSI

1. Introduction

For many years our society has relied on the use of fossil fuels such as petroleum to supply its energy demands. Although these fossil fuels can be used in many ways, their use is limited by scarcity, the impossibility of production during a human lifespan, and their negative impacts on the environment. During the last few decades the adoption of renewable energy sources has been discussed and implemented as a clean and continuous alternative to fossil fuels. In the United States, many different types of renewable energies could be adopted, woody biomass is one type which presents high chances of success. Woody biomass presents a lot of potential in the USA because it has an impressive 310 million hectares covered by forest lands and a surplus in the growing stock of forests (United States, 2019).

Plant biomass as a source of energy is currently directly associated with the use of residues or forest by-products such as bark, black liquor, sawdust and shavings. The addition of non-commercial roundwood as material for biomass production could bring biomass importance to higher levels (Thiffault et al 2016). Two main advantages of the use of woody biomass are fewer environmental concerns, as well as better opportunity cost especially because the non-commercial trees usually do not have high value. Estimations, however, show that by 2022 the potential of forestry resources to produce biomass will be underused by approximately 42% (Langholtz et al., 2016).

For woody biomass production to be efficient, there is a high need of small-scale machinery for the harvesting of the trees, especially because biomass availability is higher in small tracts of forests, and/or in the trees with smaller DBH (diameter at breast height). Out of the commonly utilized forest harvesting systems in the United States, however, whole-tree systems are the most common. This system is fully mechanized and most of the times composed by large machinery (Conrad et al. 2018). Current harvesting systems can be very impactful for the environment and a lot of the times their use is physically challenging. Therefore, current harvesting systems are not fully adequate for the type of operations required for biomass.

Unlike many other parts of the world, most of the forest land in the United States is privately-owned. The South itself is a very unique region with a higher percentage of privately-owned forests in the US, as much as 87%. There are approximately 11 million individuals and families who possess forest lands in the USA and from those, around 61% of the landowners own 10 or fewer acres (Butler 2014, MacDicken et al. 2016). While industrialization and the need for continuous growth keep pushing the boundaries for the development of higher-end machines and large-scale development, that portion of individuals and families who own small areas of forests is most of the time forgotten or not targeted. The smaller forest areas that are maintained for beauty, heritage or recreational reasons can become profitable (or add different sources of income) if the right tools are provided (Parron et al. 2015, Luederitz et al. 2015).

There are few investments being made on the development of equipment for the harvesting of small-diameter trees. Based on this evidence, we propose to develop, test, and if successful promote a cost-effective harvesting method to produce biomass feedstock for the bioenergy market. We aim to achieve an environmentally friendly system, that has low capital and operational costs, and with high fuel efficiency.

2. Methodology

2.1 Study Area

The study will take place at the surroundings of Auburn University, Auburn – AL, USA. The harvesting operations will occur mainly in softwood (pine) stands as this forest type is prevalent in the region, but if possible, we plan on also harvesting hardwood stands. We will harvest during the first thinning season when the stand is around 10 years old. Additionally, when time and transportation allow, we intend to operate in the urban interface. The forest stands will be submitted to a series of timber stand improvement treatments. We plan on harvesting a couple hundred trees according to availability until we achieve a volume that is statistically significant.

2.2 Felling Using Excavator

Although a complete harvesting system includes processes from the laying of the trees to processing and delivering a product, this project will focus on the felling part of a harvesting system, this way economic and mechanical feasibility can be checked before extending investments to other areas. A small-excavator (Figure 1) model IHI 80 VX will be used as the basis for our studies with both a DFM saw (Dougherty Forestry Manufacturing) and Fecon shear head (Figure 2). The excavator chosen has a capacity of 41.98kW and weighs approximately 9 tons, that together with the rubber tracks will provide less soil compaction guaranteeing minimum impact on the environment.

Figure 1: Small excavator (IHI 80VX)



Figure 2: Fecon shear head and DFM saw head





To improve efficiency, two main modifications will be executed: 1) boom, 2) auxiliary hydraulic pump. The small excavator originally comes with a banana boom which allows for the machine to reach trees at certain distances without the operator having to drive from tree to tree; we believe, however, that by straightening this boom we will achieve faster movements which will count towards greater efficiency (Figure 3). Because this is a small excavator, we will improve its power by adding an auxiliary hydraulic pump (26.1kW motor - Briggs and Stratton #613477-2141). This new motor will be used exclusively to run

the head. After those modifications have been completed, we will have a piece of equipment that will be similar to a small-scale feller-buncher. We believe that we can minimize soil disturbance and maximize productivity.

Figure 1: Small excavator with modified boom



2.3 Study Design

During the first weeks of the project, the felling crew will undergo a trial format for the operators to become familiarized with both the equipment and the expected silvicultural regime. This phase will serve as a way of minimizing the human variability on the final results of the harvester. This stage will be done taking into consideration the Occupational Safety and Health Administration (OSHA) instructions regarding safety.
After the period of familiarization is complete, the felling crew will start their field tests. Thinnings focusing on various basal areas will be the main silvicultural regimen selected with some other regimen, aiming for timber stand improvements (TSI). Each field test will take place at the selected experimental units with an area of 1 hectare.

2.4 Data Collection and Analyses

Before the felling crew can go to the field, it will be necessary to estimate the productivity of the experimental units. In the softwood stands, pine trees with DBHs between 3 and 14 inches will be cut, measured and weighed. The height and DBH from these trees will be compared to those found on the tables of Clark and Saucier (1990). If our results are consistent to those found by Clark and Saucier with no significant deviation, we will proceed using these tables for estimation of green weight of harvested trees. Other similar methods will be used for the estimation of green weight of hardwood trees.

Stands that share the same characteristics and are on the same age class will be inventoried prior to harvesting. To guarantee control over confounding factors, the matching of the silvicultural regimen to the stands will be done randomly. It is expected that the felling operator will determine what trees are harvested based on

their experience, but there might be a need to mark the trees identifying to which regimen they belong. To detect how effectively the felling operations were conducted, some post-harvest inventories will be done which will determine the level of accuracy of the operator.

The time study method chosen will be elemental time studies as these tend to be more detailed and consider different sources of variability. Small HD video recorders will be the main piece of equipment for this data collection. These cameras will be attached to the exterior of the excavator cabin at an angle that best captures how the machine is operating. To estimate DBH, we will adapt a measuring system on the excavator, and, if not limited by time and/or cost, we will manually collect DBH measurements as a way of getting more accuracy in our data.

After the videos are shot on the field, the files will be meticulously reviewed in the office where we will assess how long it takes for each process to be completed. The processes that we are interested in are felling, selection of trees without bunching, selection of trees with bunching, laying bunch down, movement of the excavator without tree selection (no arm movement), reaching of the boom, stems per load or cycle, and various types of delays (mechanical {excavator or head}, operational, and others).

Additional information about the feller-buncher operation that can be important for identifying the characteristics of the system will also be collected. To measure the capabilities of the feller-buncher, we will combine the mean of trees per bunch and their respective DBH to cycle time which will give an idea of productivity; we will also analyze the number of trees our feller-buncher can reach before having to move the machine). Finally, topographic and ecological characteristics of the stand such as slope, terrain composition and roughness, understory, weather, and soil type will be used to compose our variables.

It is important to set minimum productivity that has to be achieved to evaluate the economic feasibility of this project. Previous studies using a similar system will be used as guidelines for the selection of the desired productivity. To determine a $/ton basis for each silvicultural regime, we will use machine costs calculations described by Tufts (1982 and 1985). Actual data which will be used for our calculations include the cost of the equipment which will be obtained by consulting the manufacturer and/or machine dealers; results of studies from renamed peers and publications; and data from field collection (cost of fuel, lube, repairs, and maintenance). The result of these analyses will be compared to those found by O'Neal and Gallagher (2007) and will be considered economically feasible if the productivity of the feller-buncher is increased by at least 50%.

One of our objectives is that our machine is environmentally friendly or that the damages from it are minimum. To identify if this objective will be met, we will study the damages to the remaining stand immediately after the feller-buncher is used. Line transects will be established to evaluate soil disturbance and damage to residual trees. We will use scales like those proposed by McMahon (1995) and Turcotte et al. (1991) to categorize soil disturbance; along our line transects, a few plots will be created where we will measure the extent of the damage to residual trees, these plots will be of 30m each and will be spread in a way that it is representative of the stands.

3. Justification

Although we understand that for biomass operations to occur a whole harvesting system including chipping and transportation should be developed, we see the importance of starting this project with the felling section as the success of this phase is mandatory for the execution of other phases of the system.

3.1. Lack of Investments in Small-Scale Machinery

The effectiveness of mechanization for logging operations has made this sector evolve towards bigger machines over time, but there is no consensus on whether this necessarily means innovation. Some studies have shown that loggers in the United States and Canada are conservative when it comes to investing in innovations and tend to focus on short term problems such as fuel prices, insurance costs, stumpage prices,

and mill quotas, while problems such as machinery efficiency are barely considered (Baker and Greene 2008, Blinn et al. 2014).

3.2. Current Small-Scale Logging Constraints

Manual harvesting in the United States can be an option for smaller areas when the objectives of the forest stands are for family use or without commercial intents. When some level of efficiency is expected from the forest operations, manual harvesting using chainsaws can be more expensive in the long run because of the cost associated with the many operators *vs*. single-operated machines, less productive and less safe. The final required product can also prevent the use of manual harvesting (Schweier et al. 2015; Vanbeveren et al. 2015). In terms of safety, forest operations are not known for being the safest and most ergonomic activities in the world. Exposure to frequent and excessive noise, such as the noise from chainsaws, for example, can cause Noise-Induced Hearing Loss (NIHL), a permanent loss that can lead to social and health problems. Excessive heat is also another major work problem, it can cause fatigue, loss of attention, and greatly improve the chances of accidents (Smith & Thomas 1993, Minette et al. 2007). Many of these ergonomic issues that are enhanced in manual operations can be reduced when in a small-scale machine (e.g. cabins with air conditioners and sound isolation).

3.3. Advantages of Small-Scale Harvesting

Motivations behind the adoption of small-scale harvesting systems may vary from case to case or can be the only feasible option for an area. One of the biggest determining factors of the adoption of small-scale harvesting is the reduction of costs and environmental impacts. Due to their sizes, smaller forest machines tend to have their retail price and operation costs reduced when compared to large-scale machines. Their size also reflects on how impacted an area is, small-scale technologies allow better flexibility and adaptability, resulting in potentially fewer damages to the environment (Updegraff & Blinn 2000; Bliss & Kelly 2008).

4. Expected Outcomes

We strongly believe that many benefits can be accomplished with the success of this project. We expect that by demonstrating the economic feasibility of our feller-buncher we can show the importance of developing small-scale harvesting systems to operate in large thinnings and TSI operations, as well as in smaller tracts of urban forests. Besides the economic benefits, there will also be a value to be added to the residual trees, which will be a reflection of an environment with less competition for nutrients and resources. This reduction in the competition can also improve forests' health. By removing the less desirable tree and utilizing them into a marketable product we will be getting the most out of the opportunity cost of those trees. Finally, the weight and size of this smaller feller-buncher should limit ground disturbance and be much less impactful when compared to common sized feller-bunchers, those characteristics will help to minimize sedimentation into surrounding streams.

We anticipate that this feller-buncher can be available for implementation as soon as production and profitability are shown. This equipment can be directed to tree-care companies, it can add to current logging contractors, it can be niche market for new contractors, or even be used by small-scale landowners for an extra source of income. The adoption of our feller-buncher also has the potential to increase local development by providing employment opportunities for the skilled local workforce in rural areas. Finally, future expansion of supplementary plants in rural areas will improve the scope of opportunity by providing near and stable markets for biomass and bioenergy.

5. References

Baker, S.A., and W.D. Greene. (2008). Changes in Georgia's logging workforce, 1987–2007. South. J. Appl. For . 32(2):60–68.

Blinn, C.R., T.J. O'Hara, D.T. Chura, and M.B. Russell. 2014. Status of the Minnesota logging sector in 2011 . University of Minnesota, St. Paul, MN. Staff Paper Series 226. 119 p

Bliss, J. C., & Kelly, E. C. (2008). Comparative advantages of small-scale forestry among emerging forest tenures. Small-scale Forestry, 7(1), 95-104.

Butler, B. (2014). Forest Ownership in. USDA. U.S. Forest Resource Facts and Historical Trends (pp. 13-17). Retrieved from: https://www.fia.fs.fed.us/library/brochures/docs/2012/ForestFacts_1952-2012_English.pdf

Clark. III, and J.R. Saucier. (1990): Tables for estimating total-tree weights, stem weights, and volumes of planted and natural southern pines in the southeast. Georgia Forest Research Paper – 79.

Conrad, J.L., IV, W.D.Greene, and P. Hiesl. (2018). A review of changes in US logging businesses 1980s–present. J. For . 116(3):291–303. doi:10.1093/jofore/fvx014

Langholtz, M. H., Stokes, B. J., & Eaton, L. M. (2016). 2016 Billion-ton report: Advancing domestic resources for a thriving bioeconomy, Volume 1: Economic availability of feedstock. Oak Ridge National Laboratory, Oak Ridge, Tennessee, managed by UT-Battelle, LLC for the US Department of Energy, 2016, 1-411.

Luederitz, C., Brink, E., Gralla, F., Hermelingmeier, V., Meyer, M., Niven, L., ... & Abson, D. J. (2015). A review of urban ecosystem services: six key challenges for future research. Ecosystem Services, 14, 98-112.

MacDicken, K., Jonsson, Ö., Piña, L., Maulo, S., Contessa, V., Adikari, Y., ... & D'Annunzio, R. (2016). Global Forest Resources Assessment 2015: how are the world's forests changing?.- Retrieved from http://www.fao.org/3/a-i4793e.pdf

McMahon, S. (1995): Accuracy of two ground survey methods for assessing site disturbance. Int. J. of For. Eng. 6(2):27-33.

Minette, Luciano J., Silva, Emília P. da, Souza, Amaury P. de, & Silva, Kátia R. (2007). Avaliação dos níveis de ruído, luz e calor em máquinas de colheita florestal. Revista Brasileira de Engenharia Agrícola e Ambiental, 11(6), 664-667. https://dx.doi.org/10.1590/S1415-43662007000600017

O'Neal, B.S., Gallagher, T.V. (2007) Designing and testing a small-scale biomass harvesting system in the eastern United States.

Parron, L. M., Garcia, J. R., de OLIVEIRA, E. B., Brown, G. G., & Prado, R. B. (2015). Serviços ambientais em sistemas agrícolas e florestais do Bioma Mata Atlântica. Embrapa Florestas-Livro científico (ALICE).

Schweier, J., Spinelli, R., Magagnotti, N., & Becker, G. (2015). Mechanized coppice harvesting with new small-scale feller-bunchers: results from harvesting trials with newly manufactured felling heads in Italy. Biomass and Bioenergy, 72, 85-94.

Smith, L. A. & Thomas, R. E. 1993. Ergonomics research in the southern United States.

Thiffault, E., Berndes, G., & Lamers, P. (2016). Challenges and opportunities for the mobilisation of forest bioenergy in the boreal and temperate biomes. In Mobilisation of Forest Bioenergy in the Boreal and Temperate Biomes (pp. 190-213). Academic Press.

Tufts, R.A. (1985): Equipment replacement analysis. The Compiler. 3(2):16-17

Tufts, R.A., and W. L. Mills, Jr. (1982): Financial analysis of equipment replacement. For. Products J. 32(10): 45-51.

Turcotte, D.E., C.T. Smith, and C.A. Federer. (1991): Soil disturbance following whole-tree harvesting in north-central Maine North J. Appl. For. 8(2):72-76.

United States (2019). Retrieved from: http://www.fao.org/countryprofiles/index/en/?iso3=USA

Updegraff, K., Blinn, C. R. (2000) Application of small-scale forest harvesting equipment in the United States and Canada. Collage of natural resources and Minnesota agricultural experiment station, University of Minnesota. Staff paper series no. 143, Minnesota

Vanbeveren, S. P. P., Schweier, J., Berhongaray, G., & Ceulemans, R. (2015). Operational short rotation woody crop plantations: Manual or mechanised harvesting?. Biomass and bioenergy, 72, 8-18.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

ANALYSIS OF PROCESSING HEAD MEASUREMENTS IN MERCHANDIZING SOUTHERN YELLOW PINE

Marisa Sitanggang[1], Thomas Gallagher[1*], Timothy McDonald[1], Dana Mitchel[2]
[1]School of Forestry and Wildlife Sciences, Auburn University, Auburn, Alabama, USA
[2]US Forest Service, Auburn, Alabama, USA
mzs0159@auburn.edu

Abstract: *Today's timber market in the Southeast US demands a specific size log; thus, the harvested trees need to be processed on the landing. In addition, merchandizing harvested trees is more profitable for the loggers as they are able process the timber to its highest economic value. The utilization of a processing head in the logging industry is encouraged due to the presence of technology advancement on the machine that allows the loggers to merchandize and top the logs by specifying the desired measurements into the processing head's computer program. The result from this study shows that, regardless of the amount of experience owned by the operator and whether a calibration was conducted on the machine, the measurements given by the processing head is not accurate. Continuing research to understand the extent of experience and calibration in the utilization of processing head in the Southeast US are encouraged.*

Keywords: processing head, merchandizing, accuracy, Southeast US

1. Introduction

The growing presence of sawmill across the Southeast US has provided a new challenge as well as the opportunity for the loggers around the area. The requirement to transport the specific size of logs to these mills is strictly enforced. Therefore, the loggers need to process the harvested trees on the landing before they are loaded to the truck. On the other hand, the loggers' ability to merchandize the stems is providing them the opportunity to gain a higher income compared to selling the harvested woods as tree length.

The practice of merchandizing is commonly conducted by the loggers using a pull-through delimber and a slasher saw that are attached to a knuckleboom loader. The knuckleboom operator delimbs and tops the harvested trees using the delimber and merchandizes them by utilizing the slasher saw. These processes rely on the operator's subjectivity in estimating the top diameter; hence, the result of topping and merchandizing are susceptible to measurement errors.

To avoid this subjectivity, the utilization of a processing head in the logging industry is encouraged due to the technology advancement on the machine. This technology allows the loggers to merchandize and top the logs by specifying the desired measurements into the processing head's computer program. Therefore, the incorporation of a processing head in logging operations is expected to provide the exact measurements of the logs. However, with such an effective measurement, its accuracy needs confirmation.

The ability to produce logs into accurate dimensions as desired using a processing head would likely to depend on the operator. An adequate amount of experience in operating a machine provides the operator with the skill to run the operation in the most efficient way, which results in maximum production. Kärhä et. al (2013) reported that an experienced operator performed 40% higher productivity compared to an inexperienced operator. Despite higher production, the experience would also likely to affect the accuracy of processed logs. As the machine savvy operator is familiar with the computer system and panel control that are installed on the head processing head, a higher accuracy on the processed logs is expected. Purfürst (2010) examined 32 operators to understand their learning curves. Forestry machine operators showed a

slow performance level as they start operating the machine and doubled the performance in their third year. It is identified that the operator's learning curve reaches a constant performance after nine months (Purfürst, 2010).

In addition to experience, the calibration is an important element in producing the desired log dimensions. Even though a processing head is designed to handle a heavy object (trees) in the field, the machine's accuracy could be compromised after a certain amount of usage. Therefore, it is important to keep the machine calibrated to ensure that the products are measured correctly. As reported by Nieuwenhuis and Dooley (2013), conducting harvester calibration regularly could reduce the difference between harvester measurements and manual measurements which resulted in the higher accuracy in the length measurement. Additionally, when a harvester is regularly calibrated, the accuracy on the volume of timber produced can be increased by 6% (Dooley et al, 2006).

This research aimed to evaluate the accuracy of a processing head in merchandizing logs. Statistical analysis is conducted to determine the significance of the difference between processing head and post measurement.

2. Material and Methods

The study sites were located in several operations in the Southeast US where the market for cut-to-length logs exists. The observed machines include the processing head manufactured by Waratah and Tigercat. In this study, the logs are processed based on the specifications that were determined by the mills. For every operation, the data collection was divided into 4 sets where each set contains 25 logs. In addition, several aspects of operating the machine are observed while collecting the data, such as the calibration conducted by the operator and the activity performed by the operator while processing the stems.

To confirm the measurement accuracy, two types of measurement were gathered in this study. The processor's measurements were obtained by recording the processor's monitor inside the cab, while the post measurements were obtained by manually measuring the processed logs. The logs were numbered directly after they were cut by the machine, to keep them in order in the post measurement. The processing head measurements were obtained after the recordings were reviewed. Meanwhile, post measurements were collected by measuring the length and diameter using a caliper and tape. The measurements collected in this research include the butt diameter, top diameter, and length of the logs. At the post-measurement, the diameter was measured as the inside-bark diameter.

Measurement difference was calculated as the difference of processing head measurement with post measurement.

$$Measurement\ difference = Processor\ head\ measurement - Post\ measurement$$

An analysis of variance was run to assess the significance of measurements difference between processing head and manual measurements on three logging operations. This analysis was analyze using R software for every data collected (butt diameter, top diameter, and length).

3. Result and Discussion

3.1. Data Distribution

3.1.1. Butt Diameter

The data distribution of butt diameter from logger A and logger B show a normal distribution, while the data from logger C is right-skewed (Figure 1). Logger C also shows high variability in the measurement differences. It ranges from -6.6 to 1.1 inches. Meanwhile, logger A and B depict a narrower data range (-0.7 to 3.5 and -1.1 to 3.5 respectively). Diameter distribution is highly concentrated from 0 to 2 inches differences for logger A, while the other loggers intensify between -0.5 to 1 cm in their measurement differences. Unlike the first two loggers, logger C shows a high number of underestimation of butt diameter measurements. The processing head recorded a smaller diameter than the actual butt diameter.

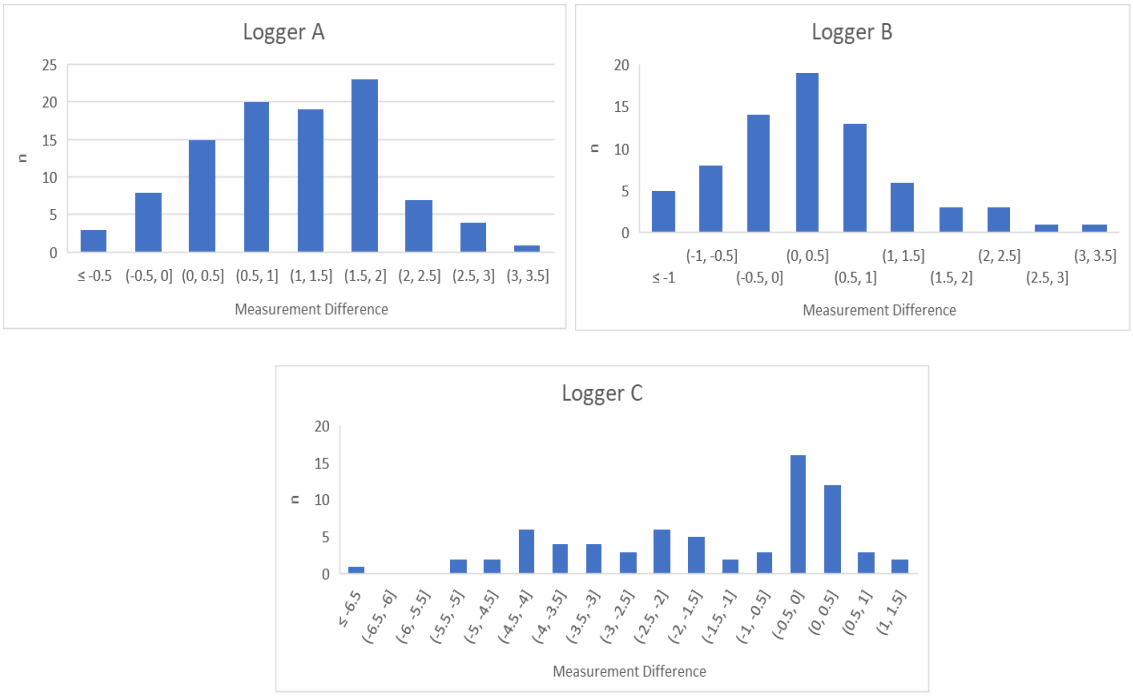


Figure 1. Butt Measurement Differences Distribution

3.1.2. Top Diameter

Data distribution for top diameter for all loggers is showing a normal distribution (Figure 2). The top diameter measurement differences concentrated from 0.5 to 2 inches for Logger A and -0.5 to 1 inches for logger B and logger C. The histogram shows underestimation was rarely performed by Logger A, whereas logger B and logger C are showing a higher number of samples that are underestimated.

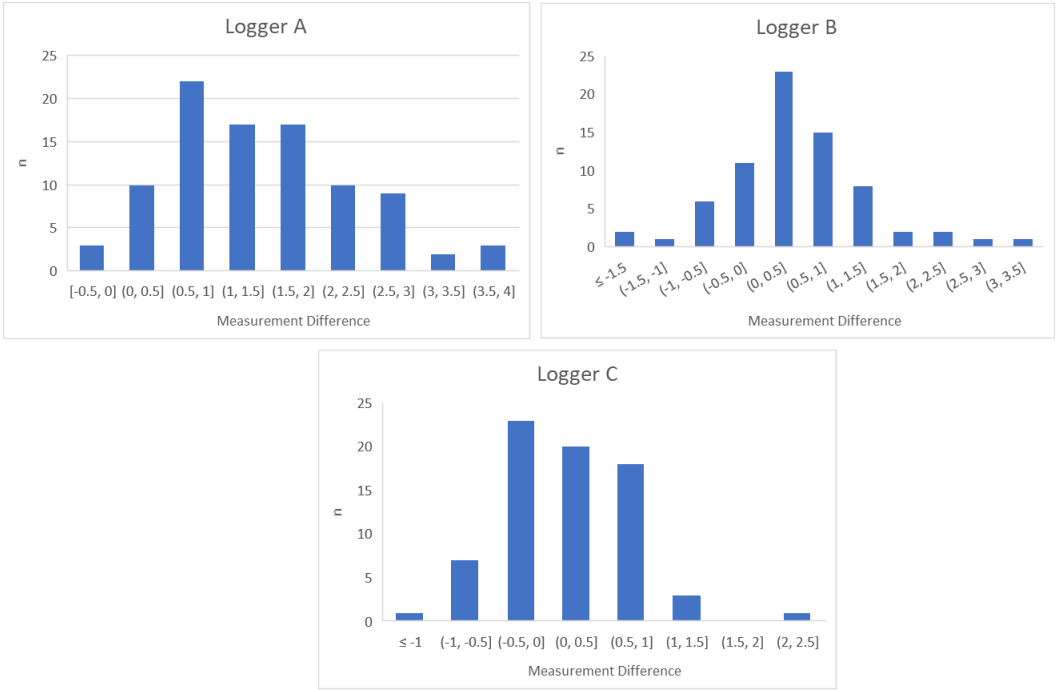


Figure 2. Top Measurement Differences Distribution

3.1.3. Length

As shown in Figure 3, the distribution data of length measurement differences are normally distributed for all loggers. The data from logger A indicates that mainly processing head gave a higher value than the actual measurement. A similar observation is seen on the data from logger B, although underestimation by the machine up to 0.6 feet was also observed. The highest length underestimation is observed from logger C, where the processing head is measuring logs shorter than the actual length by 0.8 feet.

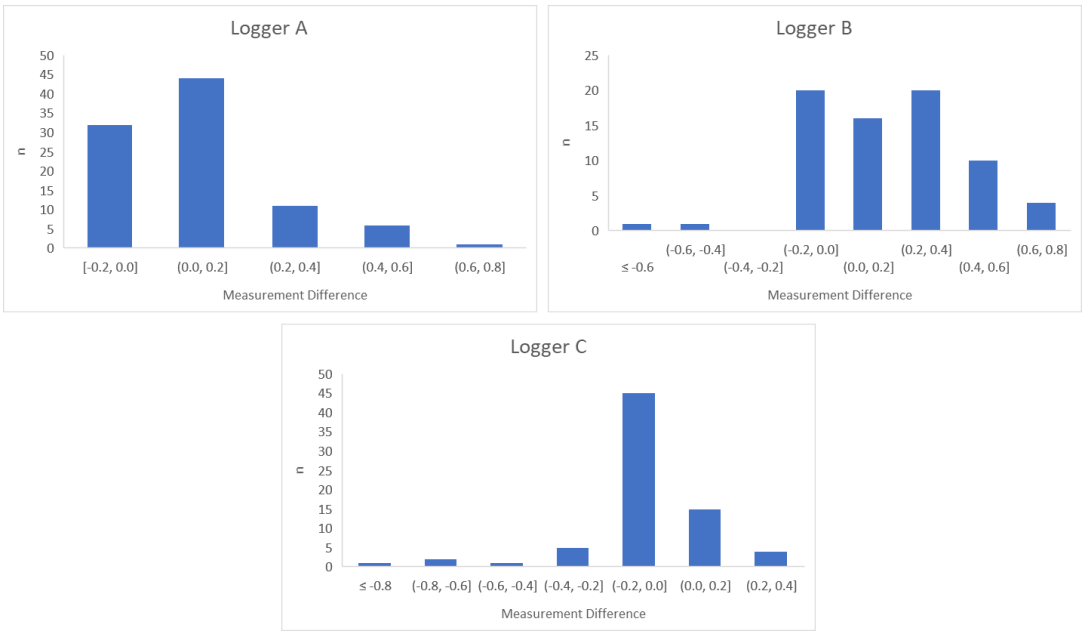


Figure 1. Length Measurement Differences Distribution

3.2. Measurement Differences Analysis

Table 1 shows that for logger A and B, the value given by processing head is higher compared to the manual measurement for all log dimensions. Meanwhile, the result of logger C is inconsistent. At this operation, butt diameter and length measurement differences show that the processing head measurement is giving lower values, whereas top diameter shows a similar correlation to measurement differences from logger A and B. As shown in the data distribution, logger C has a wide data range in the butt diameter and length measurement differences. It is also noted that for this logger, the processing head gave a smaller number in comparison to the post measurements. This results in negative measurement differences for the two log dimensions.

Table 1. Summary Data of Measurement Differences

Logger	Measurement Difference					
	Butt Diameter (in)		Top Diameter (in)		Length (ft)	
	Mean	SD	Mean	SD	Mean	SD
A	1.130	0.863	1.492	0.956	0.103	0.956
B	0.408	0.924	0.467	0.857	0.179	0.857
C	-1.525	1.895	0.222	0.571	-0.084	0.571

At the data collection, it was noticed that when a slash was not required (the stem is free from any defect), operator C did not run the machine to return to the stem's butt as he processed the trees. This resulted in a smaller butt diameter observed from the processing head as the measured diameter was away from the actual butt. The same situation observed for the length. Due to the inappropriate starting measurement, the processing head provided a lower number than the actual length.

Compared to the other two loggers, the diameter differences at operation A is the highest (1.13 and 1.492 inches). However, as the manually measured diameter was inside-of-bark, it is expected that the diameter measured by the processing head is 1 inch higher than manual measurement. Therefore, the diameter measurement differences from logger A, both for butt and top, was observed as the most accurate. In addition, logger A also provides the most accurate length measurement (0.103 feet length differences) compared to all loggers studied in this research.

The measurement difference between processing head and manual measurement could be caused by several reasons. The effect of operators' experience suggests a considerable impact in this study. Prior to conducting the data collection, an interview to understand the length of experience owned by each operator was conducted. The most experienced operator is from operation B with a total of experience for 16 years in running processing head, while operator A has 2 years of experience and operator C has only run the machine for approximately 100 hours. This insufficient experience caused different correlation of measurement differences in butt, length and top diameter. The measurement from this operation tends to underestimate the butt diameter and length yet overestimate the top diameter. The result from this study shows that experience of the operator plays an important role in producing logs with an accurate measurement. To obtain a more accurate measurement, it is recommended for the operator to run the machine from the butt of the harvested trees even though a cut from the butt is not needed.

Another factor that influence accuracy is the calibration. At the data collection, it was observed that from all operations, Logger A is the only operator who calibrated the machine. The calibration was conducted by the operator as the post-measurement data collection of the first set was performed. This calibration may contribute to the accuracy gained at this operation.

In spite of the aspects from the object studied, some measurement differences could also have resulted from the post-measurement error after the logs were processed. As an effort not to impede the operations, some processed logs were found to be overlapped on top of each other. Therefore, it resulted in difficult accessibility to manually measure the log dimensions.

Despite all the explained factors, the analysis of variance shows that processing head measurement is significantly different from post-measurement for all log dimensions in all locations studied (α=0.95). This implies that, regardless of the amount of experience owned by the operator and whether a calibration was conducted on the machine, the measurement by the processing head is not accurate. Therefore, continuing research is encouraged in order to understand the extent of experience and calibration in the utilization of processing head to merchandize southern yellow pine in the Southeast US.

4.Acknowledgements

We would like to acknowledge Auburn University, Fulbright, and United States Forest Service for supporting this research. We also appreciate all the loggers for their willingness to be involved in this study.

5. References

Dooley, T., Layton T., Nieuwenhuis, M. (2006), "The impact of Calibration on The Accuracy of Harvester Measurement of Total Harvest Volume and Assortment Volume for Sitka Spruce cCearfells in Ireland," Irish Forestry, 96-107.

Kärhä, K., Rönkkö E., Gumse S. (2013), "Productivity and Cutting Costs of Thinning Harvesters," International Journal of Forest Engineering, 15:2, 43-56.

Nieuwenhuis, M. and Dooley, T. (2006), "The Effect of Calibration on the Accuracy of Harvester Measurements," International Journal of Forest Engineering, 17:2, 25-33.

Purfürst, F. T. (2010), "Learning Curves of Harvester Operators," Croatian Journal of Forest Engineering, 32:2, 89-97.

K02 Keynote 02

DIGITALIZATION OF FOREST HARVESTING: THE POTENTIAL FOR IMPROVED ENVIRONMENTAL AND PRODUCTION EFFICIENCY
Rasmus Astrup
NIBIO

SMART FORESTRY - SMART FOREST OPERATIONS ENGINEERING AND MANAGEMENT
Hans R. Heinimann
ETH Zürich, Switzerland

LIFE CYCLE ASSESSMENT (LCA) IN FORESTRY
Martin Kühmaier
BOKU Vienna, Austria

FUTURE OF FOREST ENGINEERING AND ITS SUSTAINABILITY
Woodam Chung
Oregon State University, USA

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

LIFE CYCLE ASSESSMENT (LCA) IN FORESTRY

Martin Kühmaier[1], Iris Kral[2], Christian Kanzian[1], Gerhard Piringer[3]

[1]Institute of Forest Engineering, University of Natural Resources and Life Sciences, Peter-Jordan-Straße 82/3, A-1190 Vienna, Austria
martin.kuehmaier@boku.ac.at
christian.kanzian@boku.ac.at

[2] Institute of Agricultural Engineering, University of Natural Resources and Life Sciences, Peter-Jordan-Straße 82/3, A-1190 Vienna, Austria
iris.kral@boku.ac.at

[3]University of Applied Sciences Burgenland, Steinamangerstraße 21, A-7423 Pinkafeld
gerhard.piringer@fh-burgenland.at

Introduction

Assessing the environmental impacts of products and services gains an increasingly important role. Society is more and more realizing that resources on Earth are limited and therefore calls for a sustainable treatment of our environment. Life cycle assessment is a powerful but also complex tool for estimating environmental impacts. Although this method was already used in the 1970s, it played a minor role in forestry and was used mainly by a small group of experts. However, due to the increase of the need for tools estimating the environmental impact and the availability of more sophisticated databases, such evaluations have been made more and more, recently. While only 13 scientific publications were published in 2007 in the field of LCA in forestry, there number increased to 73 in 2017 (Figure 1).

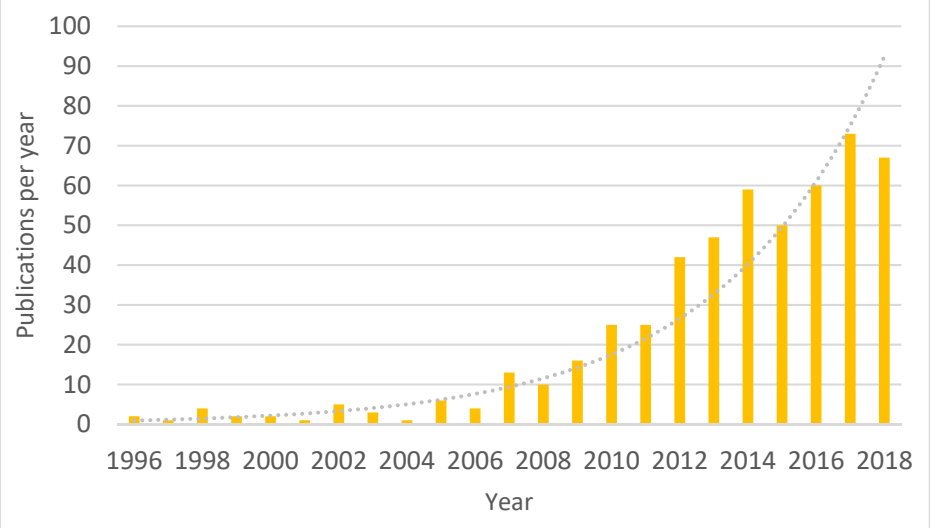


Figure 1: Publications in the field of LCA in forestry

LCA studies for Austrian forestry had been conducted seldom. Beside increasing interest of society in this topic, national regulations forces enterprises like the Federal Austrian Forests to report their environmental impacts of their activities on a yearly basis and to develop trajectories in reducing environmental impacts.

To support this activities, the goal of a national project was creating a LCA. For executing a LCA, primary and secondary data is usually considered. For assessing the production of machines and the supply of fuel and lubricants, information available in databases (secondary data) is used in particular. For the specific timber harvesting and transport processes, data from existing field studies was used or new data was collected (primary data). Among other things, the project identified fuel consumption and productivity data for chainsaws, harvesters, cable yarders, forwarders, tractors and forest trailers, tractors and winches, truck and rail transport, and resource consumption for forest road construction and maintenance.

Life Cycle Assessment of Timber Supply from the Forest to the Plant considering New Technologies

In Austria, for the first time within the framework of the project "Life Cycle Assessment of Timber Supply from the Forest to the Plant considering New Technologies", a life cycle assessment of the supply of wood from the forest to the plant was carried out. 38 timber supply processes have been analyzed (Table 1).

Table 1: Analyzed timber supply processes in Austria

ID	Process
1.1	Production, forest plants, in nursery, AT + transport, forest plants, with lorry, AT
1.2	Brush cutting, with brush cutter, AT
1.3.N	Brush cutting, with electric brush cutter, AT
2.1	Tending of young stand, with brush cutter, AT
2.1.N	Tending of young stand, with electric brush cutter, AT
2.2	Tending of thickets, with chainsaw, AT
2.2.N	Tending of thickets, with electric chainsaw, AT
3.1	Felling, with chainsaw, AT
3.1.N	Felling, with electric chainsaw, AT
3.2	Felling and delimbing, with chainsaw, AT
3.2.N	Felling and delimbing, with electric chainsaw, AT
3.3	Felling, delimbing and cross-cutting, with chainsaw, AT
3.3.N	Felling, delimbing and cross-cutting, with electric chainsaw, AT
3.4	Felling, delimbing and cross-cutting, with harvester, AT
3.4.N	Felling, delimbing, debarking and cross-cutting, with harvester, AT
3.5	Felling, delimbing and cross-cutting, with cable harvester, AT
3.6	Extracting, round wood, with tractor and forest trailer, until forest road, AT
3.7	Extracting, harvesting residues, with tractor and forest trailer, until forest road, AT
3.8	Extracting, round wood, with skidder, until forest road, AT
3.9	Extracting, trees, with skidder, until forest road, AT
3.10	Extracting, trees, with tractor and winch, until forest road, AT
3.11	Extracting, round wood, with tractor and winch, until forest road, AT
3.12	Extracting, trees, with cable yarder, until forest road & processing, trees, integrated processor, AT
3.13	Extracting, round wood, with wood pick, until forest road, AT (no emissions)

3.14	Extracting, round wood, with forwarder, until forest road, AT
3.15	Extracting, harvesting residues, with forwarder, until forest road, AT
3.16	Extracting, round wood, with cable forwarder, until forest road, AT
3.17	Extracting, round wood, with cable yarder, until forest road, AT
3.18	Cross-cutting, with chain saw, AT
3.19	Delimbing and cross-cutting, with excavator-processor, AT
3.20	Chipping, energy wood, with chipper mounted on truck, AT
4.1	Transport, round wood, with tractor and trailer, AT
4.2	Transport, round wood, with round wood truck, AT
4.3	Transport, round wood, with railway, AT
4.4	Transport, wood chips, with tractor and trailer, AT
4.5	Transport, wood chips, with truck, AT
4.6	Passenger transport, with passenger car, AT
4.6.N	Passenger transport, with electric passenger car, AT

Results

The results of the study show that timber transport usually has the highest environmental impact in the supply chain. The extraction as well as the felling and processing of wood have similar environmental impacts, whereby the chainsaw performs from an ecological point of view significantly better than the harvester. Looking at the greenhouse potential, the harvester usually emits 10 times more greenhouse gases than the chainsaw. When transporting timber, the transport distance is very important for the ecological efficiency. The transport with a round wood truck over 200 km creates more than 30 kg of CO_2 equ per m³ while transport over 50 km only emits 8 kg of CO_2 equ per m³ (Figure 2). In Austria, an average of 26 kg CO_2 equ per m³ is emitted for the supply of timber from the forest to the plant. In the small scale forests this value is about 1 kg CO_2 equ per m³ higher due to the higher share of energy wood.

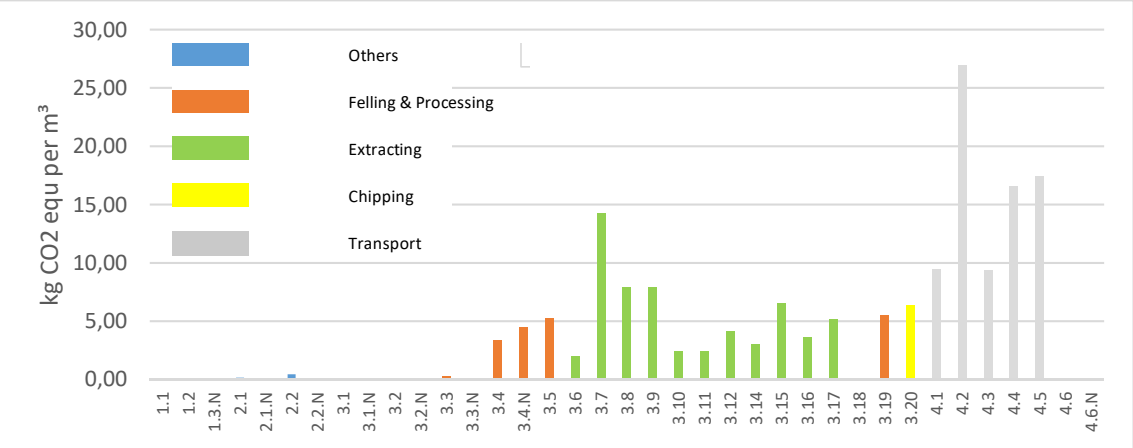


Figure 2: Global warming potential of timber supply processes

It has been shown that timber transport by truck is the largest emitter of greenhouse gases within the supply chain. Accordingly, the greatest savings potential would also be achieved here. Suitable measures for the reduction of GHG emissions include the reduction of transport distances (Figure 3), the increase of the share of rail transport, the reduction of fuel consumption or the use of non-fossil fuels.

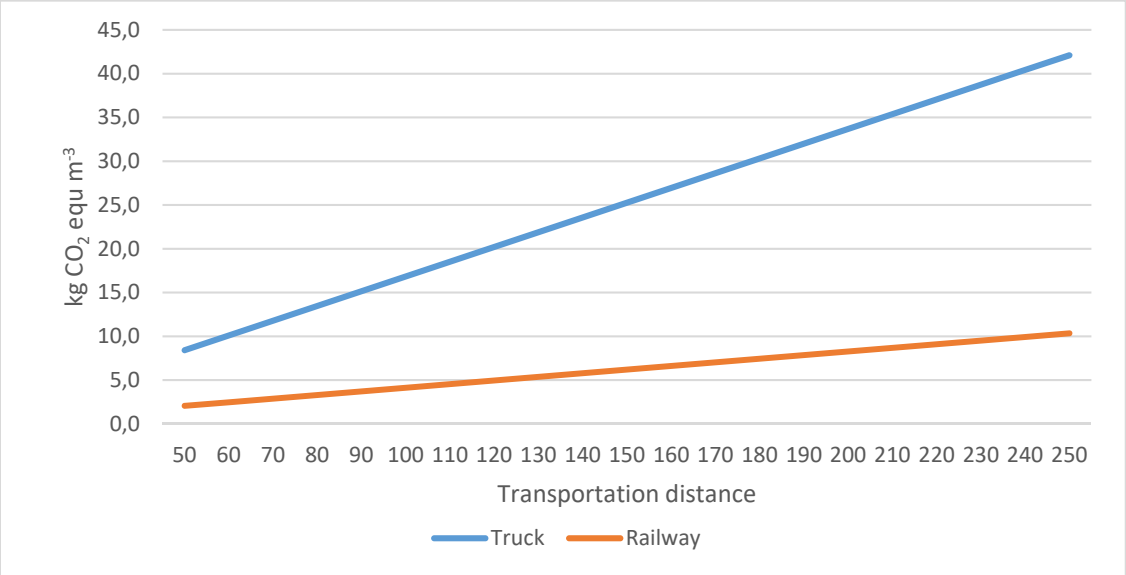


Figure 3: Effects of changing transport distances on global warming potential

Measures for reducing fuel consumption through machine settings and driver training, the use of bio diesel (Figure 4) or electric technologies also have great savings potential in timber harvesting. In Austria, there is, depending on the mix of measures, an annual savings potential of up to 100,000 t CO_2 equ. in timber harvesting and timber transport. Before implementation, however, the respective ecological improvement measures must always be compared with the technical and economic feasibility. New technologies based on electric or hybrid technology are still in the development phase and need further development steps in order to be able to be used extensively in timber harvesting and timber transport. The development steps for brush cutters, chainsaws and carriages are one step further and there are the first market-ready machines available. Hybrid technologies are already available for cable yarders, harvesters and forwarders.

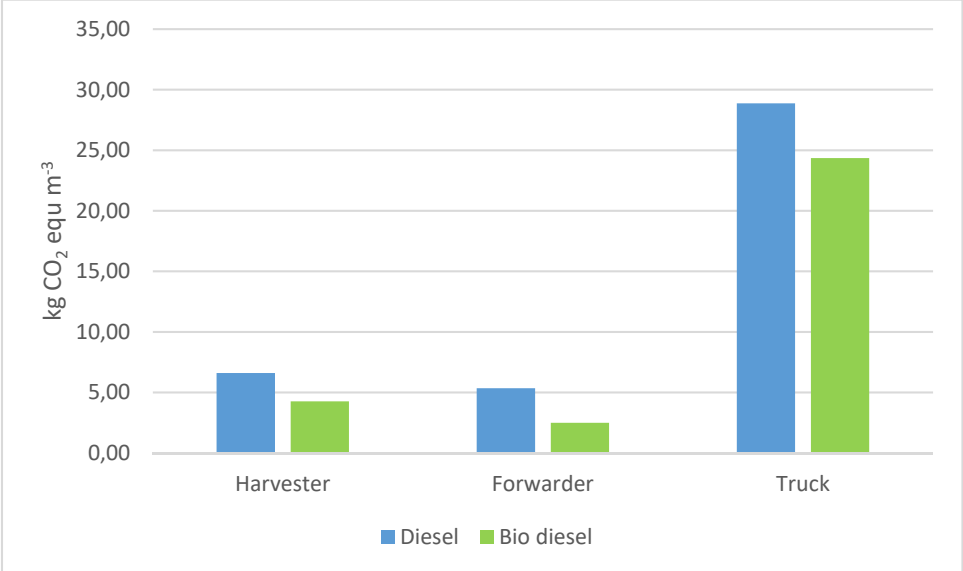


Figure 4: Effects of the transition from diesel to bio diesel on the global warming potential of harvester, forwarder and truck

For use by practitioners, two calculation tools have been developed. The "system calculator" allows the calculation of the global warming potential for the supply of 1m³ timber. Single supply processes can be selected and connected to a timber supply chain. By entering stand and location data, the environmental impact of specific harvesting operations can be calculated. This allows also the comparison with alternative

scenarios and the selection of the most environmentally sound timber supply chain. The “balance calculator” allows the calculation of the global warming potential for a forest district, a forest enterprise or another defined administrative unit. By entering the amount if harvested timber within a specified time frame for every harvesting and transport process, the total greenhouse emissions per process and subsequently for the assortments round wood, firewood, forest wood chips for the respective region are calculated.

Conclusion

The insights gained can be used to identify best practice examples and identify potential for improvement. The environmental impact of current usage patterns was analyzed to identify those processes that are highly polluting and have a high potential for improvement. Based on this, a package of measures tailored to the respective model operation was set up.

Keywords: life cycle assessment, environmental impacts, timber harvesting, timber supply, forestry

Acknowledgments: This publication is a part of the national funded project “Life-cycle-assessment of new technologies of timber supply from the forest to the plant (TILCA)”. The research leading to these results has received funding from the Austrian Federal Ministry for Sustainability and Tourism, Austrian State Forests and Forest Enterprise Franz Mayr-Melnhof-Saurau under grant agreement n° 101206.

S10 Steep terrain harvesting
Hold on tight

USING CONJOINT ANALYSES TO IMPROVE CABLE YARDER DESIGN CHARACTERISTICS: AN AUSTRIAN YARDER CASE STUDY TO ADVANCE COST-EFFECTIVE EXTRACTION

Martin Kühmaier [1], Hunter Harrill [2], Mohammad Reza Ghaffariyan [3], Manfred Hofer [4], Karl Stampfer [1], Mark Brown [3], Rien Visser [2]
[1] Institute of Forest Engineering, University of Natural Resources and Life Sciences, Vienna, Austria [2] New Zealand School of Forestry, University of Canterbury, New Zealand [3] Forest Industries Research Centre, University of the Sunshine Coast, Australia [4] Koller Forsttechnik GmbH, Austria

SHARE OF STEEP SLOPE WORLDWIDE

Mikael Lundbäck, Henrik Persson, Carola Häggström, Tomas Nordfjell
Swedish University of Agricultural Sciences

SKYLINE TENSILE FORCES IN CABLE LOGGING: FIELD MEASUREMENTS VS. THEORETICAL CALCULATIONS

Omar Mologni [1], Luca Marchi [1], C. Kevin Lyons [2], Stefano Grigolato [1], Raffaele Cavalli [1], Dominik Roeser [3]
[1] Università degli Studi di Padova - Department of Land, Environment, Agriculture and forestry. Padua - Italy [2] Oregon State University - College of Forestry - Department of Forest Engineering, Resources and Management. Corvallis, OR USA [3] The University of British Columbia - Department of Forest Resources Management. Vancouver, BC Canada

WHOLE-TREE HELICOPTER YARDING PRODUCTIVITY ANALYSIS FOR FUELS REDUCTION THINNING IN NORTHERN ARIZONA

Dylan Whitaker, Jeff Halbrook, Han-Sup Han
Ecological Restoration Institute, Northern Arizona University, Flagstaff, Arizona, USA

EXPERIMENTAL TESTS ON TREES USED AS ANCHORS IN CABLE-SUPPORTED HARVESTING SYSTEMS

Luca Marchi, Omar Mologni, Stefano Grigolato, Raffaele Cavalli
Department of Land, Environment, Agriculture and Forestry, University of Padova, Viale dell'Università 16, 35020 Legnaro (PD), Italy

APPLYING THE DELPHI METHOD TO SELECT THE SUSTAINABLE FOREST HARVESTING SYSTEM

Nopparat Kaakkurivaara
Faculty of Forestry, Kasetsart University, Bangkok, Thailand

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

USING CONJOINT ANALYSES TO IMPROVE CABLE YARDER DESIGN CHARACTERISTICS: AN AUSTRIAN YARDER CASE STUDY TO ADVANCE COST-EFFECTIVE EXTRACTION

Martin Kühmaier[1], Hunter Harrill[2], Mohammad Reza Ghaffariyan[3], Manfred Hofer[4], Karl Stampfer[1], Mark Brown[3], Rien Visser[2]

[1]Institute of Forest Engineering, University of Natural Resources and Life Sciences, Peter-Jordan-Strasse 82/3, A-1190 Vienna, Austria
martin.kuehmaier@boku.ac.at
karl.stampfer@boku.ac.at

[2]New Zealand School of Forestry, University of Canterbury, New Zealand
hunter.harrill@canterbury.ac.nz
rien.visser@canterbury.ac.nz

[3]Forest Industries Research Centre, University of the Sunshine Coast, Australia
mghaffar@usc.edu.au
mbrown2@usc.edu.au

[4]Koller Forsttechnik GmbH, Austria
office@kollergmbh.com

Abstract: *Steep country harvesting has been identified as the main bottleneck to achieving greater profitability in the forestry sector of New Zealand and Australia. An improvement of efficiency, work safety and environmental sustainability should be realized by developing an advanced steep terrain timber harvesting system based on innovative Austrian technology. To identify the best suitable configuration of a cable yarder for steep terrain harvesting, user preferences based on an online survey (conjoint analysis) have been evaluated to answer the following questions: (1) What attributes of a new yarder design are most important to consumers? (2) Which criteria do stakeholders consider when selecting a cable yarder? (3) What are the weights representing the relative importance of criteria? Using eight specific design scenarios a fourth question, being which cable yarder concept is the best, was also answered. This case study shows that conjoint analyses is an effective tool to assess, rate and subsequently integrate design characteristics. Based on the results of the analysis, a cable yarder prototype will be manufactured in Austria and transferred to New Zealand for testing and demonstration.*

Keywords: timber harvesting, cable yarding, steep terrain, conjoint, decision support, marketing research, mechanical engineering

Paper has been already published in Kühmaier, M., Harrill, H., Ghaffariyan, M.R., Hofer, M., Stampfer, K., Brown, M., Visser, R. (2019): Using conjoint analyses to improve cable yarder design characteristics: An Austrian Yarder case study to advance cost-effective extraction. Forests, 10 (2), art. no. 165.

Acknowledgments: This publication is a part of the national funded project "Technology Transfer in Steep Terrain Timber Harvesting (TechnoSteep)". The research leading to these results has received funding from the Austrian Research Promotion Agency (FFG) program for internationalization of RTI projects "Beyond Europe" under grant agreement n° 855766.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

SHARE OF STEEP SLOPE IN FOREST LAND WORLDWIDE

Mikael Lundbäck* Henrik Persson Carola Häggström Tomas Nordfjell
Department of Forest Biomaterials and Technology
Swedish University of Agricultural Sciences
mikael.lundback@slu.se

The physical properties of forest land to be harvested will always play a major part in determining the most suitable harvest equipment and methods. In Sweden and the Nordic countries the main physical properties of forest land are organized in a very structured and harmonized manner in the "terrain classification system" which describes the three properties 1) ground type, 2) surface roughness and 3) slope (Malmberg, 1989). However foresters around the world consider aspects of these three properties when planning the harvest. Slope is important because it sets definitive limits for different main kinds of equipment. Usually tracked machines can handle steeper slopes than wheeled machines and if the terrain becomes too steep the next option is cable- or air based systems (Greulich, 1999). In the global context there is a lack of consistent and comparable data of slope in forest land since most effort to classify slope has been done within smaller regions using different scales and techniques. However, modern remote sensing data enable a great span of analyses, also in the field of forest operations (Talbot *et al.*, 2017). It is a desirable approach that enable results that are consistent and comparable between different regions and countries. The aim of this study was to create a globally consistent dataset of slope in forest land.

A Geographic Information System (GIS) analysis was performed in the open source softwares QGIS, GDAL and R. The core of the analysis is a digital elevation model (DEM) from the German TanDEM-X mission with an initial resolution of 12 meters, that was aggregated and made available freely by DLR (Deutsche Zentrum für Luft- und Raumfahrt) at 90 m resolution. A slope map was computed from the DEM using the method proposed in (Zevenbergen & Thorne, 1987). All slope pixels were counted and categorized in one of four slope classes: <=15°, 15.1-20°, 20.1-30° and >30°. A raster dataset of land cover was used in combination with the DEMs to mask out all but forest land. Specifically the land cover dataset was a Forest/NonForest dataset produced from the same TanDEM-X raw data (Martone *et al.*, 2018). The intersection of the "slope" and "forest" rasters was finally computed in the GDAL raster calculator. The result consists of forest land in the four slope classes. When that figure was related to the total forest land in each country, a percentage was extracted and demonstrated for each slope class in all countries.

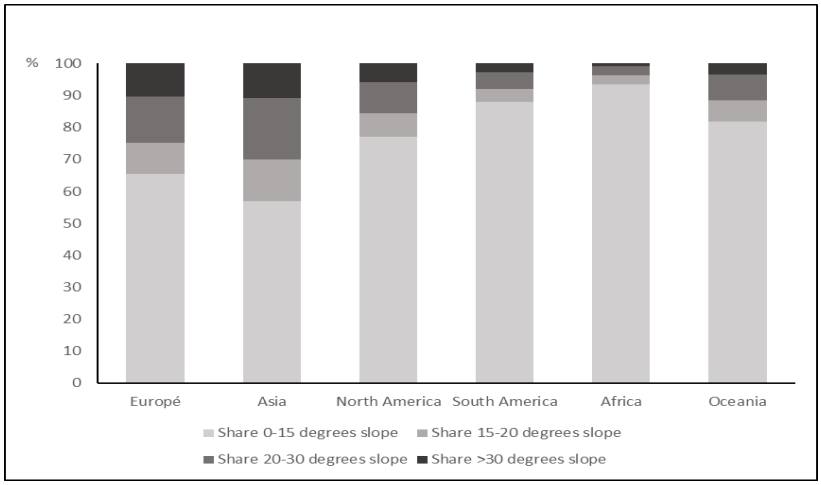


Figure 1. Distribution of forest land in four slope classes within the six continents with forestry

The share of slope in forest land varies greatly between continents with Asia and Africa being the two extremes. Africa have a very large share of forest land in flat terrain and almost no forest in very steep terrain (>30°). Asia on the other hand have less than 60 % of its forest land in flat terrain and around 10 % in very steep terrain (figure 1).

The forest land in United States, Russia and Canada is quite similarily distributed over the four slope classes. China stands out in the comparison with relatively little flat terrain and large areas in steeper terrain. Brazil stands out with almost no forest growing in steep terrain.

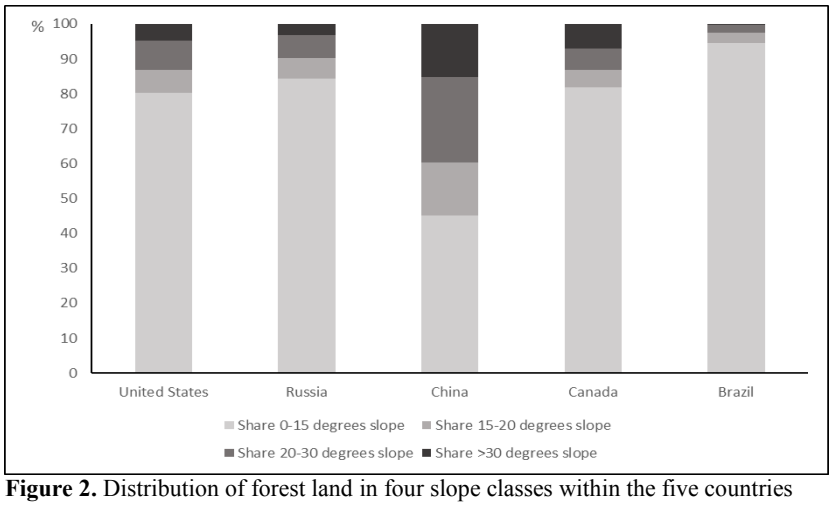


Figure 2. Distribution of forest land in four slope classes within the five countries harvesting more than half of the industrial roundwood in the world

The aggregation of the DEM from 12 to 90 meter pixel size of course imply a loss of information. To assess the impact of this procedure detailed data were calculated for both Sweden and Austria. The results from this assessment did not provide support for the more time consuming high resolution which allowed us to continue the analysis globally without changing the main method. The forest mask was also limited in resolution and accuracy in certain types of forests, e.g. clearcuts in Sweden is not always classified as forest land. The main contribution of this study is the large and consistent dataset of slope in forest land for all countries. Since the dataset is consistently calculated for the whole world it allows for reliable comparison between countries, which is a feature that have so far been missing in existing datasets.

Greulich, F.R. (1999). *A primer for timber harvesting*. Washington: Washington State University Extension.

Malmberg, C.E. (1989). *The off-road vehicle. Vol. 1*. Atlanta, Ga. ;: Joint Textbook Committee of the Paper Industry, TAPPI, CPPA.

Martone, M., Rizzoli, P., Wecklich, C., González, C., Bueso-Bello, J.-L., Valdo, P., Schulze, D., Zink, M., Krieger, G. & Moreira, A. (2018). The global forest/non-forest map from TanDEM-X interferometric SAR data. *Remote sensing of environment,* 205, pp. 352-373.

Talbot, B., Pierzchala, M. & Astrup, R. (2017). Applications of Remote and Proximal Sensing for Improved Precision in Forest Operations. *Croatian Journal of Forest Engineering,* 38(2), pp. 327-336.

Zevenbergen, L.W. & Thorne, C.R. (1987). Quantitative analysis of land surface topography. *Earth surface processes and landforms,* 12(1), pp. 47-56.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

SKYLINE TENSILE FORCES IN CABLE LOGGING: FIELD MEASUREMENTS VS. THEORETICAL CALCULATIONS

Omar Mologni [1], Luca Marchi [1], C. Kevin Lyons [2], Stefano Grigolato [1], Raffaele Cavalli [1], Dominik Roeser [3]

[1] Università degli Studi di Padova - Department of Land, Environment, Agriculture and forestry. Padua - Italy [2] Oregon State University - College of Forestry - Department of Forest Engineering, Resources and Management. Corvallis, OR USA [3] The University of British Columbia - Department of Forest Resources Management. Vancouver, BC Canada
omar.mologni@hotmail.it

Abstract: *Skyline tensile forces have shown to frequently exceed the recommended safety limits during ordinary cable logging operations. While the cable line design is normally based on static calculations, the occurrence of dynamic loads during the lateral skid and inhaul is the main causes of critical tensile forces. Avoiding the inclusion of the dynamics in the cable line layout calculations do not allow to properly estimate the real skyline working load.*

This study aims to compare direct field measurement of skyline tensile forces in ordinary operations with calculated tensile forces derived by common procedures, algorithms and software, in order to identify dynamic correction factors usable in the layout procedures.

The work is based on the comparison of the real skyline tensile forces - monitored in the Italian Alps on single span and multi spans standing skyline configurations - with the tensile forces calculated through the use of SkylineXL, purpose-built algorithms, and finite element method (FEM) models. The information available for each work cycle include the payload, the carriage weight and the total load applied to the cable structure; the transportation system; the yarding distance and its relative position regarding the cable line geometry; the detailed time study of the harvesting operations.

Results identify a range of dynamic amplification factors to be applied to static measures for cable line layout under different operational conditions.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

WHOLE-TREE HELICOPTER YARDING PRODUCTIVITY ANALYSIS FOR FUELS REDUCTION THINNING IN NORTHERN ARIZONA

Dylan Whitaker, Jeff Halbrook, Han-Sup Han
Ecological Restoration Institute, Northern Arizona University, Flagstaff, Arizona, USA
Jeffrey.Halbrook@nau.edu

Abstract: *Due to high yarding costs, helicopter logging operations have traditionally been utilized to access high value, remote timber. As land management goals for public forestlands in the western United States shift toward restoring forest function and characteristics, forest operation techniques and equipment such as helicopter yarding are being adopted as restoration tools. The watershed encompassing Flagstaff, Arizona is particularly susceptible to both high severity wildfire and to the ensuing destructive flooding. A helicopter is being used to extract whole-trees including limbs and branches attached where traditional forest equipment access is limiting. Researchers at the Ecological Restoration Institute at Northern Arizona University are studying the work productivity and logistics associated with this helicopter restoration project. A detailed work analysis of felling, hooking, helicopter extraction and landing operations is being completed. Multiple linear regression will be used to determine factors that are significant in determining cost and productivity for each phase of the operation. Outcomes from this project such as efficiencies and delays associated with extracting small-diameter stems, limbs, and tops will be discussed. This information will be used to help inform forestland managers and private contractors which factors are significant for predicting operational costs as well as variables that can be controlled in order to improve the productivity of forest fuels reduction projects using helicopters.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

EXPERIMENTAL TESTS TO ASSESS SAFETY ON TREES USED AS ANCHORS IN CABLE YARDING OPERATIONS

Luca Marchi, Omar Mologni, Stefano Grigolato, Raffaele Cavalli
Department of Land, Environment, Agriculture and Forestry, University of Padova, Viale dell'Università 16, 35020 Legnaro (PD), Italy
luca.marchi@unipd.it

Abstract: *Failures in cable yarding operations are related to both breakage of the skyline or collapse of its anchoring system, and normally culminate in nearby workers being injured. The high forces, necessary to provide a cable path that consent an efficient transportation of the logs, are dynamically amplified by the oscillation of the moving weight (in case of fully suspended loads) and by the sudden accelerations applied to the carriage sue to the skidding of the logs (in case of semi-suspended loads). These high-magnitude forces must be withstood by the anchoring system, in general consisting of a sufficiently large tree or stump available in the nearby area, over which the rope end is secured. Due to the lack of effective methods that predict the actual load carrying capacity of such anchoring solution, failure due to overturning or stem breakage of the tree is likely possible.*
The present work aims to apply the knowledge of tree stability assessment to the case of trees used as anchors in cable yarding operations. Comparison between data of experimental pulling tests that simulated failure of the anchors due to uprooting and data collected from direct field measurements are made. More in detail: i) pulling tests data consist of force vs. rotations curves obtained from destructive pulling tests on mature trees with medium-high diameter at breast height; ii) field data of real cable logging systems consist of force vs. rotations curves obtained by the synchronization between the variations of tensile forces in the skyline and the anchors' relative displacements. The correlation between the two sets of data is made in order to develop an assessment technique, based on continuous monitoring, that guarantee a better level of safety of the anchors than actual empirical methods.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

APPLYING THE DELPHI METHOD TO SELECT THE SUSTAINABLE FOREST HARVESTING SYSTEM

Nopparat Kaakkurivaara*, Laddawan Rianthakool, Chakrit Na Takuathung, Khanchai Prasanai
Department of Forest Engineering
Faculty of Forestry
Kasetsart University
50 Ngamwongwan Rd., Ladyao, Chatuchak, Bangkok, 10900
ffornrm@ku.ac.th

Abstract: *The selection of proper forest harvesting system is an important in order to balance environmental, social and economic interests. This study applied the Delphi method to identify the weight balance between environmental, social and economic aspects. The panel of experts consisted of a number of scientists in the field. The data was collected using a questionnaire distributed in two rounds. The results demonstrated that the job positions (manager assistant, forest manager, and administrator) do not have significant impact on the result. The results from both round illustrated the same direction that economic is the most concern for forest plantation, while environment and social aspects are less anxiety. Not many of responder changed their opinion in the second round. Afterwards, the weight score which received from Delphi method is used for ranking the logging systems. This study included ten different logging systems to be evaluated. There are several factors to be taken into account, such as, productivity, harvesting cost, heart rate, soil compaction, soil erosion, etc. All factors were reclassified into five classes, graded as 1, 2, 3, 4, and 5 (critical, fair, moderate, good, and excellence) according to expert's opinion. The logging system which got the highest score is felling by chainsaw, extraction by elephant together with farm tractor and transported by truck with loader. The findings could assist forest managers in selecting the right harvesting system, while taking into account the environment, economic and social aspects. This kind of a calculation model was used to facilitate an ease in comparing the logging systems, it is relatively simple tool for forest manager to help in making decision. However, the study shall apply the GIS into the implementation in the future in order to visualize the precise area with specific logging system.*

Keywords: delphi, logging system, sustainable, grading, teak plantation

Introduction

In the last decades, the term "sustainability" has become very common in the description of resource utilization intentions (Hahn and Knoke, 2010). In practice, sustainability aims to achieve social well-being, without compromising the environmental resources, through a fair economic well-being (Koehler and Hecht, 2006) that is related to three pillars – the economy, the environment and society (Kastenhofer and Rammel, 2005). Effective implementation of sustainable forest management practice depends on carrying out forest operations in a sustainable manner (Heinimann, 2007). The concept of sustainability is important in planning and practice of forest operations, and should encompass different aspects. Thus, new concept of Sustainable Forest Operations (SFO) provides integrated perspectives and approaches to effectively address ongoing and foreseeable challenges while balancing forest operations performance across economic, environmental and social sustainability objectives. For the practicality of SFO, it is essential to: (i) promote operationally safe, environmentally responsible, locally acceptable and economically viable forest mechanization; (ii) invest in workforce training that improve not only operational skills but also awareness of health and safety issues and quality operations that are sensitive to changing work conditions; (iii) develop certification programs to meet and enforce operator and performance efficiency standards; (iv) encourage forest professionals to improve their management skills and sustainable business strategies; (v) improve the forest workers' health and safety without compromising the profitability, viability and economic competitiveness of forest business and practices; and (vi) encourage renovation and innovation of forest machinery in order to improve the efficiency and reduce the negative ecological impact of forest operations (Marchi et al. 2018). In recent years some studies have been published to estimate best suitable harvesting systems on the basis of forest districts or compartments using GIS. Even some of studies were took ecological or social criteria into account, which is essential for a comprehensive analysis of the impacts of harvesting operations (Kuhmaier and Stampfer, 2010). However, the selection of suitable logging systems via GIS application required skilled operator and rather complicated for local farmers

or forests who do not have basic knowledge on GIS. Thus, the objective of this study is to develop the simple method for selecting the appropriate logging systems which serves SFO concept.

Methodology

This study was carried out in Teak plantations in Northern part of Thailand, Phrae province. The common harvesting method for Teak is tree length method. Appropriate technology is used in the area, such as, chainsaw , tractor, skidded, etc. In the study area, there are ten possible logging systems as shown in Table 1.

Table 1 Available logging systems in the study area

System	Felling & Processing	Timber extraction	Primary transportation
1	Chainsaw	Elephant	Modified self-loading truck
2	Chainsaw	Farm tractor	Modified self-loading truck
3	Chainsaw	Skidder	Modified self-loading truck
4	Chainsaw	Elephant	Truck & tractor with front end grapple
5	Chainsaw	Farm tractor	Truck & tractor with front end grapple
6	Chainsaw	Skidder	Truck & tractor with front end grapple
7	Chainsaw	Elephant & farm tractor	Modified self-loading truck
8	Chainsaw	Elephant & farm tractor	Truck & tractor with front end grapple
9	Chainsaw	Elephant & skidder	Modified self-loading truck
10	Chainsaw	Elephant & skidder	Truck & tractor with front end grapple

This study divided into two sections: the reclassification of relevant factors and the weighting score of each factors. There are several factors to be taken into account, for example, productivity, logging cost, heart rate, soil compaction, soil erosion, etc. All factors were reclassified into five classes, graded as 1, 2, 3, 4, and 5 (critical, fair, moderate, good, and excellence, respectively) according to expert's opinion (Table 2).

Table 2 Reclassification of grading score for each relevant factors

Aspect	Grading score				
	1	2	3	4	5
	Critical	Unacceptable	Fair	Good	Excellent
Productivity	<5.99 m^3/h	6-10.99 m^3/h	11-15.99 m^3/h	16-20.99 m^3/h	>20.99 m^3/h
Logging cost	>900 BTH/m^3	650-900 BTH/m^3	450-649 BTH/m^3	150-449 BTH/m^3	<150 BTH/m^3
Heart rate	>80 bpm	76-80 bpm	72-75 bpm	69-71 bpm	<69 bpm
Working posture	>= 11	8.0-10.9	4.0-7.9	2.0-3.9	<2
Soil compaction	>1.8 g/cm^3	1.6-1.8 g/cm^3	1.4-1.6 g/cm^3	1.2-1.4 g/cm^3	<1.2 g/cm^3
Soil erosion	> 9.6 mm/y	7.21-9.60 mm/y	2.41-7.20 mm/y	0.96-2.40 mm/y	<0.96 mm/y

Remark: 1EUR = 34.45 BTH (refer on 12 Aug 2019)

Afterwards, the Delphi method was applied to identify the weight balance between environmental, social and economic aspects. The panel of experts consisted of a number of forest plantation staffs (n = 22). The data was collected using a questionnaire distributed in two rounds (Table 3). Afterwards, the weight score which received from Delphi method is used for ranking the logging systems. The grading score from each factor is combined with weight score for each tools/machine and sum up according to logging system. The logging system that obtain the highest score is considered as the best logging system in certain circumstance.

Table 3 The summary of responders for Delphi method

	Round 1	Round 2
Responder	22	19
Executive/administrator	6	3
Plantation manager	5	5
Plantation manager assistant/staff	11	11

Results

The results from both round illustrated the same direction that economic is the most concern for forest plantation, while environment and social aspects are less anxiety. Not many of responder changed their opinion in the second round. The results demonstrated that the job positions (manager assistant, forest manager, and administrator) do not have significant impact on the result (Table 4).

Table 4 Weight score that obtained from Delphi method

	Aspects	Round 1		Round 2	
Economics	Productivity	25.32	48.7	26.52	51.1
	Logging cost	23.38		24.58	
Social	Heart rate	14.61	26.8	13.89	25.4
	Working posture	12.19		11.51	
Environment	Soil compaction	12.74	24.5	13.09	23.5
	Soil erosion	11.76		10.41	

The weight score which received from Delphi method is used for ranking the logging systems. Then combined the weight score and grading score of each machine in all aspects. The table 5 showed the example of calculate for skidder. The total score for each machine is equal to five. Thus the maximum score for each logging system is equal to 15.

Table 5 Example of calculation for skidder

Aspect	Info	Grading score	Weight score	Score	Total score
Productivity	17.87 m^3/h	4	0.265	1.061	3.233
Logging cost	229 BTH/m^3	4	0.246	0.983	
Heart rate	91.5 bpm	1	0.139	0.319	
Working posture	5.5	3	0.115	0.345	
Soil compaction	1.45 g/cm^3	3	0.131	0.393	
Soil erosion	4.03 mm/y	3	0.104	0.312	

The recommended logging system which got the highest score (10.794) was felling by chainsaw, extraction by elephant together with farm tractor and transported by truck with loader (Table 6). The second best logging system was felling by chainsaw, extraction by elephant together with skidder and transported by truck with loader. While the logging system that got the lowest total score (8.958) was felling by chainsaw, extraction by elephant and transported by modified self-loading truck.

Table 6 Total score of each logging system

System	Felling & Processing	Timber extraction	Primary transportation	Total score
1	Chainsaw	Elephant	Modified self-loading truck	8.958
2	Chainsaw	Farm tractor	Modified self-loading truck	9.488
3	Chainsaw	Skidder	Modified self-loading truck	9.063
4	Chainsaw	Elephant	Truck with loader	9.999
5	Chainsaw	Farm tractor	Truck with loader	10.529
6	Chainsaw	Skidder	Truck with loader	10.104
7	Chainsaw	Elephant & farm tractor	Modified self-loading truck	9.753
8	Chainsaw	Elephant & farm tractor	Truck with loader	10.794
9	Chainsaw	Elephant & skidder	Modified self-loading truck	9.507
10	Chainsaw	Elephant & skidder	Truck with loader	10.548

Discussion and Conclusions

The method could assist forest managers in selecting the right harvesting system, while taking into account the environment, economic and social aspects. However, the results may be changed if the weight coefficient is modified. The weight coefficient is pretty much relies on expert's opinion. In this case, experts mostly focused on economic than other aspects.Thus, if the circumstance is changed, then the recommended logging systems may no longer valid. This kind of a calculation model was used to facilitate an ease in comparing the logging systems, it is relatively simple tool for forest manager to help in making decision. However, the study shall apply the GIS into the implementation in the future in order to visualize the precise area with specific logging system.

Acknowledgements

This research was supported by the Kasetsart University Research and Development Institute (KURDI). I would like to extend my thanks to the Forest Industry Organization for providing study sites and all supporting during the data collection.

References

Hahn, W.A., Knoke, T., 2010. Sustainable development and sustainable forestry: analogies, differences, and the role of flexibility. Eur. J. For. Res. 129 (5):787–801. https://doi. org/10.1007/s10342-010-0385-0.

Heinimann, H.R., 2007. Forest operations engineering and management–the ways behind and ahead of a scientific discipline. Croat. J. For. Eng. 28 (1), 107–121.

Kastenhofer, K., Rammel, C., 2005. Obstacles to and potentials of the societal implementa- tion of sustainable development: a comparative analysis of two case studies. Sustain. Sci. Pract. Policy 1 (2):5–13. https://doi.org/10.1080/15487733.2005.11907968.

Koehler, D., Hecht, A.D., 2006. Sustainability, well being, and environmental protection: perspectives and recommendations from an Environmental Protection Agency forum. Sustain. Sci. Pract. Policy 2 (2): 22–28. https://doi.org/10.1080/15487733.2006.11907981.

Kulak D., Stańczykiewicz A., Szewczyk G. 2017. Productivity and time consumption of timber extraction with grapple skidder in selected pine stands. Croatian Journal of Forest Engineering 38(1): 55-63.

Marchi E. Chung W., Visser R., Abbas D., Nordfjell T., Mederski P., MxEwan A., Brink M., Laschi A. 2018. Sustainable Forest Operations (SFO): A new paradigm in a changing world and climate. Science of the Total Environment 634: 1385-1397. https://doi.org/10.1016/j.scitotenv.2018.04.084

Proto A.R., Macri G., Visser R., Russo D., Zimbalatti G. 2018. Comparison of timber extraction productivity between winch and grapple skidding: A case study in Southern Italian forests. Forests 9, 61: doi: 10.3390/f9020061.

Toppinen A., Rohr A., Patari S., Lahtinen K., Toivonen R. 2018. The future of wooden multi-storey construction in the forest bioeconomy - A Delphi study from Finland and Sweden. Journal of Forest Economics 31: 3-10.

S11 Environmental impacts
Not quick and dirty

MINNESOTA LOGGERS AND INVASIVE FOREST PLANTS: ATTITUDES, BEHAVIORS AND CONCERNS

Charlie Blinn [1], Stephanie Snyder [2], Rachel Peterson [3]
[1] Department of Forest Resources, University of Minnesota, St. Paul, MN, USA; [2] USDA Forest Service, Northern Research Station, St. Paul, MN, USA; [3] Minnesota Logger Education Program, Cloquet, MN, USA

ENVIRONMENTAL IMPACT OF MECHANIZED HARVESTING IN LARGE-DIMENSION HARDWOODS

Lorenz Breinig, Caroline Bennemann, Peter Aurenhammer, Eric R. Labelle
Assistant Professorship of Forest Operations, TUM School of Life Sciences Weihenstephan, Technical University of Munich

MODELLING FUEL CONSUMPTION IN CUT-TO-LENGTH WOOD HARVESTING OPERATIONS IN NORDIC CONDITIONS

Hanna Haavikko [1], Kalle Kärhä [2], Heikki Kääriäinen [1,2], Kimmo Roininen [2], Teijo Palander [1]
[1] University of Eastern Finland, Joensuu, Finland; [2] Stora Enso Wood Supply Finland, Helsinki, Finland

INFLUENCE OF THE EXTRACTION LINE'S DISTANCE ON THE VALUE OF THE TREE STAND

Marcus Hennek
Institute of Forest Utilisation and Forest Technology, Chair of Forest Technology, TU Dresden, Germany

WEST VIRGINIA TIMBER HARVESTING ACTIVITIES – LANDOWNERSHIP INFLUENCES ON HARVEST TYPES, COMPARTMENT SIZES, AND BEST MANAGEMENT PRACTICES COMPLIANCE

Ben Spong
West Virginia University, Morgantown, WV, USA

RESIDUAL STAND DAMAGE UNDER DIFFERENT SILVICULTURAL PRESCRIPTIONS

Evan Ross Nahor, Anil Raj Kizha, Libin Thaikkattil Louis
University of Maine, Orono, USA

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

Minnesota Loggers and Invasive Forest Plants: Attitudes, Behaviors and Concerns

Charles R. Blinn*
University of Minnesota
St. Paul, Minnesota USA
cblinn@umn.edu

Stephanie A. Snyder
USDA Forest Service
St. Paul, Minnesota USA
stephanie.a.snyder@usda.gov

Rachel R. Peterson
Minnesota Logger Education Program
Cloquet, Minnesota USA
rachel.peterson@mlep.org

Abstract: *Invasive plants impact the health and regeneration of forests due to their ability to compete with and displace native species. Loggers can serve as early detectors of invasive plants and can help prevent their introduction and spread in the woods. Logging business owners in Minnesota (USA) were studied to assess a variety of factors related to invasive forest plants. Most respondents indicated they were somewhat to slightly knowledgeable about invasive plants. Approximately 25% of respondents reported contractual obligations or voluntary efforts to inspect and clean their equipment to prevent spread. Few respondents had developed invasive treatment activities as an additional revenue stream, but one-half had some interest in doing so. The majority of respondents (87%) were concerned about potential impacts to their business operations if an invasive forest plant best management practices (BMP) program were developed. Training in identification of invasive forest plants was the most frequently cited information need.*

Keywords: Best management practices (BMPs), regulatory, voluntary, treatment, removal

1. Introduction

An invasive plant is a species whose introduction does or is likely to cause adverse economic or environmental impacts or harm to human health (Beck et al., 2006). They can greatly impact the health and regeneration of forest lands through reduced forest productivity, degraded soil and competition (Holmes et al. 2009). Additionally, they can also impact wildlife habitat and decrease suitability for a variety of recreational opportunities.

Invasive species can become established or spread during activities which disturb vegetative cover or expose bare soil. Timber harvesting and the associated development of infrastructure (roads, landings, skid trails) on-site can create pathways for invasive plants to become established and spread (Rauschert et al., 2017). Logging activities can contribute to the introduction and spread of invasives when seeds of invasive species become attached to logging and trucking equipment, employee or service vehicles driven to job sites, boots, or are transported between harvest sites or on forest products hauled to markets. Minnesota logging businesses reported harvesting an average of 9.2 tracts per respondent (median of 6 tracts) in 2016 (Blinn et al., 2019). Logging can also lead to more open canopies and soil disturbance, which can create conditions conducive to establishment of invasive plants (Setterfield et al., 2005).

While best management practices (BMPs) for invasive forest plants have not been formally developed to limit the impact of invasive species when conducting harvest activities in Minnesota, timber sale contracts on public lands do typically include requirements to prevent the introduction and spread of invasive plants. For example, on US Forest Service lands, timber sale contracts identify the location of known invasive plant infestations and outline conditions for cleaning logging equipment (USDA Forest Service, 2006). Specifically, logging equipment must be cleaned prior to moving into a cutting area of a Forest Service sale if it was last operating in an area known to contain invasive plants. Equipment must also be cleaned before moving between cutting units of the same sale if operations have occurred in an area with known invasives. Operators are instructed to clean their equipment of seeds, soil, vegetation matter, and other debris that

could contain seeds of invasive forest plants. On timber sales within Minnesota Department of Natural Resources (MnDNR) administered land, loggers need to inspect their equipment before entering and leaving a site to ensure that it is free of mud, dirt clods and reproductive plant parts (MnDNR, 2008). During the timber sale design process, MnDNR foresters work to reduce the need for loggers to apply additional invasive plant mitigation practices by rerouting access, changing the season of operation, or altering the timber sale boundaries to avoid infected areas.

We are not aware of any literature that has examined loggers' awareness, behaviors and information needs relative to invasive forest plants. To address this knowledge gap, logging business owners who were members of the Minnesota Logger Education Program (MLEP) were surveyed in Spring 2018 to gather baseline data which could help direct future efforts to limit the impact of invasive forest plants.

2. Methods

A mail survey was administered to collect information from MLEP logging business owners. MLEP is a private non-profit educational corporation. They define a logging business as a sole-proprietorship, partnership or corporation that purchases stumpage and/or is an independent contract logger, controls timber harvesting and owns timber harvesting equipment (mlep.org/membership.htm). MLEP logging businesses harvest timber on public and private lands and deliver forest products to the main wood-using industries in Minnesota. Small business operations that provide timber to small or hobby markets likely were not surveyed as they wouldn't be members of MLEP.

Following the Dillman tailored design method (Dillman, 2000), a total of five contacts were made with potential respondents. The survey was designed as a double-blind study, where MLEP created a unique code with two letters and two numbers which was printed on each survey. Surveys were returned to the University of Minnesota where MLEP was notified of the codes as surveys were received. Responses were received from 135 individuals for an overall response rate of 38% with a useable response rate of 37%. Data were entered into an Excel template, every entry was error checked, and errors were corrected.

The initial quartile of respondents (based on when the completed survey was received) was compared to the last quartile following Armstrong and Overton (1977) to check for nonresponse bias. Chi-square tests revealed that late responders were slightly more likely to have harvested at least 15,000 cords of timber in the past 12 months ($\chi 2(1, N=63) = 5.0279$, $p=0.0249$) and to be winter only harvesting operations ($\chi 2(1, N=63) = 4.0018$, $p=0.0455$). However, no significant differences were found between early and late responders relative to their general level of knowledge about invasive forest plants, perceived impacts of invasive plant BMPs on their business operations, level of interest in developing invasive plant treatment or removal expertise, or level of interest in purchasing a timber sale when invasive forest plants are known to be present.

Basic summary statistics and figures were calculated using Excel, and tests of difference were computed with SAS version 9.4. The unit of analysis was the individual respondent.

Segmentations of some of the questions were done and comparisons made using Fisher's exact test of independence (Fisher, 1992) with post-hoc tests performed when the global test was significant through pairwise comparisons with Bonferroni corrections (Armstrong, 2014). The segmentations were to determine whether differences existed among respondents within a) MnDNR forestry regions (Northeast, Northwest, Central/Southern), b) annual harvest volume size classes (1,000 cords or less, 1,001 to 5,000 cords, 5,001-15,000 cords, and greater than 15,000 cords), and c) season of operation (winter-only logging operation versus one that operated in other combinations of seasons). Only significant segmentations are reported in the results.

3. Results

3.1 Respondent demographics

The highest number of responses was from the MnDNR Forestry's Northeast region (n = 75 respondents, 57 percent of respondents) and the least from the Central/Southern region (n = 18 respondents, 14 percent of respondents). The response rates across MnDNR Forestry regions were very similar to the distribution of MLEP's logging business owner membership across Minnesota

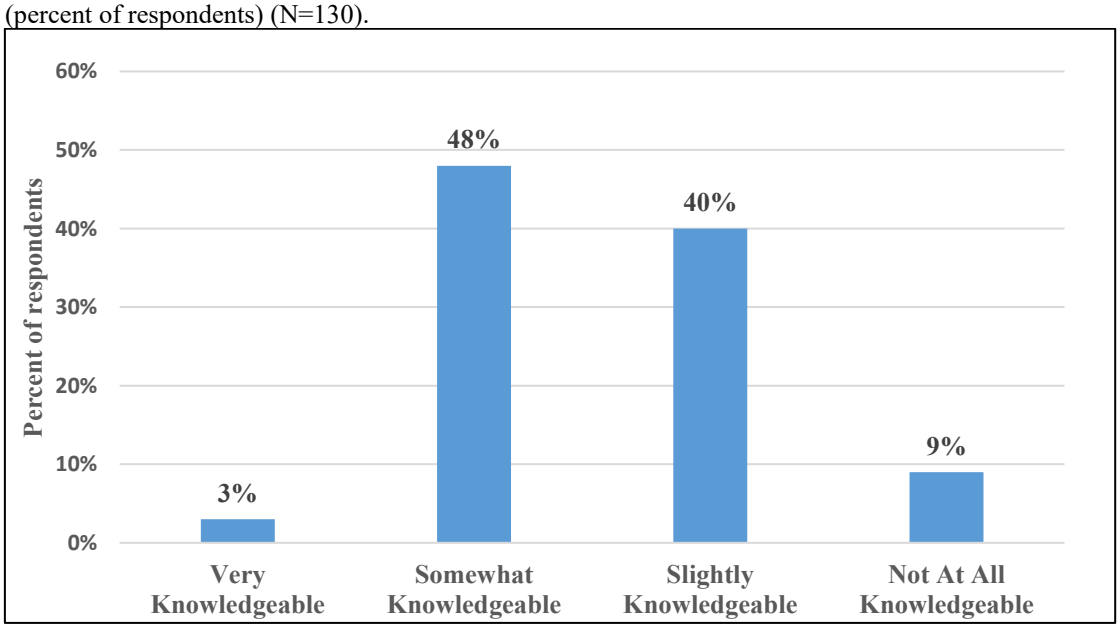
Twenty-six percent of the respondents had produced up to 1,000 cords (3,625 cubic meters) in the past twelve months. More than half of the respondents (57%) harvested 5,000 cords (18,100 cubic meters) or less, while only 9% harvested more than 30,000 cords (108,700 cubic meters). The smallest producers tended to be from the MnDNR Forestry's Central/Southern region.

Seventy-two percent of the respondents indicated that they operate year-round, 24% operate only in winter, 3% operate only in summer and winter, and 1% operate only in summer. On average, the largest percentage of harvested volume reported by respondents during the previous twelve months was derived from private forest land (38%), followed by approximately one-third from state lands (31%) and one-quarter (22%) from county or municipal lands.

3.2 Awareness and Knowledge of Minnesota's Invasive Forest Plants

Respondents were asked about their general level of awareness regarding invasive forest plant species in Minnesota. Response options, presented on a 4-point scale, ranged from Very Knowledgeable (1) to Not at All Knowledgeable (4). In general, the majority of respondents indicated some degree of but not great knowledge (Figure 1). The most common response was Somewhat Knowledgeable (48%), followed by Slightly Knowledgeable (40%).

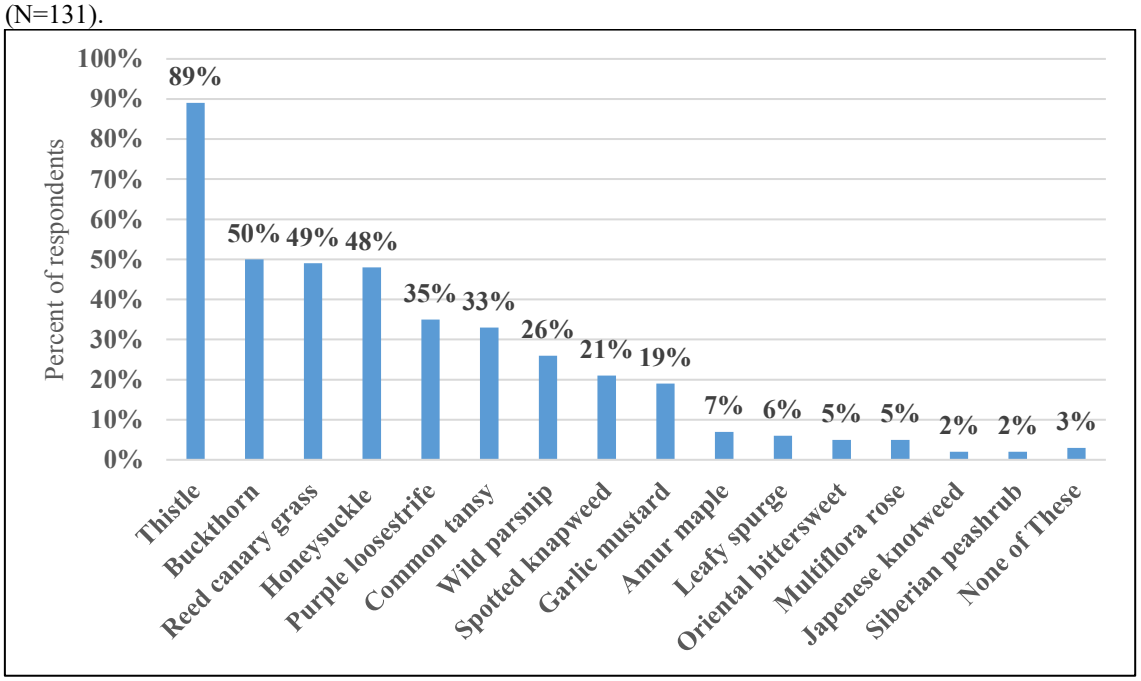
Figure 1. General level of knowledge about invasive forest plants by Minnesota logging business owners (percent of respondents) (N=130).



Respondents were presented a list of 15 common invasive forest plants in Minnesota and asked whether they were confident they or their crew could correctly identify them in the woods. Only 3% of respondents indicated they couldn't identify any of the 15 species. The average number of listed plants that the respondents stated they could identify was 4 (SD=2.22), and the mode was 2. The only plant that

a majority of respondents (89%) were confident they could identify was thistle (Figure 2). Approximately half of the respondents could identify buckthorn (50%), reed canary grass (49%), and honeysuckle (48%). Two plants were identifiable by approximately one-third of respondents: purple loosestrife (35%) and common tansy (33%). Less than a third of the respondents indicated that they or their crew could correctly identify any of the remaining nine plants.

Figure 2. Confidence in ability to identify specific invasive plants in the woods (percent of respondents) (N=131).



While 54% of respondents indicated they had not noticed an increase of sales with invasives over the past three years, 48% of respondents indicated that they had never sought information about invasive forest plants from a list of 12 organizations,

Respondents were provided a list of eleven organizations and asked which they would report invasive plants to if they were to encounter them on a timber sale. Only a small percentage of respondents indicated they would not report invasive to anyone (10% of respondents on public land timber sales and 13% on private land timber sales). Similar percentages indicated they do not know who to report invasives to (13% on public land timber sales and 15% on private timber sales). Reporting sources vary depending upon whether the sale occurs on public or private land. For public land timber sales, the two entities most likely to report to are the MnDNR (47%) and the forester/sale administrator (43%). Approximately one-third of respondents would report invasives on public land timber sales to county land departments. For private land sales, the most commonly selected reporting entity was the private forest landowner (38%), followed in smaller percentages by reporting to the forester/sale administrator (21%) and the MnDNR (17%).

The majority of respondents (54%) indicated they had not observed an increase of sales with invasives over the past three years while 29% reported not knowing. Only 17% had noticed an increase over the past three years of sales with invasive plants present.

3.2 Practices Undertaken to Address Invasive Forest Plants

To better understand the practices that logging businesses were already undertaking to prevent the introduction and/or limit the spread of invasive forest plants, respondents were provided a list of activities and asked whether they had been contractually required to undertake any of them on timber sales in the

past twelve months. The list of business practices was drawn from the literature (e.g., LeDoux and Martin, 2013) and requirements stipulated on some public land timber sales (e.g., USDA Forest Service, 2006). More than half of the respondents indicated they had not contractually undertaken any of the activities on public or private land timber sales (60% and 61%, respectively, of respondents). For three of the activities, approximately one-quarter of the respondents had been contractually required to undertake them on public land timber sales: inspecting equipment for invasives prior to moving it to a different logging site (29%), inspecting equipment for invasives prior to removing it from the job site (26%), and cleaning/washing the equipment (26%) (Table 1). These same three activities were the only ones done contractually at any appreciable level on private land timber sales as well.

Table 1. Invasive plant control and treatment activities contractually and voluntarily undertaken on timber sales in the previous twelve months (percent of respondents).

	Contractually required		**Voluntarily implemented**	
Activity	Public sales (N=95)	Private sales (N=101)	Public sales (N=96)	Private sales (N=103)
Clean/Wash equipment	26%	20%	33%	29%
Inspect equipment prior to removing from job site	26%	20%	35%	32%
Inspect equipment prior to moving to job site	29%	21%	40%	32%
Examine site for invasives	4%	6%	13%	17%
Treat invasives via burning	0%	2%	0%	2%
Treat invasives via herbicide	0%	2%	0%	4%
Manually treat invasives	0%	1%	0%	3%
Mechanically treat invasives	0%	0%	1%	4%
None of the above	61%	60%	45%	47%

Forty-five percent of the respondents indicated they had not voluntarily undertaken any of the activities to prevent the introduction and/or limit the spread of invasive forest plants on public land timber sales, while 47% indicated none of the activities had been voluntarily undertaken on private land timber sales. The same three activities undertaken by the greatest percentage of respondents under contractual requirements were also the highest implemented voluntary activities: inspecting equipment for invasives prior to moving it to a different logging site (40% public land sales and 32% private land sales), inspecting equipment for invasives prior to removing it from the job site (35% public land sales and 32% private land sales), and cleaning/washing equipment (33% public land sales and 29% private land sales) (Table 1). The percentage of respondents voluntarily inspecting job sites for invasives was approximately 3 times higher than the percentage doing so out of contractual requirements for each land ownership type.

3.3 Invasive Forest Plant Best Management Practices (BMP) Program

While the state of Minnesota hasn't formally developed best management practices (BMPs) for invasive forest plants, various practices exist elsewhere. Respondents were presented a list of 10 potential practices related to invasive forest plant control and asked to rate their perception of the difficulty to implement each practice. The list of business practices was drawn from the literature (e.g., LeDoux and Martin, 2013) and requirements specified on some public land timber sales (e.g., USDA Forest Service, 2006). Response options ranged from Very Difficult (1) to Not at All Difficult (4) on a 4-point scale. When viewed by average values, the difficulty of all of the activities was rated below a 3, indicating each of the activities was more than Slightly Difficult to implement (Table 2). The activity that was perceived to be the least difficult to perform was learning to identify invasive plants, with an average value of 2.77, with 64% of respondents indicating this practice would either be Slightly to Not at All Difficult to implement. The practice rated with the greatest average difficulty was treatment of staging areas to remove invasive plants prior to bringing in equipment (1.52) with 59% of respondents indicating that would be a Very Difficult practice to implement.

Respondents were asked to rate the perceived impact that a hypothetical statewide invasive forest plant BMP program that included the types of activities identified in Table 2 would have on their logging business, if one were to be developed. Response options were offered on a 4-point scale ranging from a Large Impact (1) to No Impact (4). Nearly half (49%) of respondents reported that a forest invasives BMP program would likely have a Large Impact on their business, with an additional 38% reported impacts would be Moderate (Figure 3). There was an overwhelming preference for a voluntary program (96%), if this type of forest invasives BMP program were to be implemented.

Table 2. Perceived degree of difficulty implementing various potential invasive forest plant BMPs (percent of respondents).

Best management practice	Very difficult (1)	Somewhat difficult (2)	Slightly difficult (3)	Not at all difficult (4)	Average value (Std Dev)
Learn to identify invasive plants (N=121)	8%	28%	43%	21%	2.77 (0.8733)
Document and notify appropriate agencies that invasive plants were found (N=123)	18%	36%	20%	25%	2.53 (1.0581)
Document that invasive plant BMPs were practiced in your operations (N=123)	20%	30%	27%	22%	2.51 (1.0509)
Create equipment staging areas where invasive plants are absent (N=123)	29%	36%	26%	9%	2.16 (0.9411)
Coordinate inspection of equipment for invasive plant materials (N=123)	32%	37%	18%	12%	2.10 (0.9917)
Inspect and clean equipment of soil, seeds and plants prior to moving between sites (N=124)	36%	39%	16%	9%	1.98 (0.9369)
Clean up staging areas after operations (N=121)	37%	39%	17%	8%	1.95 (0.9156)
Minimize the length of time that bare ground is exposed prior to re-seeding/re-vegetating (N=122)	41%	36%	17%	7%	1.89 (0.9109)
Acquire clean construction materials, fill dirt, gravel, sand and/or mulch (N=124)	50%	23%	17%	10%	1.86 (1.0228)
Mow, spray or treat staging areas to remove invasive plants before bringing equipment in (N=125)	59%	32%	9%	1%	1.52 (0.6911)

3.4 Interest in Developing Invasive Forest Plant Expertise

Logging businesses could develop invasive forest plant treatment services or be hired outside of a timber sale to treat or remove those plants as a way to diversify their operations or provide additional revenue to the business. Only 2% of respondents reported that they have developed invasive forest plant treatment or removal services and only 1% have been hired to provide such services in the past twelve months. A 4-point scale ranging from Very Interested (1) to Not at All Interested (4) was used to understand if respondents were interested in developing or expanding their expertise in invasive forest plant treatment or removal. Almost half of the respondents (49%) indicated they were Not at All Interested in developing such expertise as a means to diversify their operations (Figure 4). Approximately one-third (32%) indicated Slight Interest, while 20% indicated they were Somewhat to Very Interested.

Figure 3. Perceived impact of invasive forest plant BMPs on logging business operations (percent of respondents) (N=126).

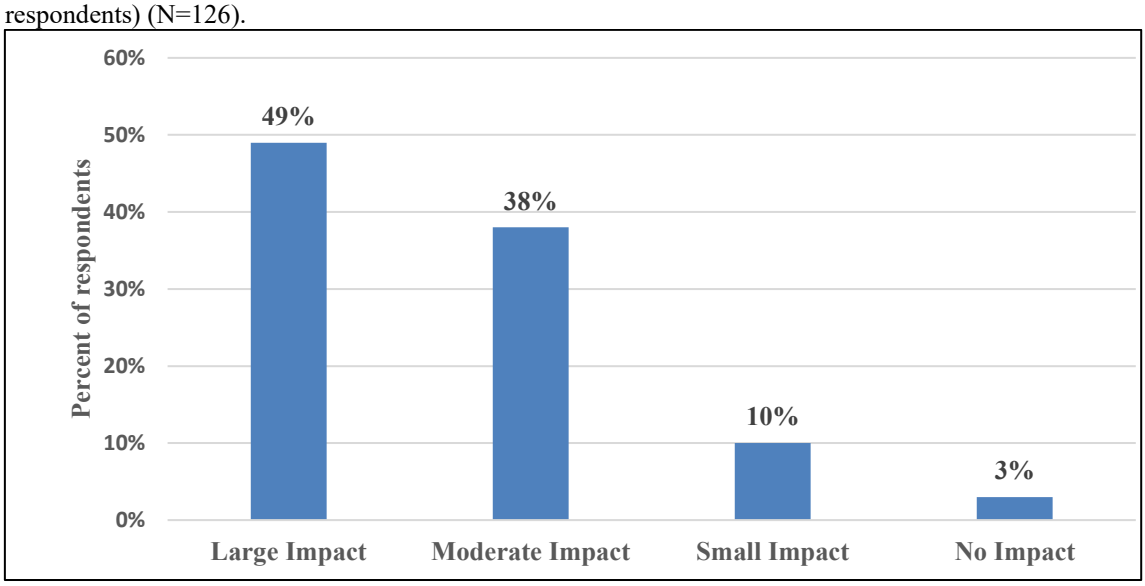
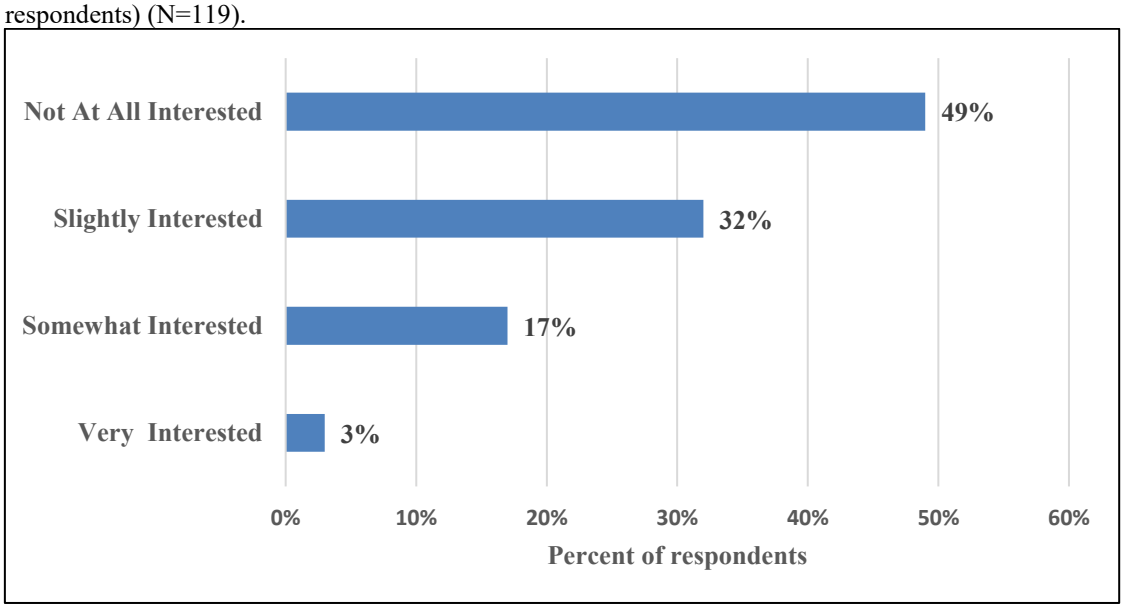


Figure 4. Degree of interest in developing invasive plant treatment and removal expertise (percent of respondents) (N=119).



3.5 Information Needs

MLEP is interested in meeting the informational needs of its members. Respondents were presented with nine education/information/training topics and asked to rank their top three needs relative to invasive forest plants or whether they had no information needs relative to invasive forest plants. Only a very small percentage (3%) of the respondents indicated they had no information needs. Identification of invasive forest plants was the most frequently cited information need and was rated as the most needed training topic by 49% of the respondents (Table 3). Business expenses associated with invasive forest plants and logging BMPs associated with invasive plants were cited second and third most frequently, respectively.

3.6 Segmentation Analyses

No statistical differences were found for most of the factors evaluated during the segmentation analyses of MnDNR forestry regions, harvest volume size class, and seasonality of business operation. A few factors did vary statistically by MnDNR forestry region. In general, when factors were found to vary, the differences were associated with the Central/Southern region versus the other two. Specifically, higher percentages of respondents in the Central/Southern regions reported noticing an increase in timber sales with invasives over the past three years than the other two regions. Respondents in the Central/Southern region also reported greater interest in developing invasive plant removal or treatment expertise than the other two regions. In terms of invasive plant activities being conducted on sales either contractually or voluntarily, when there were statistical differences, respondents in the Central/Southern region were less likely to be undertaking them, although most of the activities did not have regional variation. Specifically, Central/Southern respondents were less likely than Northeast respondents to have been contractually required to inspect their equipment prior to moving it to private land timber sales. Central/Southern respondents were less likely than loggers in the other two regions to have voluntarily cleaned their equipment on public land timber sales. 'Small producers' (e.g., 1,000 cords or less) were more commonly found in the Central/Southern region.

Table 3. Ranking of information needs (percent of respondents) (N=82).

Information topic	Percent 1st rank	Percent 2nd rank	Percent 3rd rank	Percent ranked either 1st, 2nd or 3rd
Identification of invasive forest plants	49	17	7	73
Business expenses associated with invasive forest plants	17	13	13	43
Logging BMPs associated with invasive plants	15	10	13	38
Impacts associated with invasive forest plants	9	15	10	34
Invasive forest plant spread prevention	5	18	22	45
Sources of information about invasive forest plants	4	9	6	19
Equipment requirements associated with managing invasive forest plants	1	11	11	23
Business opportunities associated with invasive forest plants	1	2	11	14
Invasive forest plant removal	0	5	6	11

A few of the factors did vary statistically by timber volume size class. In general, when factors were found to vary, the smaller cord businesses tended to be less active relative to invasive activities in comparisons to larger volume businesses. Specifically, on public land timber sales, the 1,000 cord or less companies and the 1,001-5,000 cord companies were less likely than the 5,001-15,000 cord companies to clean their equipment prior to moving it due to contractual obligations. Similarly, the 1,000 cords or less companies were less likely to have been contractually required to inspect their equipment prior to moving it than the 5,001 to 15,000 cord companies. In terms of contractual requirements on private land sale land timber sales, the 1,000 cords or less companies were less likely to inspect their equipment than the greater than 15,000 cords before moving it to a sale and less likely than the 5,001-15,000 cord companies to inspect prior to removing it from a job site. Further, the 1,001-5,000 cord business were less likely to have been required to clean/wash their equipment than the 5,001-15,000 cord companies. Also, the 1,000 cords or less companies were less likely to have voluntarily inspected their equipment prior to moving it, inspected equipment prior to removing it and clean/wash their equipment than the 5,001-15,000 cord companies. Finally, the 1,001-5,000 cord group had a higher percentage of winter only operations as compared to the greater than 15,000 cord companies.

Winter-only respondents reported lower general levels of knowledge of invasive forest plants in Minnesota. Higher percentages of winter-only businesses were in the 1,001-5,000 cord annual volume size class.

4. Discussion

While Minnesota logging business owners believe that they are somewhat to very knowledgeable about forest invasive plants, only four invasive plants could be confidently identified by about 50% or more of the respondents. The relatively low level of ability to identify specific plants may be due to the lack of training opportunities related to forest invasive plants for Minnesota's logging businesses, or logging activities occurring during the winter when the ground is likely snow-covered and foliage isn't present. Minnesota logging businesses reported harvesting 53% of their volume during the winter (Blinn et al., 2019), and 24% of the businesses reported that they only harvest timber in the winter. Additionally or alternatively, public agency foresters may be pre-treating areas with the presence of invasive plants so that logging businesses haven't had significant experience with invasive plants on their logging sites.

While more than half of the respondents hadn't undertaken any of the listed activities to prevent the introduction and/or limit the spread of invasive plants, there was a correspondence in implementation of activities undertaken contractually and voluntarily on public and private lands. Some logging businesses are voluntarily undertaking activities to prevent the introduction and spread of invasives, and there is a positive association between contractual and voluntary implementation of activities among some of the respondents.

Each of the 10 potential invasive forest plant BMP activities were perceived as being more than Slightly Difficult to implement. While respondents may have never implemented any of the practices, business owners likely perceive that each BMP has an associated cost which will raise their cost of production without a commensurate increase in delivered price. Thus, as one respondent said in a written comment, "I fear the bulk of the cost will fall on the logging industry when in fact we are a small part of the problem." while another said, "If markets don't pay for this then the logger will have to." If a statewide BMP program were to be developed, there is overwhelming support for the program to be implemented on a voluntary basis, which is similar to Minnesota's forest management guideline program with generally high levels of compliance (Rossman et al., 2018).

While few respondents had been hired outside of a timber sale to treat or remove invasive forest plants, about half of them indicated at least a slight interest in developing expertise in this area. They recognize, however, that being able to identify invasive forest plants is key to their ability to effectively treat or remove those plants and that training is needed on this topic. In response and given their greater interest in developing relevant expertise, pilot educational classes were conducted in the Central/Southern region to begin enhancing the knowledge of Minnesota's logging industry. Winter-only businesses may also be in great need of training and assistance to deal with invasive plant control activities.

Some of the differences in the Central/Southern respondents may be more of a function of being a small producer (e.g., perhaps less mechanized with lower levels of production and more time spent on-the-ground with a chainsaw and/or cable skidder), than specifically related to a producer being located in the central or southern part of the state. Thus, information and training needs may be different for small-scale producers versus larger logging business operations.

The differences we found by timber volume size class are likely influenced in part by the type of sales different sized businesses bid on. For example, the smaller volume companies may be purchasing more private land sales which may be less likely to have contractual requirements to undertake invasive plant activities. Moreover, since the smallest-volume producers were more likely to be winter-only businesses, they are less likely to encounter invasive plants during their operations. The implications for these differences by timber volume size class is that greater training and assistance may be needed for the smaller volume operators if invasive plant BMP practices were to be required given less experience in dealing with invasive plant practices.

5 Acknowledgements

We are grateful to all of the logging business owners who participated in this study. This research was supported by the Minnesota SFI State Implementation Committee, the Minnesota Logger Education Program, Minnesota Forest Industries, the USDA Forest Service Northern Research Station, the University of Minnesota's Department of Forest Resources, and the Minnesota Agricultural Experiment Station under Projects MN 42-057 and MN 42-072.

6 References

Armstrong, R.A. (2014) When to use the Bonferroni correction. Ophthalmic Physiol Opt. 34: 502-508. doi: 10.1111/opo.12131

Armstrong, J. S., and Overton, T. (1977) Estimating nonresponse bias in mail surveys. Journal of Marketing Research. 14(3): 396-402.

Beck K. G,, Zimmerman, K., Schardt, J. D., Stone, J., Lukens, R. R., Reichard, D., Randall, J., Cangelosi, A. A., Coope,r D., and Thompson, J. P. (2006) Invasive species defined in a policy context: Recommendations from the Federal Invasive Species Advisory Committee. Invasive Plant Science and Management, 1: 414-421.

Blinn, C. R., Snyder, S. A., Russell, M. B., and Peterson, R. R. (2019) Status of the Minnesota Logging Sector in 2016. University of Minnesota, Department of Forest Resources, Staff Series Paper 251. 105 p.

Dillman, D. A. (2000) Mail and internet surveys: The tailored design method. New York: John Wiley & Sons, Inc. 464 p.

Fisher, R. A. (1922) On the interpretation of χ^2 from contingency tables, and the calculation of P". Journal of the Royal Statistical Society. 85(1): 87-94.

Holmes, T. P., Aukema, J. E., Von Holle, B., Liebhold, A., and Sills, E. (2009) Economic impacts of invasive species in forests. The Year in Ecology and Conservation Biology. 1162: 18-38.

LeDoux, C. B., and Martin, D. (2013) Proposed BMPs for invasive plant mitigation during timber harvesting operations. Gen. Tech. Rep. NRS-118. Newtown Square, PA: USDA, Forest Service, Northern Research Station. 12 p.

MnDNR (2008) Timber operations on DNR lands. Invasive species guidelines. St. Paul, MN: Minnesota Department of Natural Resources, Division of Forestry. 4 p.

Rauschert E. S. J., Mortensen, D. A., and Bloser, S. M. (2017) Human-mediated dispersal via rural road maintenance can move invasive propagules. Biological Invasions 19: 2047-2058.

Rossman R, Corcoran J, and Slesak, R (2018) Timber harvesting and forest management guideline implementation on public and private forest land in forested watersheds in Minnesota: 2016 and 2017 monitoring implementation results. St. Paul, MN: Minnesota Department of Natural Resources, Division of Forestry. 51 p.

Setterfield, S. A., Douglas, M. M., Hutley, L. B., and Welch, M. A. (2005) Effects of canopy cover and ground disturbance on establishment of an invasive grass in an Australia savanna. Biotropica, 37: 25-31.

USDA Forest Service. (2006) Timber Sale Contract Division BT. Standard provisions for timber sales to be measured before felling. (https://www.fs.fed.us/forestmanagement/documents/contracts/!FS-2400-6T_Division_BT_6-06.pdf)

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

ENVIRONMENTAL IMPACT OF MECHANIZED HARVESTING IN LARGE-DIMENSION HARDWOODS

Lorenz Breinig, Caroline Bennemann, Peter Aurenhammer and Eric R. Labelle
Assistant Professorship of Forest Operations
TUM School of Life Sciences Weihenstephan
Technical University of Munich
Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany
lorenz.breinig@tum.de

Abstract: *While cut-to-length harvesters have been operating for more than two decades in Germany and have become the standard system for softwood stands under most conditions, large-dimension hardwoods are still commonly the subject of motor-manual work. Recently, growing interest to begin hardwood harvesting already in early fall in order to respond to market demand and to schedule machine traffic to periods of low soil moisture leads to harvesters being increasingly used in large-dimension hardwoods since motor-manual felling of hardwood trees with foliage is critical with respect to work safety. However, due to the large crowns and high masses of hardwood trees – especially with the leaves on – felling the trees in a controlled manner becomes increasingly difficult even for large harvesters. Therefore, the impact of utilizing a harvester for felling and processing of large-dimension hardwoods on the stand, i.e. frequency and severity of damages to the remaining trees, has been evaluated for operations performed under two conditions: in early fall with leaves on, and in winter. Furthermore, the impact on the soil has been assessed by combining in-situ measurement of soil penetration resistance with laboratory measurement of soil physical characteristics such as (relative) bulk density, air permeability and water permeability using soil-core samples taken on transects across machine operating trails, both pre- and post-traffic for each condition. A large wheeled harvester (Rottne H20) was used in both conditions that were tested within the same harvest block. The results allow for an estimation whether utilizing harvesters in technically demanding hardwood operations, and in particular for trees with foliage, are feasible from the perspective of environmental impact. In further field studies, a complementary evaluation for a large tracked harvester shall be conducted under the same conditions to allow for a comparative assessment of these two basic machine concepts.*

Keywords: deciduous trees, soil compaction, bark damage

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

MODELLING FUEL CONSUMPTION IN CUT-TO-LENGTH WOOD HARVESTING OPERATIONS IN NORDIC CONDITIONS

Hanna Haavikko[1], Kalle Kärhä[2*], Heikki Kääriäinen[1,2], Kimmo Roininen[2] & Teijo Palander[1]

[1] University of Eastern Finland
School of Forest Sciences
Faculty of Science and Forestry
P.O. Box 111, FI-80101 Joensuu, Finland
hanna.haavikko@gmail.com, teijo.s.palander@uef.fi

[2] Stora Enso
Wood Supply Finland
P.O. Box 309, FI-00101 Helsinki, Finland
kalle.karha@storaenso.com, heikki.a.kaariainen@storaenso.com, kimmo.roininen@storaenso.com

Abstract: *Comprehensive follow-up studies on the fuel consumption of logging machines (i.e., harvesters and forwarders) have not been conducted during the previous fifteen years in Finland, and only a few exist for global, long-term studies of wood harvesting machinery. Emission calculations require updated information about fuel consumption in cut-to-length logging operations, and it is essential to understand the effect of multiple factors, such as harvesting conditions (e.g., stem volume of removal, hectare-based removal, number of timber assortments, forest haulage distance, soil type, harvesting season, depth of snow cover), the machine operator, or the machine and its adjustments, on fuel consumption in cutting and forwarding. This study determined and modelled the fuel consumption of harvesters and forwarders in cut-to-length logging operations in Nordic wood harvesting conditions in Finland from March 2018 through April 2019. Fuel tanks of 17 harvesters and 13 forwarders were equipped with digital Piusi K24 flow meters featuring an accuracy of ±1% that measured the use of the fuel consumption of 309,770 dm^3 in cutting and 156,230 dm^3 in forest haulage. In cutting and forwarding, the removals of industrial roundwood were 314,663 m^3 and 222,678 m^3, respectively, with the highest average fuel consumption per hour for both harvesters and forwarders occurring during clear cuttings. In the first and later thinnings, the fuel consumption per hour was less with harvesters and forwarders. The fuel consumption per cubic meter harvested was significantly lower when logging industrial roundwood from clear cuttings. In addition to the cutting method, the results suggested that the machine-operator combinations and harvesting conditions significantly affect fuel consumption rates. With this data, the fuel efficiency in logging operations can be improved, training of machine operators enhanced, and emission calculations developed.*

Keywords: energy efficiency, cutting, forest haulage, harvester, forwarder, industrial roundwood, follow-up study

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

INFLUENCE OF THE EXTRACTION LINE'S DISTANCE ON THE VALUE OF THE TREE STAND

Marcus Hennek
Institute of Forest Utilisation and Forest Technology, Chair of Forest Technology, TU Dresden, Germany
marcus.hennek@tu-dresden.de

Abstract: *In Germany, extraction lines are built permanently and for stand generations. The shorter the distance is between the extraction line, the easier it is to harvest the timber mechanically. At the same time the intermediate area, in which silvicultural activities can be carried out, gets smaller and smaller. Hence, we focus on the research question in how far the distance of the extraction line affects the value of a tree stand. We assume, that the growth is directed to the qualitatively best trees in the stand in order to produce higher quality wood. Depending on the tree species and the age of the trees, there is an optimal distance between trees and thus a defined number of selected trees per hectare. The extraction line reduces the traffic-free zone, in which the trees should be spaced out uniformly. Here there are two extreme positions:*
1) Compliance with the distance of the trees: For example having 200 selected trees per hectare, the ideal distance between the trees would be seven metres. As a result of the reduction of the traffic-free zone and the consistently maintaining of a distance of seven metres between trees, areas occur, where no selected tree is available. Consequently, the number of selected trees is less than 200 per hectare decreasing the value of the stand.
2) Compliance with the specified number of selected trees per hectare: Instead, if the aim is to reach the specified number of selected trees per hectare, the average spacing between trees has to be less than seven metres. As a result, the intraspecific competition increases and the value of the single tree decreases.
Taking both hypotheses into consideration, one can assess a loss in value respectively, which will be illustrated in monetary terms by means of different tree stands and different improving accessibility systems.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

WEST VIRGINIA TIMBER HARVESTING ACTIVITIES – LANDOWNERSHIP INFLUENCES ON HARVEST TYPES, COMPARTMENT SIZES, AND BEST MANAGEMENT PRACTICES COMPLIANCE

Ben Spong
West Virginia University, Morgantown, WV, USA
ben.spong@mail.wvu.edu

Abstract: *Landownership in WV and surrounding areas of the eastern United States is dominated by many small private, fewer industrial, and even fewer public owners. Each of these ownership categories have different perspectives on why timber harvesting activities might occur on their property. In general, lands under public or industrial ownership have science based, multifaceted management objectives. Public lands often value multiple use and a diversity of outcomes, while the focus on industrial owners typically lean towards sustainable production of wood fiber and returns to their investors. With thousands of individual smaller scale private landowners, the objectives, guidance, and oversight regarding management and harvesting activities can be much more varied.*

Through a review of statewide harvesting data from 2013-2019, a summary of the type of harvests, harvest compartment size, and best management practices compliance will be presented. Analysis of these data will focus on in field inspection identified compliance issues with best management practice implementation and the relationship with the different landownership types. Eventually, matching key relationships between these harvesting indicators with different landowner types can be used to inform the development of future timber harvesting educational material, professional development, and other outreach activities.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

RESIDUAL STAND DAMAGE UNDER DIFFERENT SILVICULTURAL PRESCRIPTIONS

Evan Ross Nahor, Anil Raj Kizha, Libin Thaikkattil Louis
University of Maine, Orono, USA
anil.kizha@maine.edu

Abstract: *Residual stand damage is the injury caused to trees, which were not prescribed to be harvested, during forest managerial activities and is commonly a result of machine activities. The resulting damage from the operation have found to reduce the economic value of future return. The objective of the study was to evaluate residual stand damage due to timber harvesting operations under different silvicultural prescriptions. The specific objectives were to estimate the intensity and frequency of damage types (i.e., cambium, canopy, and root) both at a tree, and stand level. The study site was industrial timberland located in Grand Falls, Central Maine, USA and was dominated with red spruce (Picea rubens), and Eastern hemlock (Tsuga canadensis). Two silvicultural prescriptions, crop tree thinning, and, overstory removal, were implemented on two adjacent stands using a conventional whole tree operation. Systematic transect sampling method was employed for data collection, with each transect being 9 m wide. Of the 22 hectares harvested a total of 5 hectares were inventoried (comprised 22% of the total area) from which information on tree damage type, intensity, frequency, and GPS coordinates were collected. Two hundred thirty-one trees were found to be damaged. A total of 274 damages were recorded, as some of the trees had multiple points of damage. The most common damage type was injury to the cambium (n=185, 37%). Most of the damage, especially the root and cambium damage, was concentrated around the skid trails for both silvicultural prescription. Additionally, the more intense harvest prescription resulted in a larger amount of residual stand damage. A woodlot manager or owner who is planning harvests to improve the future of a stand financially may want to consider how residual stand damage is going to affect their stand, and how that damage can be minimized.*

S12 Supply chains
Puzzles to optimize

COMPARISON OF THE PRODUCTIVITY AND COST OF FOUR HARVEST SYSTEMS OPERATING IN A EUCALYPT PLANTATION IN WESTERN AUSTRALIA
Martin Strandgard [1], Rick Mitchell [1], John Wiedemann [2]
[1] *University of the Sunshine Coast;* [2] *WA Plantation Resources P/L*

HARVESTING PRODUCTIVITY, COST, AND TIMBER UTILIZATION IN CONVENTIONAL AND PROCESSOR HARVESTING SYSTEMS IN GEORGIA, USA
Joe Conrad
Warnell School of Forestry & Natural Resources, University of Georgia, Athens, GA, USA

MOTOR MANUAL AND MECHANIZED WTS BIOMASS HARVESTING IN SPANISH QUERCUS COPPICES. PRODUCTIVITY, COST AND ENVIRONMENTAL ANALYSIS
E Tolosana, R Laina, R Spinelli, G Aminti, I López-Vicens

APPLYING THE SYSTEM INTEGRATOR CONCEPT TO FOREST SUPPLY CHAIN
Luc LeBel [1], François Morin [1], Luis de Santa Eulalia [2], Denise Dubeau [3]
[1] *Université Laval;* [2] *Université de Sherbrooke;* [3] *MFFP*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

COMPARISON OF THE PRODUCTIVITY AND COST OF FOUR HARVEST SYSTEMS OPERATING IN A EUCALYPT PLANTATION IN WESTERN AUSTRALIA

Martin Strandgard [1], Rick Mitchell [1], John Wiedemann [2]
[1] University of the Sunshine Coast; [2] WA Plantation Resources P/L
mnstra@unimelb.edu.au

Abstract: *Worldwide eucalypt plantations exceed 20 million hectares, however, there have been very few comparative harvest system studies to provide a basis to understand the cost and productivity of harvest systems used in these plantations. The current study compared four harvest systems producing eucalypt wood chips on a single site in south-west Western Australia over a period of nine days. Two of the harvest systems were 'cool' systems producing logs at roadside (CTL – cut-to-length method at the stump, WTM – whole tree method) and two were 'hot' systems producing chips at roadside (IFC-DDC – infield chipping using a debark/ delimb/chipper, IFC-F/C – infield chipping using a separate fail and chipper). The logs were chipped at a static mill that also received the chips produced infield.*

The WTM and IFC-F/C harvest systems were the most productive. The productivity of the CTL and IFC-DDC harvest systems was about 25% less than that of the other two harvest systems. The infield chipping systems had the lowest wood production costs. The CTL harvest system had the highest wood production cost as it had a large number of machines without a correspondingly high productivity level. However, CTL harvest systems are commonly used world-wide to harvest eucalypt plantations. This highlights that harvest system costs and productivity are not the only considerations used by harvest contractors and forest managers to select harvest systems. The CTL harvest system has a number of advantages over the other systems through retaining evenly distributed logging residues, low machinery impact on the site, low establishment costs (two machines required for a harvest system), flexibility to add or subtract machines as conditions change and flexibility to move to sawlog production.

Two limitations of this study were that the harvest systems were only compared at a single mean tree size and operator performance differences may have influenced harvest system productivity.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

HARVESTING PRODUCTIVITY, COST, AND TIMBER UTILIZATION IN CONVENTIONAL AND PROCESSOR HARVESTING SYSTEMS IN GEORGIA, USA

Joseph L. Conrad, IV* **and Joseph Dahlen**
Warnell School of Forestry and Natural Resources
University of Georgia
190 E. Green St., Athens, GA 30602
jlconrad@uga.edu

Abstract: A designed study of processor (i.e., feller-buncher, grapple skidder, processor, loader) and conventional (i.e., feller-buncher, skidder, loader) systems was conducted in Georgia, USA. Four sites were split, and half of each site harvested by a processor system and the other half by a conventional system. Elemental time studies and work sampling were conducted to estimate productivity and utilization. Cut-and-load costs averaged \$15.08 and \$16.30 t^{-1} on the processor and conventional harvests, respectively ($p > 0.10$). Harvesting costs on the processor treatments could be reduced by increasing utilization through more efficient skidding practices. The processor treatment increased volume and value recovery relative to preharvest estimates, but these differences were not statistically significant ($p > 0.10$). This study suggests large landowners and/or sawmills should consider incentivizing logging contractors to add processors to improve volume and value recovery and increase mill efficiency.

Keywords: U.S. South, value recovery, logging costs

1. Introduction

Whole-tree timber harvesting systems have been used by the vast majority of logging businesses in Georgia and the U.S. South since the 1980s (Greene et al. 1988, Baker and Greene 2008, Conrad et al. 2018a, Conrad et al. 2018b). A conventional harvesting system in Georgia and the U.S. South consists of a rubber-tired, drive-to-tree feller-buncher, 1-2 grapple skidders, and 1-2 knuckleboom loaders with pull-through delimbers and slasher saws. Most mills in the region purchase timber in random tree-lengths based on specified minimum and maximum large- and small-end diameters and allowable defects (Conrad et al. 2018b). Log-length (i.e., multiples of 4.9 m [16 ft]) timber is also delivered by loggers in the region, but the majority of the timber is delivered in lengths greater than 7.6 m (25 ft). Cut-to-length harvesting systems are nearly non-existent (none identified in Georgia in 2017) in the region. Conventional whole-tree systems rely on ocular estimation of lengths and diameters, limiting bucking precision. The conventional system is premised on high production and minimizing material handling by felling, skidding, and processing multiple stems at a time and minimizing bucking cuts.

The conventional whole-tree system is well-adapted to mill demands and harvest site conditions in the U.S. South. Pine plantations with relatively gentle terrain, soils capable of supporting heavy equipment, and minimal seasonal operability issues make this harvesting system ideally suited to the region. Pulp recovery improves with longer pulpwood lengths, and the pulp and paper industry purchases approximately 40-60% of the annual harvest volume in many southern states (Cooper et al. 2011, Bentley et al. 2014). In addition, the conventional whole-tree system allowed loggers in the U.S. South to achieve the lowest harvesting costs in the U.S. and competitive costs internationally (Siry et al. 2006, Gibeault et al. 2015, Mac Donagh et al. 2017).

Because lumber is sold in standard lengths, sawmills must either purchase logs in standard lengths or cut logs to standard lengths inside the sawmills. Purchasing random tree-length logs necessitates cutting logs to appropriate lengths inside mills, which generates process residuals that must be marketed or disposed. In addition, the mill must

pay sawtimber prices for portions of logs that will not be made into lumber. Historically, many sawmills in the U.S. South were owned by vertically integrated forest products companies that owned both pulp mills and sawmills, which gave them a market for process residuals and an incentive to purchase tree-length logs. Today, most sawmills are owned by stand-alone companies that do not own pulp mills, meaning process residuals are not necessarily an asset and may be a liability.

In order to improve sawmill efficiency and reduce process residuals, some companies are purchasing logs in specific lengths, hereafter referred to as "prime lengths." These mills purchase prime lengths in multiples of finished product dimensions. This change in specifications requires loggers to perform additional bucking cuts and estimate lengths and diameters more precisely than when producing tree-length logs. Past research suggests conventional systems are poorly equipped to produce prime lengths. Because conventional systems rely on ocular estimates of length and diameter, they are ill-equipped to meet the new prime length specifications. In addition, past research suggests conventional system productivity can be reduced by approximately 50% when producing log lengths shorter than 6.1 m (20 ft) (Cass et al. 2009).

Some loggers in Georgia have added track-mounted, dangle-head processors on the landing of their whole-tree systems to conduct delimbing, topping, and bucking to produce prime length logs. This system uses a feller-buncher, 1-2 grapple skidders, a processor, and a knuckleboom loader and will be referred to as a processor system here. The processor system is designed to efficiently produce specific lengths with precise measurement of lengths and diameters, while retaining the high productivity and low per-unit costs of conventional whole-tree systems.

The shift from tree-lengths produced by conventional systems to prime lengths produced by processor systems has raised important questions from mills, loggers, and forest landowners. Mills and loggers need to compare harvesting productivity and cost between conventional and processor systems. Landowners primary concern is that the shift from tree-length specifications to prime length specifications may reduce the amount of volume that is delivered as sawtimber, and consequently reduce stumpage revenue.

The purpose of this study was to compare harvesting costs and stumpage value recovery between whole-tree conventional and processor systems in the state of Georgia, USA. This paper will summarize the principal conclusions of the study, while additional details are provided elsewhere (e.g., Conrad and Dahlen 2019).

2. Methods

This study was conducted in the Upper Coastal Plain and Piedmont of Georgia, USA. Four harvest sites ranging from 31 to 40 hectares were split, with half of each site harvested by a processor system and the other half by a conventional system. The processor system employed one feller-buncher, one (Site 1) or two (Sites 2-4) grapple skidders, one processor, and one knuckleboom loader. The conventional system employed one feller-buncher, one (Sites 1,3, and 4) or two (Site 2) grapple skidders, and one knuckleboom loader. Three logging businesses harvested processor sites and three logging businesses harvested conventional sites, with the same businesses harvesting sites 1 and 3. Processor crews produced prime length timber, while conventional crews produced tree-length timber (Table 1).

Time-and-motion studies were conducted on each harvest unit to compare harvesting productivity and costs between treatments. Elemental time studies were conducted to estimate harvesting productivity for each machine in each system (Conrad and Dahlen 2019). Hourly costs of owning and operating each machine were estimated using the machine rate method (Miyata 1980, Brinker et al. 2002, Dodson et al. 2015) and standard assumptions (Table 2). For each machine, we assumed an off-road diesel price of \$0.71 l^{-1} (EIA 2018). Each equipment operator was assigned compensation of \$17.75 hr^{-1} (BLS 2018), plus overhead and fringe benefits equivalent to 40% of the hourly wage. We assumed 2,000 scheduled machine hours per year for all equipment and employees. In addition to hourly machine costs, we assumed that each harvest unit required \$3,500 of roadwork. Initial movement to the site was assumed to require 5 hours at a distance of 64 km (40 mi). One company truck was assigned to each crew at a cost of \$0.339 km^{-1} (\$0.545 mi^{-1}) with 129 km (80 mi) driven per day. Owner salary of \$6,000 per month was assigned to each crew along with \$3,000 per month in overhead. Two saws worth \$1,500 apiece were assigned to each crew. No profit was included in the calculations. Hourly productivity and costs were combined in the Auburn Harvesting Analyzer to calculate cost per ton (Tufts et al. 1985).

Preharvest inventory estimates were provided by our industry partner. Georgia average stumpage prices from TimberMart-South (2018) were used to estimate stumpage revenue. Paired sample t-tests were used to compare tract-level sample means between the two harvest treatments. Data were analyzed using Microsoft Excel and JMP Pro 13.2.0 (SAS Institute Inc. 2016).

Table 1: Tree-length, prime 4.9 m, and prime 6.1 m specifications used during the study.

Category	Product	Minimum LED, SED (cm)	Allowable lengths
Tree-length	Pulpwood	N/A, 7.6	3.7 m minimum
	Chip-n-saw	N/A, 12.7	5.0 m short-log, otherwise 7.6 m minimum
	Sawtimber	35.6, 20.3	5.0 m short-log, otherwise 7.6 m minimum
Prime 4.9 m (16 ft)	Pulpwood	N/A, 7.6	3.7 m minimum
	Chip-n-saw	N/A, 12.7	5.0, 10.1, 13.9, 15.1, 18.9 m
	Sawtimber	35.6, 20.3	5.0, 10.1, 13.9, 15.1, 18.9 m
Prime 6.1 m (20 ft)	Pulpwood	N/A, 7.6	3.7 m minimum
	Chip-n-saw	N/A, 12.7	3.8, 5.0, 6.2, 10.1, 11.3, 12.5, 15.1, 16.3, 18.7 m
	Sawtimber	35.7, 20.3	3.8, 5.0, 6.2, 10.1, 11.3, 12.5, 15.1, 16.3, 18.7 m

Table 2: Machine rate assumptions for all harvesting crews.

Machine	Feller-buncher	Skidder	Loader	Processor
Purchase price (USD)	$260,000	$280,000	$239,000	$500,000
Salvage value (% of purchase price)	25%	20%	20%	20%
Economic life (yr)	5	5	5	5
Interest, Insurance, & taxes (% of average value invested)	10%	10%	10%	10%
Fuel consumption (l pmh^{-1})	24.6	19.3	14.0	18.9
Maintenance and repair (% of depreciation)	100%	100%	100%	100%
Utilization	65%	60%	65%	65%

PMH: productive machine hour (excluding delays)

3. Results and Discussion

Harvesting costs (onboard truck) averaged \$14.96 t^{-1} and \$16.17 t^{-1} on the processor and conventional harvests, respectively ($p > 0.25$) (Table 3). Harvesting costs ranged from \$13.36 t^{-1} to \$18.75 t^{-1} on the processor harvests and \$10.93 t^{-1} to \$21.03 t^{-1} on the conventional harvests. Small sample size and high variability meant that differences in harvesting costs between treatments were not statistically significant.

Processor crews produced approximately 68% more timber per hour and per week compared to the conventional crews ($p = 0.17$) (Table 3). The productivity of the conventional crews was typical of harvesting crews in the study area, while processor crews' productivity was well above average production of 35-40 loads per week per crew in Georgia (Conrad et al. 2018b). Processor crews were constrained by skidding capacity on all four sites, but this constraint was particularly problematic on site 1 where the crew operated only one skidder. The processor utilization was only 35% on site 1 because of time spent waiting on the skidder. The processor was capable of producing approximately 70 tonnes per productive machine hour, unconstrained by the rest of the system (Table 4). Processor crews produced more timber per hour than conventional crews because of high productivity from the processor (Table 4) and because three of the four processor crews employed two skidders, whereas only one of the conventional crews used two skidders.

Harvesting costs on the processor treatment could have been reduced by improving skidder productivity, especially on site 1. Processor crews should plan to employ either two skidders or replace an average-sized skidder with a large model. In addition, each of the processor crews used skidders to conduct initial delimbing with a delimbing gate or by

driving over the tree tops with the skidder. This strategy may be helpful in a conventional system when loading and processing is the limiting factor in production, but it is counterproductive in a processor system. The processor is capable of completing all delimbing without assistance from the skidder. Skidder delimbing increased skidder cycle time by approximately 1-2 minutes per turn and we estimated this strategy increased harvesting costs on processor harvests by an average of \$2.10 t^{-1}.

The high harvesting cost on the conventional harvest at site 4 was the result of poor harvest planning. On this site, the logger harvested 14.6 ha with one landing, which resulted in average skidding distance of approximately 370 m. In contrast, the conventional harvest at site 1 achieved low harvesting costs because skidding distance averaged approximately 190 m with the result a well-balanced system in which skidder productivity and loading/processing productivity were similar and harvesting costs were low.

Table 3: Harvesting productivity and cost (USD) by site and treatment for the processor and conventional harvesting treatments.

Site and treatment	Harvesting cost (\$ t^{-1})	System productivity (t smh^{-1})	Loads wk^{-1}	Limiting Production Factor
Site 1				
Processor	\$18.75	24.30	35	Skidding
Conventional	\$10.93	32.48	46	Loading/Processing
Site 2				
Processor	\$13.36	46.43	64	Skidding
Conventional	\$14.59	32.69	47	Loading/Processing
Site 3				
Processor	\$13.89	48.08	68	Skidding
Conventional	\$18.11	18.22	26	Skidding
Site 4				
Processor	\$13.86	48.24	70	Skidding
Conventional	\$21.03	16.18	24	Skidding
Average				
Processor	\$14.96[a]	41.76[a]	59[a]	--
Conventional	\$16.17[a]	24.89[a]	35[a]	--

SMH: scheduled machine hour

Table 4: Processor productivity, cost (USD), and utilization by site.

Site	T pmh^{-1}	Estimated t smh^{-1}	Utilization	Cost (\$ t^{-1})
1	70	24	35%	\$4.52
2	67	46	69%	\$2.95
3	70	48	69%	\$2.85
4	63	48	77%	\$2.99

PMH: productive machine hour
SMH: scheduled machine hour

The combined cost of processing and loading was higher on the processor treatment than the conventional treatment ($p = 0.14$) (Figure 1). The average difference between the two was \$1.76 t^{-1}. This finding was not surprising given the high initial cost of the processor and productivity levels achieved during the study. The lowest combined processing and loading cost on the processor treatment occurred on site 2 at \$4.55 t^{-1}. In contrast, the lowest combined processing and loading cost on the conventional treatment occurred on site 2 at \$2.71 t^{-1}. For the processor system to achieve combined processing and loading costs of \$2.71 t^{-1}, the harvesting crew would need to produce approximately 132 loads (3,592 t) per week (Figure 2), which is more than double the production observed in this study (Table 3) and approximately 10% higher than observed by an experienced operator in another recent study (Daniel et al. 2019).

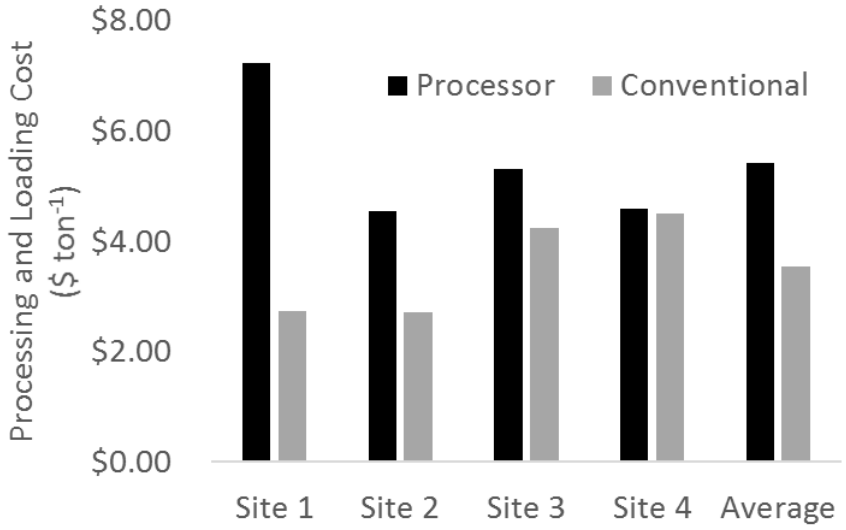


Figure 1: Combined processing and loading costs (USD) on the processor and conventional treatments on four sites in Georgia, USA.

Adding a processor to a whole-tree logging crew raises their break-even production level. Adding the processor could increase their profitability through increased production, better merchandizing, and earning a higher logging rate. However, adding a processor leaves crews vulnerable during periods of restrictive quotas. We imposed a 1,224 t wk^{-1} quota on both systems to evaluate the impact on harvesting costs. The quota increased average harvesting costs on the processor treatment by \$3.42 t^{-1}. The quota increased harvesting costs on the conventional treatment by just \$0.25 t^{-1}. High production is critical to the success of processors crews and likely quota levels must be considered before purchasing a processor.

The processor crews recovered 18.1% more volume than preharvest inventory estimates and conventional crews recovered 9.3% more than the preharvest inventory estimates ($p > 0.10$) (Figure 3). Similarly, the processor crews recovered an average of \$507 ha^{-1} more than the preharvest inventory predicted, whereas the conventional crews recovered \$212 ha^{-1} in excess of preharvest estimates ($p > 0.10$) (Figure 4). Although not statistically significant, improved volume and value recovery with the processor versus conventional equipment is consistent with past research (Gingras 1996, Gingras and Soucy 1999, Hamsley et al. 2009).

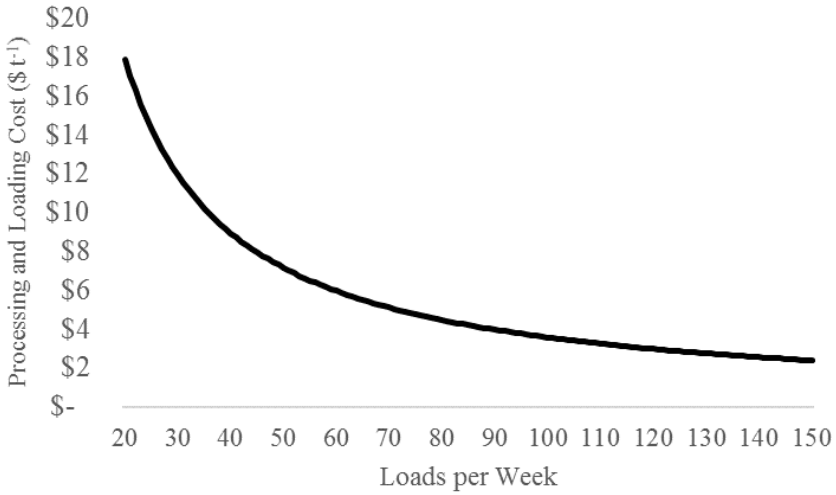


Figure 2: Combined processing and loading cost for a processor and loader at production levels ranging from 20 to 150 loads per week (1 load = 27.2 t).

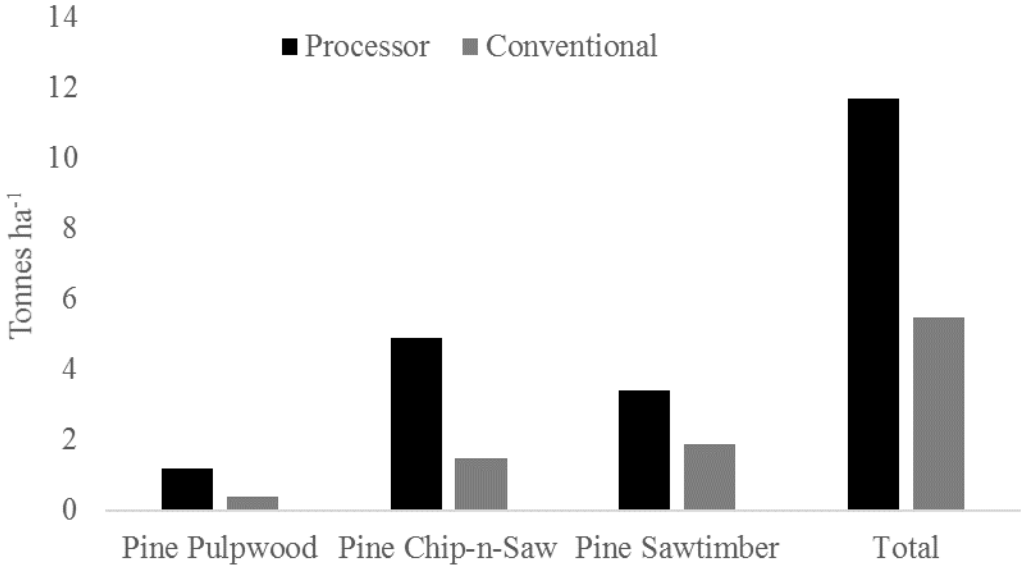


Figure 3: Average difference between preharvest inventory estimates and harvest volume by treatment and product class. Positive numbers indicate more volume was harvested than predicted by the inventory.

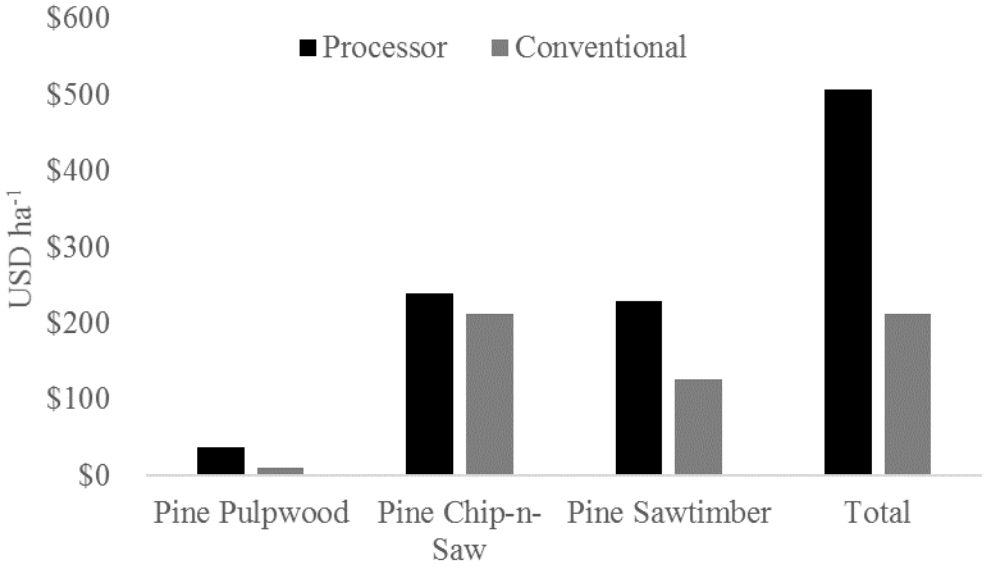


Figure 4: Average difference in stumpage revenue per hectare between preharvest inventory estimates and actual harvest by product class and treatment.

4. Conclusion

This study demonstrated that whole-tree harvesting systems using a processor can produce timber at competitive cost with conventional harvesting systems using a knuckleboom loader, pull-through delimber, and slasher saw. Harvesting costs were slightly lower on processor harvests in this study, primarily due to poor harvest planning and system balance on several conventional harvests. Combined processing and loading costs were higher on the processor harvests (Figure 1) and productivity would need to increase substantially for processing and loading to equal that of the most efficient conventional crews (Figure 2). In addition, because of high capital investment, restrictive quotas are much more problematic for processor crews compared to conventional crews. Therefore, loggers adopting processors will

likely require a modest logging rate premium and quotas allowing them to produce approximately 100 loads of timber per week.

Volume and value recovery were higher on processor harvests than conventional harvests, but these differences were not statistically significant due to small sample size. Improved volume and value recovery with processors is consistent with past research (Gingras 1996, Gingras and Soucy 1999, Hamsley et al. 2009). Given that harvesting costs were comparable between the processor and conventional systems, even though the processor systems was producing prime lengths, suggests incentivizing loggers to invest in these machines may be advantageous for both landowners and mills to increase volume and value recovery. Conventional systems rely on ocular estimates of length and diameter; consequently, precision of these measurements is limited. If mills wish to purchase prime lengths and require close adherence to mill specifications, adding processors to southern whole-tree systems can enable loggers to achieve high volume and value recovery while maintaining high productivity and low cost per tonne. Loggers, however, are unlikely to invest in processors unless they receive a logging rate premium, preferential quota, and/or specifications are strictly enforced at receiving mills.

5. Acknowledgements

The authors gratefully acknowledge the support of Interfor Corporation. This work was supported by the USDA National Institute of Food and Agriculture McIntire Stennis project 1018443. The authors thank John Bell for assistance during data collection as well as the foresters and harvesting contractors that worked with us during the study.

6. References

Baker, S. A. and Greene, W. D. (2008), “Changes in Georgia’s Logging Workforce, 1987-2007,” Southern Journal of Applied Forestry, 32(2), 60-68.

Bentley, J. W., Cooper, J. A. and Howell, M. (2014), “Alabama’s Timber Industry, 2011 – Timber Product Output and Use – Forest Inventory and Analysis Factsheet,”. USDA For. Serv. e-Science Update SRS–087. 4 p.

Brinker, R. W., Kinard, J., Rummer, B. and Lanford, B. (2002), “Machine Rates for Selected Harvesting Machines,” Circular 296 (revised), Alabama Agricultural Experiment Station, Auburn University, Auburn, AL. 32 p.

Bureau of Labor Statistics (BLS) (2018). May 2017 state occupational employment and wage estimates: Georgia, available online at https://www.bls.gov/oes/current/oes_ga.htm#45-0000; last accessed September 6, 2018.

Cass, R. D., Baker, S. A. and Greene, W. D. (2009), “Cost and productivity impacts of product sorting on conventional ground-based timber harvesting operations,” Forest Products Journal, 59(11/12), 108-114.

Conrad, J. L., IV and Dahlen, J. (2019), “Productivity and Cost of Processors in Whole-Tree Harvesting Systems in Southern Pine Stands,” Forest Science doi: 10.1093/forsci/fxz036.

Conrad, J. L., IV, Greene, W. D. and Hiesl, P. (2018a), “A Review of Changes in US Logging Businesses 1980s-Present,” Journal of Forestry, 116(3), 291-303.

Conrad, J. L., IV, Greene, W. D. and Hiesl, P. (2018b), “The Evolution of Logging Businesses in Georgia 1987-2017 and South Carolina 2012-2017,” Forest Science, 64(6), 671-681.

Cooper, J. A., Johnson, T. G, New, B. D. and Altizer, C. B. (2011), “North Carolina’s Timber Industry – an Assessment of Timber Product Output and Use, 2009,” USDA For. Serv. Res. Bull. SRS-178. 31 p.

Dodson, E., Hayes, S., Meek, J. and Keyes, C. R. (2015), “Montana Logging Machine Rates,” International Journal of Forest Engineering, 26, 85-95.

Daniel, M. J., Gallagher, T., Mitchell, D., McDonald, T. and Via, B. (2019), "Productivity and Cost Estimates for Incorporating Tracked Processors into Conventional Loblolly Pine Harvesting Regimes in the Southeastern United States," International Journal of Forest Engineering, 30, 155-162.

Energy Information Administration (EIA). (2018), "Gasoline and diesel fuel update", available online at https://www.eia.gov/petroleum/gasdiesel/; last accessed September 6, 2018.

Gibeault, F. M., Coutu, P. J. and Stuber, D. (2015), "Wood Supply Chain Component Costs Analysis: A Comparison of Wisconsin and U.S. regional Costs – 2015 update (Data period: Q3 2013 through Q2 2015)," Steigerwaldt Land Services, Inc. and Forest2Market, Inc., Tomahawk, WI, and Charlotte, NC. 40 p.

Gingras, J. F. (1996), "The Cost of Product Sorting During Harvesting," Forest Engineering Research Institute of Canada (FERIC), Technical Note TN–245.

Gingras, J. F. and Soucy, M. (1999), "Sorting of Multiple Products with a Cut-to-Length System," Forest Engineering Research Institute of Canada (FERIC), Technical Note TN–296.

Greene, W. D., Cubbage, F. W. and McNeel, J. F. (1988), "Characteristics of Independent Loggers in Georgia," Forest Products Journal, 38(7/8), 51-56.

Hamsley, A. K., Greene, W. D. and Baker, S. A. (2009), "Comparison of Value Harvested by Modified and Conventional Tree-Length Systems in the Southeastern United States," Forest Products Journal, 59(4), 29-34.

Mac Donagh, P., Botta, G., Schlichter, T. and Cubbage, F. (2017), "Harvesting Contractor Production and Costs in Forest Plantations of Argentina, Brazil, and Uruguay," International Journal of Forest Engineering, 28, 157-168.

Miyata, E. S. (1980), "Determining Fixed and Operating Costs of Logging Equipment," USDA Forest Service General Technical Report NC-5, 16 p.

SAS Institute Inc. (2016). "JMP Pro 13.2.0.," Cary, NC.

Siry, J. P., Greene, W. D., Harris, Jr., T. G., Izlar, R. L., Hamsley, A. K., Eason, K., Tye, T., Baldwin, S. S. and Hyldahl, C. (2006), "Wood Supply Chain Efficiency and Fiber Cost: What Can We do Better?" Forest Products Journal, 56(10), 4-10.

TimberMart-South (2018), "3rd quarter 2018," Norris Foundation, Athens, GA.

Tufts, R. A., Lanford, B. L., Greene, W. D. and Burrows J.O. (1985). "Auburn Harvesting Analyzer," The Compiler Forest Resources Systems Institute, Florence, AL, 3(2), 14-15.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

MOTOR MANUAL AND MECHANIZED WTS BIOMASS HARVESTING IN SPANISH QUERCUS COPPICES. PRODUCTIVITY, COST AND ENVIRONMENTAL ANALYSIS.

Tolosana E*[1], Laina R[1], Spinelli R[2], Aminti G[2], López-Vicens I[1].
[1] E.T.S.I. Montes, Forestal y del Medio Natural. Technical University of Madrid (U.P.M.), Spain
[2] C.N.R. – IVALSA. Via Madonna del Piano 10. 50019 Sesto Fiorentino. Firenze (Italy)
eduardo.tolosana@upm.es

Abstract: *Two alternatives for whole tree system biomass harvesting from strong thinnings on dense coppices of the two most important Quercus Species in Spain have been tried. Chainsaw felling and manual piling is compared with a previous study on a heavy drive-to-tree feller-buncher. Productivity predictive equations for felling and bunching are fitted for both Species, being the main explanative variables, for the motor-manual option, the Species and the unit dry weight per tree. The unit cost derived equations show that the felling-bunching costs are lower for the motor-manual option in both Species stands, particularly for the smaller DBHs. Nevertheless, when the strongly reduced loading times in forwarding associated to the mechanization is had into account, the unit cost for the felling, forwarding and loading operations is lower for the mechanized option for Q. ilex only for DBHs greater than 9 cm, while for Q. pyrenaica is lower only for DBHs greater than 14 cm. Also standing trees damages were studied, being low to moderate, but always significantly greater for the mechanized systems, while soil damages were very low for both options. The stumps suffered significantly greater damages in the mechanized felling and bunching, but further research will be needed to determine if these damages are relevant for the future sprouting capability and sprouts vigor. The greater productivity and tree damages' level in Q.ilex when compared to Q. pyrenaica are discussed, being likely due to the narrower and lighter crown of the latter.*

Keywords: Thinnings, Forest operations, Work study, Soil and stand damages, Feller-buncher, Motor-manual

1. Introduction

Coppice harvesting has been abandoned in most European Countries after WWII, because of the social and economic changes which reduced the profitability of coppicing traditional practices (Carvalho *et al*., 2017). The abandonment has led to a relevant underutilization of many natural resources, besides a loss in the biodiversity associated to those traditional practices (Müllerová *et al*., 2015). Coppice forest aging and densification has increased the vulnerability to natural disasters such as windthrown and wildfires. Coppice thinning would reduce wildfire suppression costs, especially if whole-tree harvesting (WTH) is adopted, because complete biomass removal reduces potential fire severity compared with other harvesting methods that leave large amounts of slash within the stand (Corona *et al*., 2015).

In Spain, coppice forests cover roughly 4 M ha and represent 20% of the total forest area, Holm oak (*Quercus ilex*) and Melojo oak (*Q. pyrenaica*) are the dominant forest species in Spanish coppice forests (Piqué & Vericat in Nicolescu et al., 2017).

Harvesting of coppice forests is technically and economically difficult, due to the difficulty encountered by a harvester head when approaching stems that are gathered in a clump on the same stump (Schweier *et al*., 2015).

In 2017, the Spanish forest company SOMACYL began the field trial of a drive-to-tree disc saw feller-buncher for use in coppice harvesting, which provided an ideal opportunity for conducting time and motion studies for evaluating operational productivity, cost, product recovery and site damage. The results were presented in Tolosana *et al*. (2018).

Further on, the same enterprise thinned in the same way the very same coppices, also using the WTH system, but the felling and bunching operations were performed motormanually. This allowed comparing the tried mechanized system with the more traditional motor-manual treatment.

Thus, the main goals of the present phase of the study have been:

- Developing productivity predictive equations for motormanual felling and bunching and both species coppices, using them to model the operational unit cost of the treatment and to compare with the mechanized one.
- Assessing the environmental impacts of the motor-manual option on the soil, the remaining trees and the stumps, comparing it to the previously analyzed mechanized system.
- Estimating the biomass collection efficiency (percentage of available biomass actually collected).

2. Material and methods

The tried mechanized feller-buncher was a John Deere 643J (130 kW, 12.7 t), equipped with a JD FD45 head, working in a drive-to-tree way, as the head was attached to the base machine, not in a boom tip. The motor manual team was composed by three workers using medium-sized chainsaws, two out of them performed felling and bunching tasks while the other one only bunched the felled whole trees. The machine forwarding the trees in both cases was a John Deere 1910E (186 kW, 19 t loading capacity), attached to a compressor trailer Dutch Dragon PC-48.

Both the feller buncher and the motormanual team worked in paired 25x25 m^2 plots considered as replications in order to ease the comparison, in each of the two studied coppice forests, dominated respectively by *Quercus ilex* L. and *Quercus pyrenaica* Willd. Both forests were inventoried before and after harvesting using conventional forest mensuration techniques and tools.

2.1. Pre-harvest and post-harvest inventories

For the pre-harvest inventory, 17 pairs of 25x25 m^2 square plots were ramdomly allocated, 9 of the pairs in the *Q. illex* coppice and the remaining 8 pairs in the *Q. pyrenaica* forest. DBHs of every tree were measured. Measured trees and plots borders were marked.

In the post-harvest inventory, DBHs of every remaining tree inside each plot were measured. To estimate the dry weight of the felled trees, a weight table was fitted in the previous study using around 30 trees per specie and sampling them for assessing moisture content, accordingly to the ISO 18134-3:2015 standard.

2.2. Time study and produced biomass evaluation.

For the motor-manual time study, a time-sampling method was adopted, as long as three workers were time-studied simultaneously. To assess the biomass extracted from each plot, the forwarder piled the whole trees coming from each one of them in a different bunch at the roadside. These piles were chipped, transported and weighed separately, sampling them for determining moisture content.

To fit the productivity equation, a multiple linear regression analysis was performed, using the data from 14 out of the 17 studied plots (one was felled before the work study, other two were rejected because of the out-of-range studentized residuals). The independent tried variables were Specie, dry weight per tree (initial stand), dry weight per extracted tree, removals – dry weight per ha -, initial number of trees per ha, extracted number of trees per ha, extracted basal area and percentage of extracted basal area.During the forwarding, one whole shift was studied for each work system, measuring the number of trips and piles in order to get an estimate of average extraction productivity.

In order to assess the unit costs, machine hiring costs and workers actual hourly costs were provided by the enterprise (SOMACYL, 2018).

2.3. Damages assessment.

To assess the damages on the soil, stumps and remaining trees, a damages inventory was performed after forwarding. The damages on the remaining trees were characterized inside each of the 25x25 m^2 plots, following the methodology proposed by Tavankar *et al.* (2013). Soil damages were measured using the Mc Mahon (1995) methodology, applied in sub-plots with 4 m radius whose centers was located in the crossing points of the square plots diagonals. The stumps inside those subplots were also counted, measuring their heights and assessing their damage levels.

2.4. Measurement of biomass collection efficiency.

Inside the above-mentioned sub-plots, the biomass left on the terrain was collected and weighed, taking two samples for moisture content estimation.

3. Results

3.1. Coppice inventory and treatment description

The *Quercus ilex* coppice had an initial density of 5,310 tress·ha^{-1}, an aaverage DBH of 5.9 cm, average height 4.1 m, and basal area 14.3 $m^2 \cdot ha^{-1}$. The average number of stools per ha was 886, and the average number of sprouts per stool was 6.0. The treatment consisted on the extraction of a 90% of the tres number and a 70% of the basal area, leaving 545 remaining trees per ha.

The *Quercus pyrenaica* coppice had initially 3,868 trees·ha^{-1}, average DBH = 6.7 cm, average height close to 6.0 m, basal area 13.6 $m^2 \cdot ha^{-1}$. The number of stools·ha^{-1} was 1,004, with an average number of sprouts per stool of 2.8. There were also 2,564 isolated oaks·ha^{-1}. The treatment led to the extraction of a 81,5% of these trees and a 45% of the initial basal area, leaving 716 trees·ha^{-1}.

The removal ranged between 18 and 59 odt·ha^{-1} in the *Q. Ilex* coppice (averaging 40 odt·ha^{-1}) and between 6 and 38 odt·ha^{-1} (averaging 21 odt·ha^{-1}) for *Q. pyrenaica*.

3.2. Time study

In the *Q.ilex* coppice, the productivity of motor-manual felling and bunching ranged, for the three workers team, between 2.54 y 3.51 odt·$ProdHour^{-1}$. Delays were practically zero, as no incident ocurred during the study. Average Productivity inside the studied plots was 2.85 odt·$ProdHour^{-1}$.

In the *Q. pyrenaica* forest, the values ranged between 0.89 and 3.16 odt·$ProdHour^{-1}$. Delays or incidents were also not relevant, so average productivity reached 2.18 odt·$ProdHour^{-1}$.

3.3. Productivity equation for motor-manual felling and bunching

The explanative significant variables were specie (as a dummy variable, with *Q. pyrenaica* as null and *Q. ilex* as dummy) and the dry weight per tree – estimated average value for the initial stand, before thinning. The fitted equation and its regression statistics are shown in Table 1. Using the average values of productivity and the average removal per ha, the required time per ha in the studied conditions was 14.0 productive hours (16.5 whE0)·ha^{-1} for *Q. ilex* coppice and 9.6 productive hours (11.3 whE0)·ha^{-1} for *Q. pyrenaica.*

3.4. Unit cost estimation.

Hourly cost for the workers team (21 €·$WorkHour^{-1}$ per worker, 63 for the team, including chainsaws) was provided by SOMACYL (2018), as well as the renting costs of the machines, in hourly basis in the forwarder case (€·$WorkHour^{-1}$) or in fresh tonne basis for chipping and chip transport (€·fresh $tonne^{-1}$). Transportation distance, as for the mechanized case, was supposed to be 80 km, one way).

Unit costs and incomes estimations were based in the chips measured average moisture content of 15.3 and 34.5%, respectively, for *Q.ilex* and *Q.pyrenaica* (humid basis) and the utilization coefficient for workers equal to 85%. The loss of loading time in forwarding – due to the longer loading time because the manual bunching was less efficient than mechanized – has been taken into account. Cost calculation results are shown in Table 2.

Multiple regression - Prod dw·hProd-1

Dependent variable: Prod dw·hProd-1 (ODT·Prodh-1)
Independent variables:
Qilex (1 if Species = Quercus ilex, 0 if Species = Q. pyrenaica)
DW·Tree^{-1} (average ODkg·Tree-1 before thinning)
Observations number: 14

Parameter	*Estimation*	*Standard error*	*T-Statistic*	*P-Value*
Constant	0,945	0,399	2,37	0,0372
Qilex	0,867	0,205	4,23	0,0014
DW·Tree-1	0,082	0,024	3,45	0,0055

R-square = 67.2 %
R-square (adjusted by d.f.) = 61.2 %
Standard est. error = 0.36
Medium Absolute Error = 0.24
Durbin-Watson Statistic = 2.32 (P=0.60)

Fitted regression equation is:

$$\textbf{Prod dw·hProd}^{-1}\textbf{, ODT = 0,945 + 0.867·Qilex (0/1) + 0,082·DW·Tree}^{-1}\textbf{ (ODkg)} \qquad \textbf{(1)}$$

Table 1: Fitted productivity regression curve

Total direct cost in destination was 66 €·ODT^{-1} for *Q. ilex* chips and 82 €·ODT^{-1} for *Q. pyrenaica* chips. If these figures are increased in a 15% to cover fixed, indirect and structural costs, unit cost would grow up to 76 €·ODT^{-1} and 94 €·ODT^{-1}, respectively. The cost for *Q. ilex* is slightly lower than that corresponding to the estimated for the mechanized option in former studies; this is partially due to its chips' observed moisture, quite low. This fact reduced the transport and chipping costs, paid on a fresh tonne basis. For *Q. pyrenaica*, the motor-manual cost is lower than for the mechanized option.

Operation/s	Hourly cost team / machine (€·WorkH^{-1})	Hourly cost team / machine (€·ProdH^{-1})	Average Productivity (ODT·ProdH^{-1})		Unit cost -renting (€·fresh tonne^{-1})	Unit cost (€·ODT^{-1})	
			Quercus ilex	*Q. pyrenaica*		*Q. ilex*	*Q. pyrenaica*
Felling/bunching	63.0	74.1	2.85	2.18	---	26.00	33.99
Extraction w/ Forwarder	71.5	79.4	4.28	4.02	---	18.56	19.77
Chipping	---	---			11.0	12.99	16.79
Chip transport (dist = 80 km)	---	---	---	---	7.46	8.81	11.39
Total (Unit direct cost)	---	---	---	---	---	66.36	81.94
+15% Fixed and structural costs	---	---	---	---	---	**76.31**	**94.23**

Table 2: Operational costs and total unit costs for motor-manual operations

Regarding the influence of the explanative variables on this cost, the productivity equation (1) can be transformed using the team hourly cost combined with the equation (1), as:

$$\textbf{Unit cost (€·ODT}^{-1}\textbf{) = 63.0·[0.945 + 0.082· DW·Tree}^{-1}\textbf{, kg + 0.867·Qilex(1/0)]}^{-1} \qquad \textbf{(2)}$$

The total operational cost – without an stumpage price for biomass nor benefits for the contractor – in the average observed conditions for both coppices can be transformed in a cost per hectare, having into account the average removals (40 ODT·ha^{-1} for the *Q. ilex* coppice and 21 ODT·ha^{-1} for the *Q. pyrenaica* one). The result would be 3,052 €·ha^{-1} for Q.ilex and 1,979 €·ha^{-1} for *Q. pyrenaica*.

Present prices (end of 2018) for a fresh tonne of whole tree chips with moisture contents of 15.3% and 34.5%, as in the studied coppices, are 63 and 46 €, corresponding to equivalent process for ODT of 74 and 70 €, respectively (SOMACYL, 2018). In these conditions, the net operational value would be -92.0 €·ha^{-1} for *Q. ilex* and -509 €·ha^{-1} for *Q. pyrenaica* – without considering stumpage price nor benefits –. The situation would be closer to a self-financing operation in the first case, partly for having produced much drier chips.

3.5. Environmental impacts.

The frequency and relevance of the damages on the remaining trees are reflected in Table 2, separately for both studied Species. The different letters (a and b) for each specie indicate 95% statistically significant differences. The results show higher damages frequency for *Q.ilex*, particularly those affecting the wood and those produced by chainsaw. It is possibly due to the higher stand density and smaller size of *Q. ilex* trees, which have also less bark width than *Q. pyrenaica*.

Nevertheless, injures are mostly small or medium-sized (surface smaller than 200 cm^2), particularly in *Q. ilex*. The only cause of injures in the *Q. pyrenaica* coppice is the forwarder movements, while in the Q.ilex coppice a 25% of the damages are felling injures caused by the chainsaws – possibly this is the reason why more damages affect wood.

DAMAGES IN REMAINING TREES (% DAMAGED TREES OVER TOTAL NUMBER)														
Type	**Qi**	**Qp**	**Location**	**Qi**	**Qp**	**Height**	**Qi**	**Qp**	**Size**	**Qi**	**Qp**	**Cause**	**Qi**	**Qp**
Bark	4.0 a	6.2 a	Stem	10.6 a	9.5 a	Low (0-0.3 m)	2.0 A	0.0 a	**Small (<50 cm^2)**	**12.1 a**	**5.9 b**	**Machine movement**	**75.0 a**	**100.0 b**
Wood	**5.2 a**	**0.3 b**												
Broken branches	4.8 a	4.5 a	Crown	3.6 a	1.5 a	Medium (0.3-1.0 m)	4.4 A	3.3 a	Medium-sized (50-200 cm^2)	1.6 a	2.1 a	**Cutting injure**	**25.0 a**	**0.0 B**
Destroyed crown	0.0 a	0.0 a												
Total	14.1 a	11.0 a	Roots	0.0 a	0.0 a	High (> 1.0 m)	7.3 a	7.7 a	**Large (>200 cm^2)**	**0.4 a**	**3.0 b**	Others	0.0 a	0.0 a
Severe	5.2 a	3.9 a												

Table 3: Damages on remaining trees from motor-manual coppice harvesting by species.

	SOIL DAMAGES, PERCENTAGE OF TOTAL SURFACE			
SPECIE	**No damage evidence**	**Litter still in place, slight alteration**	**Litter removed, topsoil exposed**	**Litter and topsoil mixed, ruts deeper than 5 cm**
Quercus ilex	0.0	15.7	0.0	0.0
Quercus pyrenaica	0.0	6.4	0.0	0.0

	STUMP HEIGHT, % OF STUMPS NUMBER			**STUMP STATUS, % OF STUMPS NUMBER**				
SPECIE	<10 cm	10-20 cm	>20 cm	No damage	<50% bark separated	>50% bark separated	Cracked stump	Destroyed stump
Quercus ilex	45.6	50.6	3.8	58.7	26.0	6.8	3.4	5.1
Quercus pyrenaica	28.9	59.8	11.3	71.1	17.5	3.1	5.2	3.1

Table 4: Soil and stumps damages after motor manual harvesting by species.

The percentage of severe damages in similar for both species, close to 5%, but while for *Q. ilex* they are due to small chainsaw cuts affecting the wood, in the *Q. pyrenaica* case there are a significantly greater proportion of large damages (surface bigger than 200 cm^2).

The observed damages on soil and stumps are summarized in Table 4. Soil damage was not severe – the damages were characterized as slight alterations, with present litter layer, in most cases they consisted on swallow rutting lees deep than 5 cm. In the *Q. pyrenaica* coppice the affected Surface was 6.4%,while in the *Q. ilex* coppice it reached a 16% as an average, probably due to the forwarder transit.

Most stumps were not damaged or with slight bark damages. In none of the species, the percentage of cracked or destroyed stumps reached 10%.

3.6. Efficency in biomass collection.

The actual harvested biomass (dry chips weight) ranged between the 82.9 and 99.8% of the theoretical weight estimated through the weigh tables applied on the inventory results, respectively for *Q. ilex* and *Q. pyrenaica.* The remaining biomass left on the terrain, including the removed shrub, reached as an average 3.7 $ODT \cdot ha^{-1}$ for *Q. ilex* and 2.1 $ODT \cdot ha^{-1}$ for *Q. pyrenaica*.

3.7. Comparison with the mechanized option.

3.7.1. Felling-bunching costs

As the differences in moisture among the different studied operation affect the global costs, in this chapter only the unit cost depending on felling and bunching means are going to be analyzed.

These operations are felling and bunching and extraction by forwarder, the last case affected in its cost by the more efficient bunching in the mechanized case. Regarding felling and bunching, unit cost equations as a function of Species and unit dry weight for the motor-manual option have been fitted in the present study (2). For the mechanized option, similar equations were developed as a function of Species, unit dry weight and percentage of extracted basal area (Tolosana *et al*., 2018). Focusing on the common factor, tree size, the mechanized unit cost equation will be applied using the observed values for the average extracted basal areas, 70% in the *Q. ilex* case and 45% for *Q. pyrenaica*.

Trying to use an explanative factor simpler and easier to measure than unit dry weight per tree, the weight tables developed as a function of DBHs for Tolosana *et al*. (2018, *Op. Cit.*) will be used to substitute the initial explanative variable.

Besides, the increment of unit costs for forwarding in the motor-manual operation reached 7.2 $€ \cdot ODT^{-1}$ for *Q. ilex* and 8.4 $€ \cdot ODT^{-1}$ for *Q. pyrenaica*. These costs will be added to the direct costs of felling and bunching in the motor-manual case to compare both options having into account these overcosts.

The result of the cost comparison for each species is shown in Figures 1 and 2.

In the *Q. ilex* case (Fig. 1), felling and bunching – having into account their influence in forwarding cost – is less costly for the mechanized option for DBHs greater than 9 cm, particularly for the larger DBHs (although the difference is small). In fact, in the studied case and for the average value of DBH, the unit cost for the feller-buncher is 31.5 $€ \cdot ODT^{-1}$, while for the motor-manual option is less (26.0 $€ \cdot ODT^{-1}$), but if the additional forwarding cost (7.2 $€ \cdot ODT^{-1}$), is added, the result is a unit cost slightly greater, 33.2 $€ \cdot ODT^{-1}$.

In the *Q. pyrenaica* coppice (Fig. 2), the mechanized option is more expensive, particularly for small DBHs such as the observed ones. The DBH equaling motor-manual and mechanized costs is around 14 cm, for greater values the mechanized option would be slightly preferable, having into account the extra forwarding cost of 8.4 $€ \cdot ODT^{-1}$. These values of DBH are unusual in this kind of dense coppices.

For the average conditions in the *Q. pyrenaica* studied coppice, the mechanized option would have an average felling and bunching unit cost of 69.0 €·ODT^{-1}, clearly more expensive than the motor-manual option (direct cost 34.0 €·ODT^{-1}, added to the 8.4 €·ODT^{-1} forwarding extra cost, would be 42.4 €·ODT^{-1}).

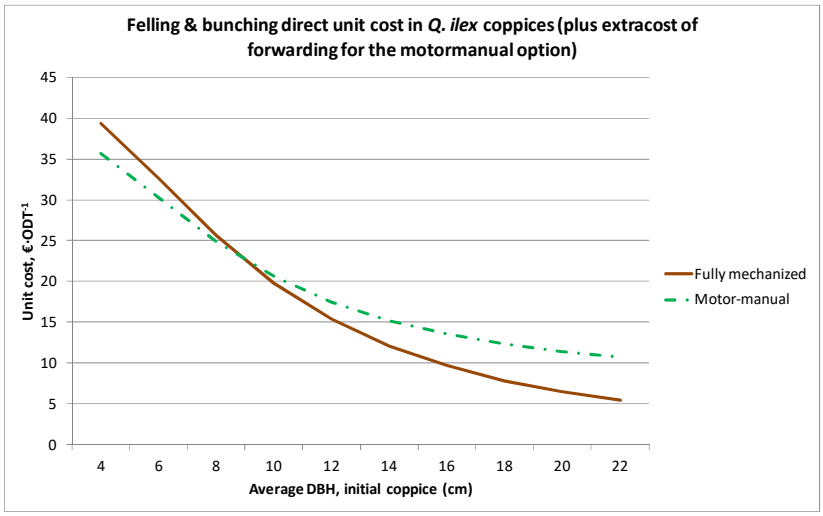


Figure 1: Unit costs of felling and bunching for *Q.ilex* coppice thinning

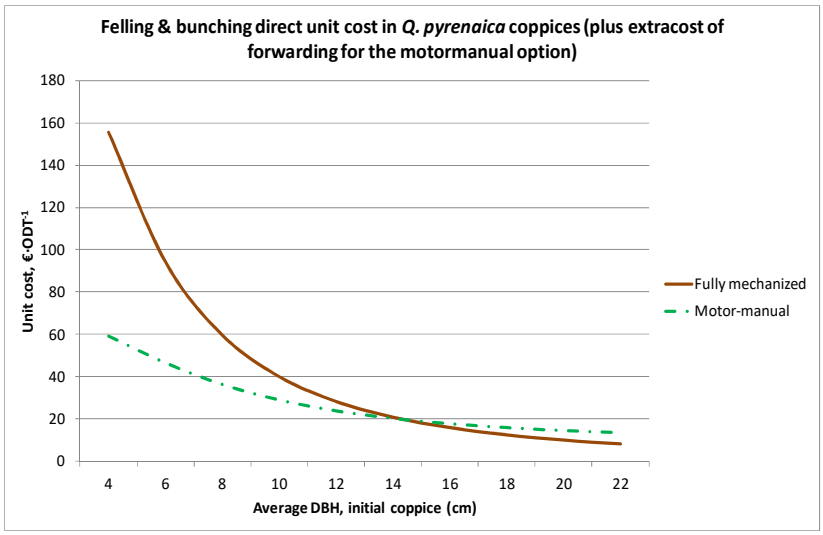


Figure 2: Unit cost of felling & bunching for *Q. pyrenaica* coppice thinning.

3.7.2. Treatment quality and environmental effects.

Treatment conditions regarding thinning intensity and selectivity has been quite similar in the plots mechanized with feller-buncher if compared to the felled and bunched motor-manually.

The percentage of damaged remaining trees for *Q. ilex* increases from 14 to 54% comparing the motor-manual system with the mechanized one. Focusing in the percentage of severe damages – affecting the wood or having a size bigger than 200 cm^2 -, also grows in average – from 5.2% to 10.0% - although the difference is not statistically significant.

For *Q. pyrenaica*, the damages percentage also grows significantly, from 11.0 to 22.4%. The high percentage of damaged trees during the mechanized harvesting of the *Q. ilex* coppice if compared to the *Q.pyrenaica* forest is due to the bulkier crowns and thicker branches of the first species and, as secondary reasons, to its

higher stand density and thinner bark. Regarding the severe damages percentage, in *Q.pyrenaica* it increases with mechanization from 3.9 to 10.3%, being the difference statistically significant.

Soil damages have been not relevant in both treatments, mechanized and motor-manual, probably because of the plain terrain and the sandy soils, dry during the harvesting operations.

The stumps have been strongly damaged in the case of mechanized harvesting, and in much less degree in the motor-manual case. Anyway, the future relevance of such damages is not clearly stated by literature.

4. Discussion and conclusions

The tree size (DBH, unit volume or weight), as in the present case, is a common explanative variable in most of the productivity studies about felling and bunching (Spinelli *et al*., 2007; Schweier *et al*., 2015; Erber *et al*., 2016; Chakroun *et al*., 2016: Spinelli *et al*., 2016). On the contrary, the extracted volume, weight or basal area has not been significant as independent variables, in spite that they usually work in this kind of studies (Spinelli *et al*., 2016). Probably the range of variation in the studied coppices has not been wide enough.

The influence of the species, making more productive the operations on the *Q. ilex* coppices, comes from the fact that, for equal DBHs, the crown of this specie is bulkier and its branches are thicker than those of *Q. pyrenaica*. Because of that, the *Q.ilex* trees are heavier for the same DBH than the *Q. pyrenaica* ones.

As exposed above, the coppice harvesting operations were not self-financing, but they are close to the balance in the case of *Q. ilex*. Using the studied technologies, reaching profitability would require applying them to coppices with bigger trees – not available in most cases, except very aged coppices. In addition, reducing costs – managing the machinery instead of renting it – and procuring a better drying of the produced whole trees and thus chips, may improve the economic balance.

The balance point of unit cost between the motor-manual and the fully mechanized harvesting for *Q. pyrenaica*, around a 14 cm DBH, is consistent with former studies comparing motor-manual felling and processing to conventional forest harvesters (Tolosana *et al*., 2017)

The damages in the remaining trees are much less frequent than in the fully mechanized treatment, and so are the severe damages, on the contrary as the thinning experiences studied by Magagnotti *et al*. (2012) and Spinelli *et al*., (2014). The most probably reason of this high damage level is the “drive-to-tree” work pattern of the studied feller-buncher (Tolosana *et al*., 2002). It could be strongly reduced using a lighter “swing to tree” feller-buncher (Tolosana *et al*., 2018).

The same occurs with the damages on the stumps, which has been found to be high in other studies about coppice mechanized harvesting (Schweier *et al*., 2015), although the future relevance for the vigor and growth of the regeneration has not been found to be clear (Aminti *et al*., 2017).

The main conclusions of the present work are the following:

- Strong thinnings in Quercus coppices, using the WTH system have been time-studied, comparing the motor-manual felling and bunching with a previous study using a heavy “drive to tree” feller buncher.

- Predictive productivity equations for motor-manual felling and bunching were fitted, The main explanative factors were the specie – been more productive *Q. ilex* than *Q. pyrenaica* – and the average weight of the trees from the initial stand.

- The economic balance of the studied operations have not reached the profitability, although has been close to it in the case of *Q. ilex* coppices, particularly using the fully mechanized system. Main measures to increase the operational profitability could be the self-managing of the machinery (instead of renting it), the optimized management of biomass moisture and the minimization of transport distances.

- Mechanized felling and bunching has a higher cost than the motor-manual equivalent operations. Nonetheless, the mechanized bunching allows reducing significantly the whole trees forwarding cost, compensating the felling-bunching difference in the *Q. ilex* case for DBHs greater than 9 cm, in this cases the combined harvesting operations are slightly less costly for the mechanized option - more when DBH is greater. For *Q. pyrenaica*, the operational cost is only less for the mechanized option for DBHs greater than 14 cm, having the mechanized operations very high costs for the smaller diameters of the studied range.

- Although the silvicultural results of the treatments have been similar and adequate to the management prescriptions regardless of the mechanization level, the remaining stand and stumps damages has been significantly more frequent for the mechanized option. This has been particularly true in the *Q. ilex* trees, which have bulkier crowns with thicker branches. Nevertheless, the severe damages – affecting wood or bigger than 200 cm^2 – have been limited to less than 10% of the remaining trees in all the studied cases and will not be much relevant considering the destination of the harvesting – chips for energy or firewood.

- The stump damages were more severe in the mechanized harvesting case, and even if the negative effect of stump damage on stump sprouting and shoot growth is not ascertained, it would be safer to follow-up the regeneration on the study sites.

In any case, the convenience of forest operations mechanization is undeniable, both because of the bigger and continuous production capacity of the machines and of the reduction of work safety risks. Nevertheless, more applied research is needed in order to adapt the adequate machinery and to define the optimized work system for coppice harvesting, despite their difficult conditions if compared to other stand types.

5. Adknowledgments.

The authors are indebted to the SOMACYL Natural Resources Director Rubén García Pérez and the forest engineers Alberto Fernández López y Carlos Martínez Torres, from the same public forest enterprise. Financial support for the study has been obtained from La Caixa, through the Fundación Patrimonio Natural de Castilla y León, and also from the European COST Action FP1301 (www.eurocoppice.uni-freiburg.de) in the scope of its program of Short Term Scientific Missions (STSM).

6. References

Aminti, G (2017). Coppice forests harvesting mechanization:multidisciplinary approaches applied on case studies. PhD Thesis. Universiyu of Florence. 94 pages.

Carvalho J, N Magagnotti1, V N Nicolescu, P Ruch, R Spinelli, E Tolosana (2017). Active management of traditional coppice forests: An interface between silviculture and operations. Eurocoppice COST Action report. Ed: Univ. Friburg. 4 pag.

Chakroun M., A Bouvet, P Ruch, X Montagny (2016). Performance of two shear heads for harvesting biomass in hardwood stands in France. Biomass and Bioenergy 91: 227-233.

Corona P, D Ascoli, A Barbati, G Bovio, G Colangelo, M Elia,V Garfì, F Iovino, R Lafortezza, V Leone, R Lovreglio, M Marchetti, E Marchi, G Menguzzato, S Nocentini, R Picchio, L Portoghesi, N Puletti, G Sanesi, F Chianucci (2015). Integrated forest management to prevent wildfires under Mediterranean environments. Annals of Silvicultural Research 39 (1): 1-22

Erber G, F Holzleitner, M Kastner, K Stampfer (2017). Effect of multi-tree handling and tree-size on harvester performance in small-diameter hardwood thinning. Silva Fennica vol. 50 (1) article id 1428. 17 pag.

Magagnotti N, R Spinelli, O Güldner, J. Erler (2012): Site impact after motor-manual and mechanised thinning in Mediterranean pine plantations. Biosystems Engineering 113(2):140–147

Mc Mahon, S (1995). Accuracy of two ground survey methods for assessing site disturbance. International Journal of Forest Engineering 6 (2): 27-33.

Müllerová J, R Hédl, P Szabó (2015). Coppice abandonment and its implications for species diversity in forest vegetation. Forest Ecology and Management 343 (1): 88-100

Piqué M, P Vericat (2017). Spain. In Nicolescu V N, D Bartlett, P Buckley, D Rossney, P Pyttel, A Unrau, Eds. (2017). National Perspectives on Coppice from 35 EuroCoppice Member Countries. Eurocoppice COST Action report. Ed: Univ. Freiburg, pag. 70-71.

Schweier J, R Spinelli, N Magagnotti, G Becker (2015). Mechanized coppice harvesting with new smallscale feller-bunchers: Results from harvesting trials with newly manufactured felling heads in Italy. Biomass and Bioenergy 72, 85-94.

Short I, J Campion (2014). Coppice-with-standards: An old silvicultural system with new potential? Forestry & Energy Review 4(1): 42-44.

SOMACYL (2018). Personal communication of the operational responsible of biomass supply from the Company.

Spinelli R, E Cuchet, P Roux (2007). A new feller-buncher for harvesting energy wood: Results from a European test programme. Biomass and Bioenergy 31(4): 205-210

Spinelli R, C Nati (2009). A low-investment fully mechanized operation for pure selection thinning of pine plantations. Croat J For Eng 30 (2): 89-97.

Spinelli R, C Lombardini1, N Magagnotti (2014). The effect of mechanization level and harvesting system on the thinning cost of Mediterranean softwood plantations. Silva Fennica vol. 48 no. 1 article id 1003. 15 p.

Spinelli R, E Cacot, M Mihelic, L Nestorovski, P Mederski, E Tolosana (2016). Techniques and productivity of coppice harvesting operations in Europe: a meta-analysis of available data. Annals of Forest Science 73:1125–1139.

Tavankar F, B Majnounian, A E Bonya (2013). Felling and skidding damage to residual trees following selection cutting in Caspian forests of Iran. Journal of Forest Science, 59 (5): 196–203.

Tolosana E, Y Ambrosio, S Vignote (2002). Productivity, cost and environmental effects of fully mechanised thinnings on *Pinus sylvestris* L. planted stands in Spain. Forest Systems 11(1):39-65.

Tolosana E, R Laina, R Martínez-Ferrari, M Martín, Y Ambrosio (2017). Economic evaluation of mechanized and motormanual options for selective felling of Quercus pyrenaica coppices in Leon (NW Spain). EuroCoppice Final Conference: "Coppice Forests in Europe: a traditional natural resource with great potential." Limoges, France, 19-21 June 2017.

Tolosana E, R Spinelli, G Aminti, R Laina, I López-Vicens (2018): Productivity, Efficiency and Environmental Effects of Whole-Tree Harvesting in Spanish Coppice Stands Using a Drive-to-Tree Disc Saw Feller-Buncher. Croatian Journal of Forest Engineering. Volume: 39, issue: 2.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

APPLYING THE SYSTEM INTEGRATOR CONCEPT TO THE FOREST SUPPLY CHAIN

François Morin[1], Luc LeBel*[1], Luis Antonio de Santa-Eulalia[2], Denise Dubeau[3]

[1]Département des sciences du bois et de la forêt, Université Laval
2405 rue de la Terrasse, Québec (Québec), G1V 0A6, Canada
Luc.Lebel@sbf.ulaval.ca ; francois.morin.6@ulaval.ca

[2]Département système d'information et méthodes quantitatives de gestion, Université de Sherbrooke
2500 boulevard de l'Université, Sherbrooke (Québec), J1K 2R1, Canada
L.Santa-Eulalia@USherbrooke.ca

[3]Direction de la recherche forestière, ministère des Forêts, de la Faune et des Parcs
2700 Einstein, Québec (Québec), G1P 3W8, Canada
Denise.Dubeau@mffp.gouv.qc.ca

Abstract: *Forest stands heterogeneity and the distributed environment of Quebec forest supply chain make it more difficult to implement effective collaborative planning. To address this issue, which exists in other forest regions around the world, we explored the potential benefits of systems integration for the forest sector. The literature pertaining to this organizational and management concept of supply chains shows significant benefits for other manufacturing sectors, e.g. automobile and aerospace industry. However, there is little evidence in the literature of the contributions of systems integration to the particular context of forest supply chains. To achieve this, we conducted a multiple case study using a qualitative research method. Five case studies were selected based among other things on the level of systems integration and collaboration. From our results, we first observed that a systems integrator third party helps to make the wood supply planning process more efficient when there is a good fit between the level of complexity in the coordination context and the observed level of systems integration. We then found that a systems integrator third party helps to ensure and maintain a collaborative culture and build trust in the collaborative planning exercise being studied. Finally, a systems integrator third party allows forest supply chains under study to improve the management of information sharing by enhancing interoperability between ministry and industry organizations.*

Keywords: Collaborative planning, forest planning, systems integration, supply chain collaboration, forest supply chain, case study, wood supply.

1 Introduction and problematic

The supply context for wood processing plants in Northeastern Canada is characterized by extensive management of "large natural forests". These forests are heterogeneous, that is to say that they are composed of different species, having different sizes and which are distributed unevenly over the territory. This feature results in the presence of several marketable products in the same harvesting areas. For the various wood processing plants operating in a given territory, the desired raw material can thus be found in the same harvesting areas. And since these different plants that share the same supply area do not usually have the same needs at the same time, they must coordinate their operations.

A dual challenge of collaborative planning characterizes this context. On the one hand, the different plants have to work together to produce a common forest management plan. Disagreements may occur during this

exercise. For example, since the timber license, or supply guarantees in today's jargon, granted by the Ministry of Forests, Wildlife and Parks (MFFP) do not specify the level of quality of the wood material allocated, the factories will inevitably be looking for the better woody material. The direct impact of a low-quality woody material on supply costs and on the performance of processing explains in part these behaviors (Beaudoin et al., 2010). The distribution of the sectors of intervention among the group of beneficiaries of guarantees of supply (BGS) is difficult in such a setting since it requires compromises from each one of them in order to meet the global constraints of the group.

The second aspect of this dual planning challenge is inter-organizational collaborative work. The MFFP is responsible for strategic and tactical forest planning (long term and medium term). The BGSs collaborate on the tactical portion and are responsible for operational (annual) forest planning (supply). A great deal of information needs to flow between ministerial and industry organizations to produce planning that meets both the economic constraints of markets and good operation management practices as well as environmental and social constraints. The physical distance between these planners and the organizational boundary make it more difficult to share information.

To meet these challenges, Azouzi et al. (2012) and LeBel et al. (2019) proposed the concept of Supplier-Integrator (SI). Based in part on the systems integration literature (Pavitt 2003, Hobday et al., 2005, Davies et al., 2007, Davies and Mackenzie 2014), the SI acts as an intermediary between the government and the wood processing plants. These authors define SI as an entity involved in forest planning by MFFP planners and industry planners. In particular, it works to integrate supply needs for a group of wood processing plants and collaborates with the MFFP in forest planning through the various planning levels. These tasks constitute the integration component of its service offering. According to the work of Azouzi et al. (2012), SI is also involved in harvest and transportation management. It maintains relationships with a network of harvesting and transportation companies to harvest the designated areas of intervention and transport timber to the mills. It is able to provide wood to his customers. The Supplier-Integrator has expertise in forest planning, but also in operations, logistics, and optimization. Its position at the "center" of the forest sector supply chain allows it to propose scenarios of optimized management plans (Figure 1). The Supplier-Integrator is described as a prime contractor in forest management and forestry operations.

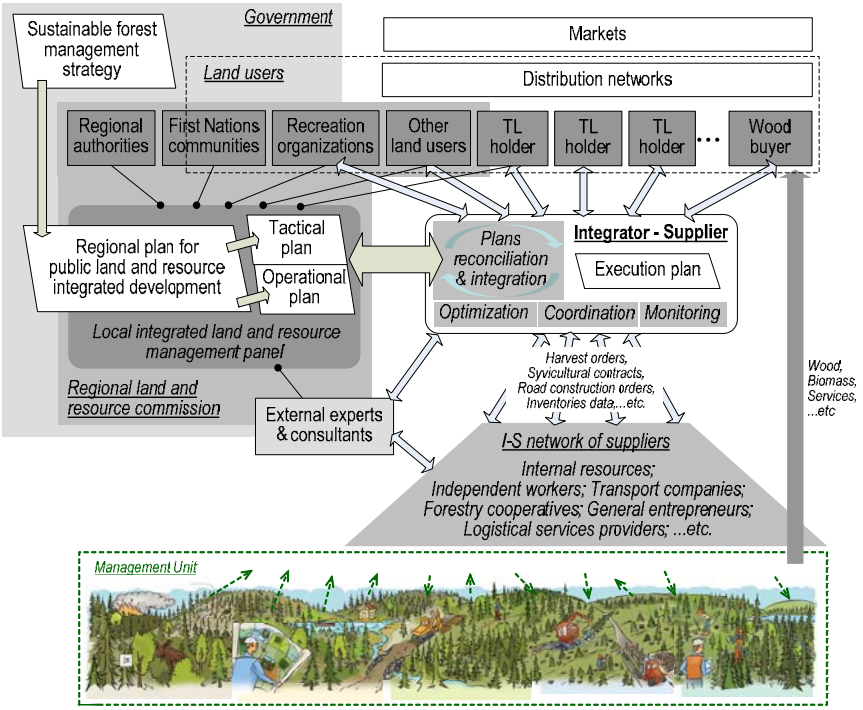


Figure 1. Generic representation of the SI (LeBel et al., 2018). The various relationships managed by the SI are highlighted (TL: timber license).

The SI concept, however, has not been the subject of a formal field study. More specifically, Azouzi et al. (2012) and Lebel et al. (2019) did not observe in situ organizations that could be related to the concept put forward. The benefits of system integration remain unclear for the public-private multi-factor environment of forest supply chains.

In the context of this conference article, we present a summary of François Morin's thesis work (Morin 2019). Morin's main objective was to study existing system integration initiatives that would help to evaluate the benefits of the SI concept. More specifically, the objective of the thesis was to understand how a systems integrator involved as a third party is able to support the performance of wood supply planning. The result section of this article presents a summary of three specific objectives:

1. Outline the role of a system integrator-type third party in the collaborative supply planning exercise and assess its impact on the performance of forest planning.
2. Explain and theorize the interactions between a systems integrator and other organizations of a supply chain in the exercise of operational forest planning with a specific focus on the sociological factors that influence collaboration.
3. Describe and understand the role of a systems integrator in managing the information sharing required for collaborative forest planning.

A brief presentation of the methodology will first be presented. Next, in section 3, results pertaining to each of the three objectives are summarized. The conclusion highlights the opportunities and challenge offered by the SI model in forestry.

2 Methods

To achieve our research objectives, we used a qualitative research method. Specifically, we designed a multiple case study experiment. Yin (2014) explains that case studies provide a detailed and in-depth understanding of the phenomenon under study in its real context. Using this research strategy, we were able to have direct access to forest planners who work in different organizations and participate in the collaborative forest planning exercise. It should also be noted that we followed a deductive approach. Contrary to an inductive approach, regularly used in qualitative research, elements of the literature have been used systematically to prepare data collection as well as for conducting data analysis.

To begin, we defined the boundaries of the case study (also called the unit of analysis). These are the organizations involved in forest planning: the MFFP, the BGSs, and a system integrator where appropriate. Subsequently, concerning the selection of case studies (sampling), we carried out a comparative and theoretical sampling (Patton, 2015). We therefore established sampling criteria from our review of the literature in order to compare the case studies. These criteria were formulated based on the literature associated with system integration and the Supplier-Integrator concept as well as the literature on collaboration in supply chains. In addition, it must be added that our unit of analysis implies an intrinsic territorial component. Indeed, the exercise of forest planning is linked to its specific territorial context. We therefore added a "territorial" criterion to our comparative and theoretical criteria: the regional variability of Quebec's forests.

The result of the sampling process led to the selection of four forest regions in Quebec and one in Ontario. We took the opportunity to observe a third party involved in forest planning in the province of Ontario. The observations made there were a good complement to those made in Quebec since the system integrator observed in Ontario is fully involved in forest planning, compared to what we saw in Quebec. Of the five case studies, three have a system integrator who participates in forest planning. Forest planners in the other two case studies carry out planning using the coordination mechanisms provided by the forest regime. Table 1 presents a summary of the different cases. The five selected case studies are associated with a Roman numbering from I to V for the sake of confidentiality. With these five case studies, we considered that we had the necessary information to reach the set objective. Indeed, we judge to have reached theoretical saturation (Glaser and Strauss, 1967). This saturation state means that adding more information no longer helps to refine the analyzes.

Table 1. Summary of the five case studies resulting from the sampling process.

Characteristics	Case I	Case II	Case III	Case IV	Case V
A System integrator is present	Yes	Yes	Yes	No	No
Location	Far North	South	North	Far North	North
Number of BGS	4	10	11	4	11

As regards data collection, let us first specify that in order to ensure the validity of our theoretical constructs (Yin, 2014, Gibbert et al., 2008), we have sought to obtain different sources of qualitative data. It is thus possible to triangulate the perspectives so as to adequately reflect the reality studied. In other words, we observed the same phenomenon with different types of qualitative data in order to make comparisons and overlaps across different perspectives. The interview is our main method of data collection. We conducted individual and group interviews. Regarding the individual interviews, we did 27 interviews and they lasted an average of 1 hour and 45 minutes. These interviews were recorded and transcribed. Group meetings were conducted after the completion of the individual interview analyzes. These meetings were designed to more directly assess the performance of operational forest planning, validate our understanding of the information collected during individual interviews, and gather some information deemed missing. To complete, we also conducted documentary analysis and non-participant observation when possible.

We also applied "explanation building" (Yin, 2014). This analysis technique is described as comparative and iterative. It is, on the one hand, comparative because it aims at comparing the different perspectives of the actors within the case studies as well as those of the case studies between them. It also aims to compare the explanations produced by the researchers with the theory. On the other hand, it is iterative because the process of analysis is done by iteration; the explanations given must be compared between the different sources of qualitative data, between the different levels of aggregation of the data as well as with the theory. This iterative process continues until the researchers obtain a satisfactory explanation of the phenomenon under study.

Concerning data aggregation and comparisons with theoretical models, we developed grids that guided our analyzes. These analysis grids consist of explanatory factors derived from the theoretical frameworks. These frameworks were identified during our review of the literature. During our analyzes, we aggregated (or coded) portions of the data that matched each theoretical factor. We then performed comparisons of different data sources and perspectives (inter- and intra-case) for each theoretical factor to produce explanations related to our three research objectives. The first grid we have developed is derived from the concept of Supplier-Integrator. It allowed us to describe the different systems integration initiatives. The second analysis grid developed was designed to assess the performance of forest planning. We used the matrix proposed by De Snoo et al. (2011). The value of this matrix lies notably in the consideration of the influence of the level of uncertainty in the planning context. Considering the high level of uncertainty associated with the forestry sector, this attention is appropriate. The third analysis grid is adapted from the conceptual framework of Cao and Zhang (2013) (Figure 2). This conceptual framework relates factors that describe and characterize collaboration in supply chains. The relationships between these factors also explain how it is possible to achieve the benefits of collaboration suggested in the literature. The conceptual framework of Cao and Zhang (2013) combines the organizational and informational perspective. The grid developed from this framework allowed us to answer the research questions associated with objectives 2 and 3.

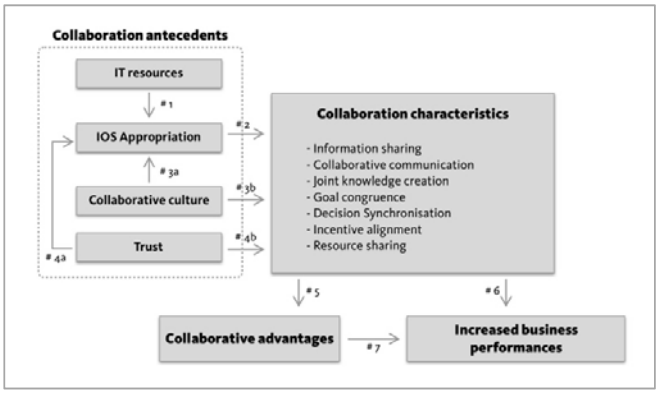


Figure 2. Conceptual Framework of Cao and Zhang (2013) that articulates the role of interorganizational systems (IOS), trust and collaborative culture in a collaborative context of supply chains.

3 Results

3.1 Objective 1 : Role of a system integrator in collaborative supply planning and its impact on performance

We used the classification for coordination mechanisms proposed by Frayret et al. (2004) to schematize the organization of operational forest planning (Figure 3). This classification has allowed us to describe the roles and functions of the three types of third parties observed in our case studies. As a result, we observed what tasks a systems integrator can perform for the forest industry group that employs it. The systems integrator studied would mostly carry out forest planning in public forests for a group of forest industries. The manufacturers were then able to focus on their core business, wood processing. The following paragraphs present this finding for the systems integrator third-party case studies (I, II and III).

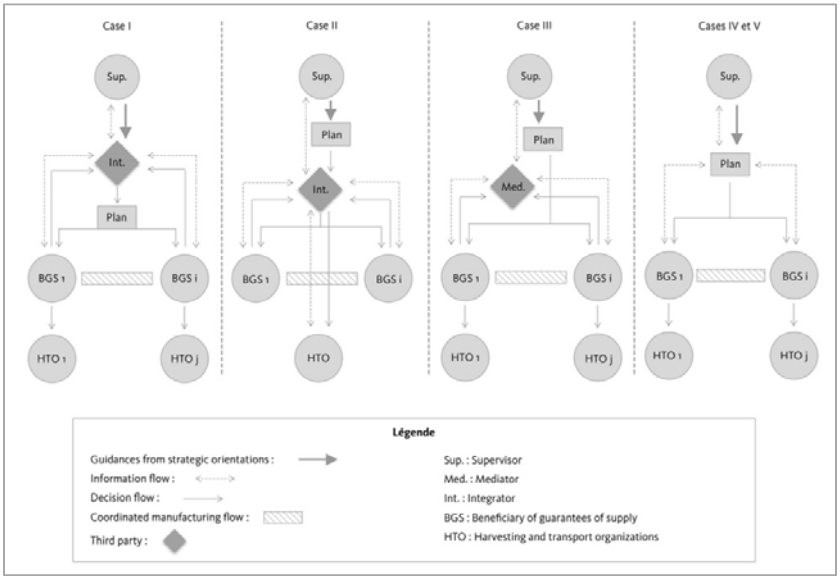


Figure 3. Schematization of our case studies according to the conceptual framework of Frayret et al. (2004). The first three schemas show the completion of the collaborative planning exercise with the support of a third party (Case I, II and III). The last schema has no third party (cases IV and V).

Regarding the forest planning tasks carried out by third parties, let us first recall that there are some differences between the Ontario model and the Quebec model because of the different legislation. Forest planning responsibilities assigned to the third party are therefore also different. For the Ontario model (Case I), the systems integrator performs all the tasks associated with forest planning in public forests. We found Case I to be close to the concept of "metasystem integrator" (Davies and Mackenzie, 2014). Indeed, we have seen that it reconciles divergent interests, different motivations as well as priorities specific to organizations that constitute several distinct subsystems. First, there is the "economic" subsystem. The shareholders of the joint venture wish to receive a forest management plan that enables them to carry out the activities associated with the supply of factories in a successful way. In particular, they expect a forest management plan that ensures, as far as possible, low supply costs. The SI of Case I must also consider the environmental and social aspects of forest management. The third party must therefore, on the one hand, identify the silvicultural treatment methods (volume harvested, type of cut, follow-up after cutting, etc.) that will meet the environmental requirements, and on the other hand, perform all the tasks surrounding the public consultation. In summary, the third party of case I tends towards a “metasystem integrator” since it seeks to understand all the subsystems well enough to find the required compromises needed to take the right decisions that would satisfy the entire system.

For case II to V, the MFFP is responsible for strategic and tactical forest planning. The BGSs are consulted for tactical planning, and have a greater involvement in the annual planning. The integrator in Case Study II carries out all forest planning tasks that BGSs would normally have to do. In addition, it manages harvesting operations. This particularity makes it possible to analyze the synergies between the different levels of planning. The third party is considered an “information node” for all forest operations activities in the region. Clearly, the third party of Case II is similar to the Supplier-Integrator proposed by Azouzi et al. (2012) as well as Lebel et al. (2019). However, it was also explained that the SI is responsible for only 4 to 10% of the BGAs’ total supply. Moreover, for all other case studies, we have observed resistance to entrust a SI for the direct management of harvest and transport operations. Forest planners interviewed who shared this view expressed that they preferred to maintain control over these activities.

For Case III, we qualified the third party as a "mediator" in reference to the Frayret et al. (2004) typology. This third party has the mandate to facilitate the exercise of operational planning in an environment where the level of complexity is high and coordination difficult. Unlike the third parties in cases I and II, the third party in case III is not responsible for planning tasks for the BGA group. Rather, it contributes to supply planning by structuring the needs of the BGA group in order to facilitate exchanges with the MFFP. It also performs mediation for the distribution of harvest areas between the BGAs. Forest planners interviewed explained that the recent arrival of the third party has contributed greatly to improving the performance of the forest planning process in the region.

We used a matrix provided by De Snoo et al. (2011) to evaluate the performance of supply planning. This matrix combines factors that address the performance of the plan, as well as the performance of the planning process in relation to the level of uncertainty in the environment. We thus assessed the performance of the planning processes of our five case studies. The results of these analyzes allow us to argue that a systems integrator contributes to making the forest planning process more efficient when there is a proper match between the level of complexity of the coordination context and the level of system integration. Indeed, we observed that for situations where the level of complexity is high, a higher level of system integration seemed to favor a better performance of the planning process. This conclusion is consistent with the theories of contingency (Lawrence and Lorsch, 1967, Danese, 2011). However, contingency theories can overlook some of the organizational and sociological aspects that influence performance.

3.2 Theorize the interactions between a systems integrator and the organizations of a forest supply chain

It has been explained in Morin (2019) that the literature remains unclear as to how to establish an appropriate "multi-organizational" governance model for distributed and interdependent contexts. Indeed, the tension between the desire for autonomy of the various organizations and the necessary management of interdependencies complicates forest planning. More concretely, the modalities for group decision-making

which favor at the same time an efficient collaborative planning process as well as effective collaboration remained vague. The second research objective aimed to improve this observation. By adopting a sociological perspective, we wanted to identify some of the intangible aspects that are at work during the collaborative operational forest planning exercise when support is provided by a third party. To achieve this, the conceptual framework of Cao and Zhang (2013) was used to frame our approaches. This conceptual framework articulates the role of inter-organizational systems, trust and collaborative culture in a collaborative supply chain context. This framework provided us the foundation to fill the informational, organizational and sociological gaps that we had identified in the literature dedicated to collaborative planning.

First, we found that a systems integrator contributes to ensuring and maintaining a collaborative culture. It also contributes to trust in the collaborative planning exercise. In particular, third party involvement in collaborative supply planning ensures power symmetry by monitoring the implementation of the collaborative principles to which the partners are committed. This monitoring, which reassures the partners, reduces potential opportunistic behaviors that can harm the group's benefit.

We also noticed that the trust placed in the third party has an impact on the "group benefits". It was explained that it is not always possible to meet the procurement objectives of all BGSs on the same annual horizon. A third party then aims on a long-term horizon to achieve as best as possible the objectives of all the BGSs. The trust they place in the third party allows for better collaboration. The collaborative planning exercise is also more efficient under these conditions.

Finally, we identified three elements that characterize a third party able to improve collaborative forest planning. They are impartiality, credibility and transparency. First, we observed in our case studies that BGSs employed third parties that did not have a forest license. Instead, they chose models that encourage impartiality. Based on our analysis, the unbiased third-party perspective helps to produce equitable forest planning for the BGS group. Secondly, the third party must show credibility to those who employ it, especially in supply planning. The different organizations in the supply chain, but especially the BGSs, want to be able to count on plan that meets their requirements. Finally, in addition to impartiality and credibility, we have noted the contribution of transparency in the development of trust. Based on our analysis, we believe that the ability to audit the work of the third party is part of the process of building the trust needed to achieve true collaboration.

Our result clearly points towards factors that explain how a system integrator influence supply chain collaboration. We can also argue that a systems integrator plays the role of a "firewall" for the daily defence of the collaborative principles that partners in a forest supply chain engage in. Its presence provides some form of insurance to the group, which encourages collaboration and promotes more collaborative supply planning. Figure 4 schematizes the results of the second research objective.

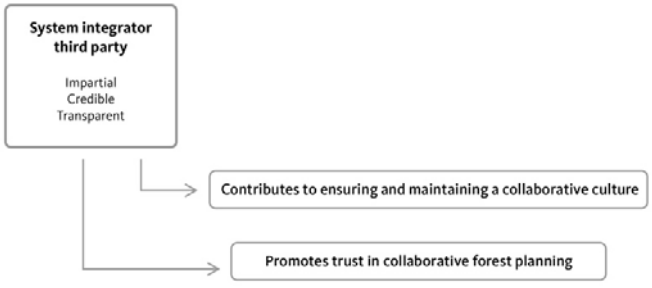


Figure 4. An impartial, credible and transparent third party is able to provide two inputs to the exercise of operational forest planning. It is about "contributing to ensuring and maintaining a collaborative culture" and "Promoting trust in the collaborative forest planning exercise".

3.3 Managing the information sharing required for collaborative forest planning

In his thesis, Morin (2019) describes the amount of time and resources needed to reconcile all the information used to carry out supply planning. Considering the capacity of third parties to introduce centralized information into decentralized systems (Frayret et al., 2004), it is interesting to study the contributions of a systems integrator to information management. Because of its intermediate position between the MFFP and the BGSs, we hypothesized that a system integrator was able to positively contribute to the management of information sharing as well as to the processing of information needed for forest planning.

We observed that the third parties of cases I and II, and to a lesser extent the third party of case III, manage the "communication channel" between the landowner (State) and industrial actors. They play an interface role between them. This responsibility makes it possible, among other things, to manage cultural differences between ministerial and industrial organizations. This third-party capability joins the interoperability described by Vernadat (2007, 2010). According to our analysis, a systems integrator allows forest supply chains under study to improve the management of information sharing by enhancing interoperability between departmental and industry organizations. It achieves this by reconciling the organizational differences between these two groups (organizational dimension of interoperability). It also ensures better consistency in the interpretation of information exchanged (semantic dimension of interoperability).

A systems integrator can also reduce the number of actors actively involved in forest planning. According to our analysis, a systems integrator manages to provide all the organizations that employ it with sufficient IT expertise to involve them in collaborative forest planning. We also argue that, consistent with the Cao and Zhang (2013) framework, a systems integrator would be in a position to contribute to IT developments across the entire supply chain, and thus offer the benefits of collaboration for the supply chain as a whole.

We suggest that systems integrator play a more active role in IT development across the supply chain. Indeed, the middle position they occupy between departmental and industrial organizations would allow them to coordinate "jointly" the development of IT for the entire supply chain. Figure 5 illustrates the results of the third research objective.

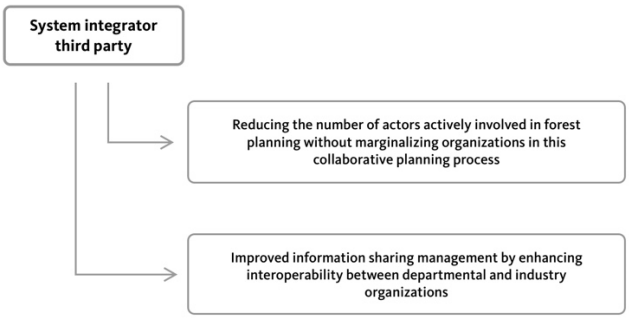


Figure 5. Summary of third-party systems integrator inputs to information sharing management.

4 Conclusion

The generic concept of system integrator, well document in the aerospace and automobile industries, had not previously been empirically studied in forest supply chains. Five case studies, with and without a third party integrator, were analysed using the formal framework proposed by Cao and Zhang (2013). We also used De Snoo et al. (2011) performance matrix to evaluate the forest collaborative planning performance. Results suggest that systems integration applied to the forestry sector generates several benefits:

- Forest planning process is more efficient when there is a good fit between the coordination context

and the level of system integration.
- Systems integrator promotes collaboration in the complex context of forest supply chains.
- A systems integrator is able to play a positive role in information sharing management.

Furthermore, our result indicate that information management is a relevant research avenue in the development of knowledge about the contributions of system integration in the forest sector. In addition, principles of Industry 4.0 may be relevant in proposing ways to manage information effectively and efficiently. However, participants in our study were hesitant about providing an individual partner with complete access of their company tactical information needed to propose global solutions. Cyber-physical systems combined with artificial intelligence might contribute to resolve some of these "trust" issues, and further improve the impartiality associated with systems integrator.

5 Acknowledgements

The authors wish to thank the Quebec Fund for Research on Nature and Technology (Fonds québécois de la recherche sur la nature et les technologies – FRQNT) for funding this study, the FORAC research consortium for the support given to the project, and all anonymous participants.

6 References

Azouzi, R., Lebel, L. & D'Amours, S. (2012). Restructuring the forest value chain using intermediaries: a methodology with application to community-managed forest (CIRRELT-2012-02). Québec, Canada : Centre interuniversitaire de recherche sur les réseaux d'entreprise, la logistique et le transport (CIRRELT).

Beaudoin, D., Frayret, J. M. & Lebel, L. (2010). Negotiation-based distributed wood procurement planning within a multi-firm environment. Forest policy and economics. 12(2), 79-93.

Cao, M. & Zhang, Q. (2013). Supply Chain Collaboration - Roles of Interorganizational Systems, Trust, and Collaborative Culture. Londres : Springer-Verlag.

Danese, P. (2011). Towards a contingency theory of collaborative planning initiatives in supply networks. International Journal of Production Research, 49(4), 1081-1103.

Davies, A., Brady, T. & Hobday, M. (2007). Organizing for solutions: Systems seller vs. systems integrator. Industrial marketing management, 36(2), 183-193.

Davies, A. & Mackenzie, I. (2014). Project complexity and systems integration: Constructing the London 2012 Olympics and Paralympics Games. International journal of project management, 32(5), 773-790.

De Snoo, C., van Wezel, W. & Jorna, R. J. (2011). An empirical investigation of scheduling performance criteria. Journal of operations management. 29(3), 181-193.

Frayret, J.-M., D'Amours, S. & Montreuil, B. (2004). Coordination and control in distributed and agent-based manufacturing. Production planning and control, 15(1), 42-54.

Gibbert, M., Ruigrok, W., & Wicki, B. (2008). What passes as a rigorous case study? Strategic management journal, 29(13), 1465-1474.

Glaser, B. G., & Strauss, A. L. (1967). The discovery of grounded theory: strategies for qualitative theory. New Brunswick: Aldine Transaction.

Gouvernement du Québec. (2016). Budget 2016-2017 : Compétitivité de l'industrie forestière au Québec. Bibliothèque et Archives nationales du Québec.

Hobday, M., Davies, A. & Prencipe, A. (2005). Systems integration: a core capability of the modern corporation. Industrial and corporate change, 14(6), 1109-1143.

Lawrence, P. R., & Lorsch, J. W. (1967). Differentiation and integration in complex organizations. Administrative science quarterly, 1-47.

Lebel, L., Azouzi, R. & D'Amours, S. (2019). Exploring new forms of intermediation in the forest value chain. Journal of science & technology for forest products and processes, 7(4), 46-56.

Morin, F. (2019). Planification collaborative dans l'environnement multiacteur public-privé des chaînes d'approvisionnement forestier du Québec : perspectives systémique, sociologique et informationnelle. (Thèse de doctorat). Université Laval.

Patton, M. Q. (2015). Qualitative research & evaluation methods. 4e édition. Thousand Oaks.

Pavitt, K. (2003). Specialization and systems integration: where manufacture and services still meet. Dans Prencipe, A., Davies, A. & Hobday, M. (dir.), The Business of Systems Integration. Oxford: Oxford University Press.

Yin, R. K. (2014). Case study research: Design and methods, 5e Édition. Sage Publications.

S13 Infrastructure & market
On the way

HEAVY METAL LEACHING FROM FOREST ROADS REINFORCED WITH FLY ASH

Antti-Jussi Lindroos [1], Kira Ryhti [2], Tomi Kaakkurivaara [1], Jori Uusitalo [1], Heljä-Sisko Helmisaari [2]
[1] Luke, Finland; [2] University of Helsinki, Finland

LEGAL, SOCIAL AND ECONOMIC REQUIREMENTS FOR INTEGRATION OF HARVESTER DATA IN LOGISTICS CHAINS IN GERMANY

Julia Kemmerer, Florian Hartsch, Lorenz Breinig, Eric R. Labelle
Assistant Professorship of Forest Operations Department of Ecology and Ecosystem Management Technical University of Munich Hans-Carl-von-Carlowitz-Platz 2 85354 Freising Germany

DETERMINING THE RESILIENT MODULI OF HRB STABILIZED SOILS BY THE CYCLIC CBR METHOD

Péter Primusz, Balázs Kisfaludi, József Péterfalvi
University of Sopron, Faculty of Forestry, Institute of Civil Engineering, Sopron, Hungary

CONSIDERATION OF NEAR OPTIMAL FOREST ROAD DENSITIES FOR SWITZERLAND

Moritz Dreher, Michael Starke, Julia Menk, Christoph Schaller, Lorenz Diefenbach, Patrick Dietsch, Luuk Dorren, Martin Ziesak
Bern University of Applied Sciences (BFH) - School of Agricultural, Forest and Food Sciences (HAFL), Bern, Switzerland

AN AGENT-BASED MODELL OF WOOD MARKETS

Stefan Holm [1], Renato Lemm [1], Lorenz Hilty [2], Oliver Thees [1]
[1] Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Switzerland; [2] University of Zurich, Switzerland

OPTIMIZING THE LAYOUT OF AN EXISTING FOREST ROAD NETWORK IN HILLY AND FLAT TERRAIN

Leo Bont, Fritz Frutig, Christoph Fischer, Marielle Frafel
WSL, Birmensdorf, Switzerland

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

HEAVY METAL LEACHING FROM FOREST ROADS REINFORCED WITH FLY ASH

Lindroos A.-J.*, Kaakkurivaara T., Uusitalo J.
Natural Resources Institute Finland (Luke)
Latokartanonkaari 9, FI-00790 Helsinki, Finland
Ryhti K., Helmisaari H.-S.
Department of Forest Sciences,
University of Helsinki,
P.O. Box 27, FI-00014 University of Helsinki, Finland
tomi.kaakkurivaara@gmail.com

Abstract: *The aim of this study was to determine the effect of leaching of heavy metals (Cr, As, Cd, Cu, Ni, Pb, Zn, Co, Mo) and earth-alkaline metal, barium (Ba), on the percolation and ditch water quality from the forest roads that contained ash in the road structures. Water quality was studied in the immediate vicinity below the ash layers as well as deeper in the road structure. Water quality was also determined in the drainage water in ditches that crossed the forest roads. A mixture of wood and peat based fly ash was used in the road structures. The treatments were: 1) no ash, 2) a 15 cm layer of ash/gravel mixture, 3) a 20 cm layer of ash/gravel mixture, 4) a 25 cm layer of ash, and 5) a 50 cm layer of ash. Large variation in the concentrations of Cr, As, Cu, Ni, Pb, Mo and Ba in the percolation water, even within the same treatment, caused difficulties to generalize the results. The concentrations of Cr, As, Ni, Pb, Mo and Ba in water samples were high in some treatment plot lysimeters containing ash compared to the control (no ash). On the other hand, many lysimeters had low and similar concentrations in water samples in the treatment plots containing ash compared to concentrations in the control plots. The ash in the roads did not affect the concentrations in the ditches. The leaching is uneven and seems to take place only from some parts of the ash layer. Risk for leaching is minimal if such parts are not widely spread.*

Keywords: lysimeter, recycling, forest road rehabilitation, environmental impact assessment, low-volume road

References

Lindroos A.-J., Ryhti K., Kaakkurivaara T., Uusitalo J., Helmisaari H.-S. (2019). Leaching of heavy metals and barium from forest roads reinforced with fly ash. Silva Fennica vol. 53 no. 2 article id 10088. https://doi.org/10.14214/sf.10088

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

LEGAL, SOCIAL AND ECONOMIC REQUIREMENTS FOR INTEGRATION OF HARVESTER DATA IN LOGISTICS CHAINS IN GERMANY

Julia Kemmerer, Florian Hartsch, Lorenz Breinig, Eric R. Labelle
Assistant Professorship of Forest Operations
Department of Ecology and Ecosystem Management
Technical University of Munich
Hans-Carl-von-Carlowitz-Platz 2
85354 Freising
Germany
julia.kemmerer@tum.de, florian.hartsch@t-online.de, lorenz.breinig@tum.de, eric.labelle@tum.de

Abstract: *Today we live in the era of Forestry 4.0, meaning that we are in the industrial revolution of cyber-physical systems. It is often linked to the term "smart forestry". As a consequence, "digitalization" and "networking" play a pivotal role in the future of forestry, and in particular for forest operations and mechanization. The collection and use of digitalized data not only requires the appropriate technical implementation but also hinges on the clear understanding of the legal, social and economic requirements. In an attempt to further our understanding, the aim of this study was to identify and analyze the legal, social and economic requirements of harvester data integration in Germany. In detail the research questions were:*

1. *Which legal basics determine the harvester data integration?*
2. *How do the stakeholders, participating in the wood supply chain, see potentials and challenges of such data integration?*
3. *What is the current situation of economic value creation in data markets and is it possible to trade harvester data?*

To analyze the legal conditions of harvester data, a literature review of the relevant German laws was performed. A qualitative content analysis of expert interviews was also conducted to identify and analyze the opinions of the stakeholders in the wood supply chain. Furthermore, an additional literature research was performed to ascertain approaches for monetary valuation of data.
In Germany, the legal situation surrounding data acquisition and use is generally not clearly defined since only ownership-related rights for data can be described. Because of this situation, the meaning of ownership and rights is highly fluid and depends on the different stakeholders. From an economic perspective, there is no universal method for a monetary evaluation of harvester data. All things considered, a recommendation of how to diligently handle harvester data is needed in Germany, like it already exists in other countries, such as Finland.

Keywords: legal conditions, social perspectives, economic evaluation, supply chain

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

DETERMINING THE RESILIENT MODULI OF HRB STABILIZED SOILS BY THE CYCLIC CBR METHOD

Péter Primusz, Balázs Kisfaludi, József Péterfalvi
University of Sopron, Faculty of Forestry, Institute of Civil Engineering, Sopron, Hungary
kisfaludi.balazs@uni-sopron.hu

Abstract: *As computer-aided analytical pavement design gets wide-spread and affordable even in low volume road design, there is an increased need for cheap determination of elastic properties of road building materials. Such measure is the resilient modulus (Mr). It is traditionally measured by dynamic triaxial testing, a complex and expensive process. The cCBR (cyclical California Bearing Ratio) method was developed at the Technical University of Delft in 1995 to provide a simple tool to estimate Mr of granular soils. Ever since researchers adapted and tested the method on cohesive and stabilized soils with great results. In this study the suitability of cCBR testing for HRB (Hydraulic Road Binder) stabilized soil samples was assessed. The cCBR test consists of a standard CBR test – where a 50 mm diameter metal rod is pushed 2,50 mm deep in the sample by 1,25 mm/min speed – followed by at least 50 loading cycles. The loading force equals the force needed for the 2,5 mm penetration. In a loading cycle the sample suffers permanent (plastic) and reversible (elastic) deformation. In order to get information on the elastic behavior, the sample should be loaded repeatedly until only reversible deformation occurs. Based on the sample's elastic deformation and the force equations were developed to estimate Mr. Silty sand (SM) soil was used for the experiments. 24 samples were produced with lime and lime-cement binder. Water content ranged from 8% to 23%, while binder proportion was set to 3, 5 and 7%. The samples were left curing for 28 days then cCBR tests were conducted. It was found that the strength of correlation between CBR and estimated Mr seems to depend on the binder. The average CBR value of lime-treated soils was higher than lime-cement treated ones, while it was the opposite in the case of Mr values. From the investigated calculations, Opiyo's equation resulted more realistic Mr values for the used soil. In the light of the results the cCBR test looks like a promising tool though more comparative research is needed for routine application in the Hungarian forest road design practice.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

CONSIDERATION OF NEAR OPTIMAL FOREST ROAD DENSITIES FOR SWITZERLAND

Moritz Dreher, Michael Starke, Julia Menk, Christoph Schaller, Lorenz Diefenbach, Patrick Dietsch, Luuk Dorren, Martin Ziesak
Bern University of Applied Sciences (BFH)
School of Agricultural, Forest and Food
Sciences (HAFL), Bern, Switzerland
Länggasse 85, CH-3052 Zollikofen, Switzerland
moritzkaspar.dreher@bfh.ch, michael.starke@bfh.ch, julia.menk@bfh.ch, christoph.schaller@bfh.ch, lorenz.diefenbach@bfh.ch, patrick.dietsch@bfh.ch, luuk.dorren@bfh.ch, martin.ziesak@bfh.ch

Abstract: *The full use of the forest wood potential is of major concern in Switzerland. Therefore, the Federal Office for the Environment (FOEN) and the cantons provide substantial funding for an active forest management. One key element in this context is the maintenance of an adequate forest road network. This study targets at providing orientation values about the minimum amount of forest roads to classify a certain forest as opened. Thus, guaranteeing sufficient access to the targeted wood resources. This is the basis to make the linkage with construction cost values referring geological and terrain structures on-site. In the end the Federal Office for the Environment (FOEN) will elaborate an according funding system underpinned by the findings of the study.*

Keywords: forest road network, subsidy system, construction costs

1. Background situation of the project

Forest roads are essential for providing access to forests and their wood. Forest road networks usually were established over several decades, always in accordance with logging, hauling and transport abilities of that planning and establishment period. These road construction activities culminated in Middle Europe long ago, with now several roads reaching or exceeding their financial depreciation age (Anonymous 2008). This is also true for Switzerland. Thus, is a good opportunity to determine if the road network structure is convenient and how large the deviation compared to an ideal structure is. The redesign of the road network is crucial in relation with the efficiency of forest management and wood harvesting (Ziesak et al. 2005). It is one of the most promising approaches but to find the best situational solution is a challenging task especially in mountainous regions like in Switzerland (Bont 2016; Bont 2017).

2. Aim of the project

Based on newly available harvesting, skidding and transport options it is a good idea to review actual configuration requirements of forest road networks. A first step was done in this study, intended to find ideal orientation values for forest road densities for larger areas in Switzerland. The analysis aim was to define value ranges for the forest road networks in respect of the existing forest patterns and terrain structures in 23 cantons and to elaborate a value range per canton. This generated cantonal value ranges have then to be linked with corresponding value ranges of construction costs regarding the geological and terrain structures in the examined area. In the end the *Federal Office for the Environment (FOEN)* will elaborate an according funding system underpinned by the findings of the project (BAFU 2013).

3. Elaboration of near optimal road densities and value ranges for construction costs in Switzerland

The study uses a two-step methodology, which results in an orientational or recommended road density value per plot. The first step generates road density values per sample area; these values are then summarized in to different value ranges in the subsequent GIS based cluster analysis in the generalization step.
Within the set approach already existing forest road networks were excluded from the contemplation as they can be considered as fully amortized, furthermore they often do not reflect nowadays needs in road delineation, due to their construction time long ago (Ghaffarian et al. 2007; Heinimann 2017). The newly elaborated forest road networks are based on an expert-study. These experts were considering the forest patterns, terrain structures (map-based), latest harvesting and transport technologies in their model road network solution per test area (Heinimann 1998; Heinimann et al. 1999; WSL 1999a, 1999b; LWF 2002; DWA-Regelwerk 2005). The resulting database is therefore highly influenced by forest operations related production factors, thus providing a comparison set towards further needs as coming from other inquiries like tourism, agriculture or water management. Overall 73 sites with an extent of 11km^2 each, containing mainly forested areas, were placed with the minimal condition of one site per canton. The sites were analysed in this second step with the aid of GIS. Several layers were investigated and over 30 variables were incorporated and calculated to reflect the variability of structural features. In this second step an exploratory regression was computed to generate a model able to explain the occurring road densities by taking into consideration the geological, terrain and forest land structures. This provides the required relationship between the regarded variables and the resulting road densities in Switzerland. This analysis framework was implemented in RStudio to make the linkage between the variables and the model enabling the assignment of new (uninvestigated by experts) sites into the defined road density clusters. In that way it is possible to calculate a value range for a reasonable road density needed for a specific site to assure a sufficient forest exploitation without any need for manual survey by experts or exploring the areas in the field. The actual status is that the calculation of the value range can be made adequately for the cantons Berne and Argovia. To enable the successful implementation of the approach throughout Switzerland it has become evident that additional variables have to be incorporated to achieve the objective appropriately.
To enable the assessment of the occurring forest road construction costs on-site, a collection from *the Federal Office for the Environment (FOEN)* is used which contains many forest road construction projects and their new construction costs. Additionally, data from tree Swiss cantons (Berne, Grisons and Fribourg) were included in the analysis. In total around 1500 projects since 1993 were selected for the investigation. Ziesak and Tschamun (2012) have analysed the described dataset and used 5 clusters reflecting different regional characteristics (alps, south side of the alps, prealpes, jura and midlands). In the context of this study the new construction costs regarding forest roads without hard cover are essential (N=545). Unfortunately, this 5 regional clusters cannot directly be used as explanatory because when estimating the near optimal road densities, the geological and terrain structure variability appeared higher within these regions than between them. This means also that there has to be found another way to connect the construction costs with the near optimal road densities than by allocating them to one of the 5 regions. At the moment the most expedient way to do so is under examination.
After the successful implementation of a sufficient interface approach, in a subsequent step BFH will support *the Federal Office for the Environment (FOEN)* the design process to define the according system of contributions based on the two different kinds of value ranges and their viable linkage.

4. References

Anonymous (2008): FORSTBAR. Kapitel 8: Abschreibungsdauer, 5/13/2008.
Bont, Leo (2016): Optimales Layout einer Walderschliessung. Schweizerische Zeitschrift für Forstwesen: September/October 2016, Vol. 167, No. 5, pp. 294-301. DOI: 10.3188/szf.2016.0294.
Bont, Leo (2017): Reengineering forstliches Erschliessungsnetz Zernez Schlussbericht. Eidg. Forschungsanstalt für Wald, Schnee und Landschaft WSL.

Bundesamt für Umwelt (BAFU) (2013): Waldpolitik 2020. Visionen, Ziele und Massnahmen für eine nachhaltige Bewirtschaftung des Schweizer Waldes. Bundesamt für Umwelt, Bern: 66 S.
Ghaffarian, Mohammad Reza; Stampfer, Karl; Sessions, John (2007): Optimum Road Spacing of Forwarding Operations: A Case Study in Southern Austria. In AUSTRO / FORMEC Proceedings. Available online at https://www.formec.org/images/proceedings/2007/session_8_pdf/8_1_paper_ghaffarian_stampfer_sessions_austro_formec_2007.pdf, checked on 8/19/2016.
Heinimann, Hans Rudolf (1998): A Computer Model to Differentiate Skidder and Cable- Yarder Based Road Network Concepts on Steep Slopes. In: Journal of Forest Research, vol. 3, pp. 1–9.
Heinimann, Hans Rudolf; Bürgi, Othmar; Rechberger, Stefan (1999): Praxishilfe Geometrische Richtwerte von Waldwegen und Waldstrassen. Herausgeber: Bundesamt für Umwelt, Wald und Landschaft (BUWAL). 43 S.
Heinimann, Hans Rudolf (2017). Forest Road Network and Transportation Engineering–State and Perspectives. Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering, 38(2), 188-173.
LWF (Ed.) (2002): Aktuelle Holzernteverfahren am Hang. Berichte aus der bayerischen Landesanstalt für Wald und Forstwirtschaft 2002 (36). Freising: Bayerische Landesanstalt für Wald und Forstwirtschaft.
DWA- Regelwerk, Oktober 2005: Richtlinien für den ländlichen Wegebau.
WSL (1999a): Produktionssystem "konventioneller Seilkran". Dokumentation HeProMo – Teil A. With assistance of Lemm, Näf, Breitenstein, Erni, Holm.
WSL (1999b): Produktionssystem "Mobilseilkran". Dokumentation HeProMo – Teil A. With assistance of Fritz Frutig, Lemm, Breitenstein, Erni, Holm. WSL.
Ziesak, Martin; Tschamun, Salome (2012): Erstellung von Faktenblättern zu den Kosten und Erlösen der Walderschliessung. Interner Bericht Bundesamt für Umwelt (BAFU).
Ziesak, Martin; Uhl, Enno; Herman, Saul Walter (2005): Möglichkeiten der Rationalisierung. LWF aktuell 50/2005, S. 4-7.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

AN AGENT-BASED MODELL OF WOOD MARKETS

Stefan Holm [1], Renato Lemm [1], Lorenz Hilty [2], Oliver Thees [1]
[1] Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Switzerland; [2] University of Zurich, Switzerland
oliver.thees@wsl.ch

Abstract: *We present an agent-based model of wood markets. The model covers softwood and hardwood markets for sawlogs, energy wood, and industrial wood. Our study region is a mountainous area in Switzerland. The wood markets in this study region are characterized by many small-scale wood suppliers, and a mix of private and public-owned forests. The model was developed to investigate the availability of wood in the study region under different market conditions. We defined several scenarios that are relevant to policy makers and analyzed them with a focus on the two most important assortments of wood in the study region, namely, sawlogs softwood and energy wood softwood. The development of the prices and amounts sold in the scenarios are compared to a business-as-usual scenario. The scenarios were designed to investigate i) the influence of intermediaries, ii) the influence of the profit-orientation of forest owners, iii) the influence of the exchange rate, and iv) the consequences of set-asides in the study region. The presented model has a large potential to support the planning of policy measures as it allows capturing emergent phenomena, and thereby facilitates identifying potential consequences of policy measures planned prior to their implementation. This was demonstrated by discussing the scenario findings with respect to Switzerland's forestry policy objective of increasing the harvested amount of wood to the sustainable potential. We*
showed that a higher profit-orientation of forest owners would be beneficial for this objective, but also revealed potential conflicts of different economic goals.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

OPTIMIZING THE LAYOUT OF AN EXISTING FOREST ROAD NETWORK IN HILLY AND FLAT TERRAIN

Leo Bont, Fritz Frutig, Christoph Fischer, Marielle Frafel
WSL, Birmensdorf, Switzerland
leo.bont@wsl.ch

Abstract: *Most existing forest road networks in Switzerland were built between the 1950s and the 1980s, so they were planned for different conditions that we find today (different harvesting and hauling technology as well different financial restriction). At latest when reaching the end of the life cycle, those road networks need to be redesigned. For example some road segments will not be required anymore, some need an upgrade and some road pieces need to be new constructed. In particular in the hilly and flat terrain in Switzerland road densities are considered rather as too high. Based on an existing road network, we are aiming to identify a harvesting and road network layout that minimizes concurrently the cost for the road network (construction, upgrade and maintenance), the wood harvesting and the hauling operations over an entire life cycle. Since road networks in flat terrain are much more complex (in terms of potential combinations of road segments) than in the mountains terrain, existing methods developed for steep terrain cannot simply be adopted. We will present an optimization and analysis method that is able to deal with such complex road networks and compare it with existing approaches. The method will be applied for a project of the Swiss national forest inventory, aiming to identify forest areas with a too dense or a too sparse road network and proposing a strategy for further developments of those road networks. Results from a first case study in the cantons of Bern and Basel will be presented and discussed.*

S14 The future of forest engineering
No borders

FOREST MACHINES FOR THE FUTURE – LEARNING FROM NATURE
Richard Parker, Peter Clinton, Brionny Hooper
Scion - NZ Forest Research Institute Christchurch New Zealand

ESTIMATING THE NEED FOR PRE-HARVEST CLEARING BY MULTISPECTRAL AIRBORNE LASER SCANNING.
Blanca Sanz [1], Jukka Malinen [1], Jussi Heiskanen [2], Timo Tokola [1]
[1] University of Eastern Finland, Joensuu, Finland; [2] Savonia University of Applied Sciences, Varkaus, Finland

PLANTERBOT (PLANTING ROBOT)
Robert I Radics, Linh N. K. Duong
Scion Forest Research, New Zealand

A FORECAST OF SILVICULTURE RE-ESTABLISHMENT TECHNOLOGIES OF THE FUTURE IN PLANTATION FORESTRY
Muedanyi Ramantswana [1], Michal Brink [2], Keith Little [1], Raffaele Spinelli [3], Paxie Chirwa [2]
[1] Nelson Mandela University, South Africa; [2] University of Pretoria, South Africa; [3] CNR IVALSA, Italy

MEASURING LOG PILES WITH PHOTO-OPTICAL MONO CAMERA SYSTEMS
Hans-Ulrich Dietz
Kuratorium fuer Waldarbeit und Forsttechnik (KWF); Gross-Umstadt, Germany

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

FOREST MACHINES FOR THE FUTURE – LEARNING FROM NATURE

Richard Parker, Peter Clinton & Brionny Hooper
Scion
10 Kyle Street, Riccarton, Christchurch, New Zealand
Richard.Parker@scionresearch.com

Abstract:

We present our view for the future of forest machine development that is inspired by nature. As forestry professionals designing machinery and systems we can learn from nature's forest experts – the animals that live among trees all their lives. Arboreal animals have developed behavioural, structural and physiological adaptations to the forest environment. Some animals move slowly from branch to branch, like the stick insect. Others, such as Gibbons, can move rapidly using brachiation, engaging in the arboreal equivalent of running through the forest tree tops. Hands, claws, arms, muscles and other body parts have evolved over time to make movement efficient. An opportunity exists to use these biological adaptations in the design and movement of forestry machinery. We can even learn from the behaviour of forest animals to inspire the development of intelligent forest machine control systems.

One common feature of forest animals that live in trees is that they avoid the forest floor when possible, preferring to move from tree to tree. Another feature is they tend to have a low body mass so more branches are available for locomotion and there is less energy required for movement. We designed and built a prototype forest locomotion machine inspired by forest animals. It is designed to always stay above ground moving from tree to tree and to be as light weight as practically possible. The machine is designed to eliminate the problem of soil disturbance and movement on steep terrain. Additionally, by not interacting with the ground surface, navigation and traction are much easier – slippery soil, slopes, rocks, holes, fallen logs and other barriers to terrestrial locomotion can be ignored.

We will present a possible future for forest operations mechanisation where economically valuable forestry tasks are performed by machines inspired by, and working in harmony with, nature.

Keywords: robot, tree to tree locomotion, biomimetics, forestry

1. Introduction

In the past, people used only an axe or chainsaw to fell a tree. This felling system of person and axe (or chainsaw) weighed on average less than 100 kilograms. Modern harvesting machines, although faster and with a bunching ability, can weigh in excess of 30,000 kilograms. Mechanised harvesting on steep slopes can therefore create soil impacts and environmental hazards in downstream waterways, particularly due to compaction of soil (from heavy machinery), and soil erosion (due to traction and skidding) affecting future soil productivity, and debris slips from loosened soil and exposure to rainfall runoff (Adams et al. 2003; Baker 2014; Fahey & Coker 1989; Ghafferin et al. 2012). Reduction of sediments into waterways is a primary concern for forest management when harvesting in steeper terrains. Safety of the forest worker is of extreme importance and any new technology must not introduce more hazards. Robotic harvesting is seen by the forest industry as improving worker safety (Bayne & Parker, 2012).

The forest is a difficult environment. Milne et al. (2013a, 2013b) states that the forest setting provides a unique challenge to robotic progress requiring operation in an unstructured and uncontrolled environment,

and Ringdahl (2011) notes the more complex in-field decision-making than agricultural practices. Operating paths are rarely straight or flat, with a high degree of logging residue and high variability in vulnerability to soil compaction (Ringdahl 2011).

2. Background

2.1 The Forest Environment

The forest terrain in New Zealand is often steep and the ground covered in obstructions such as logs, rocks, tree limbs and holes. The soil surface can also be difficult to negotiate with slippery pine needles or mud. There is ever present danger in the forest environment with cones and branches falling from above and during high wind events – falling trees. High levels of moisture stored in the forest canopy during wet weather make the transmission of radio waves difficult. For example, the needles of *Pinus radiata* are the same length (10-15cm) as a quarter-wave length that mobile phones work on. This severely disrupts signal transmission within the forest (Savage et al, 2003) making radio control of machines difficult.

2.2 Forest Mechanisation

Many tasks, such as planting, pruning, thinning and tree measurement rely on manual labour. However, in New Zealand there is difficulty recruiting skilled and qualified workers. Mechanisation is potentially a way to increase the productivity of the smaller workforce and improve safety of workers

There have been attempts to develop mechanised silvicultural devices for pruning and thinning. The Clouston Tree Shaver (Young, 2002) rotates around the stem of the tree and as it climbs a router bit cuts off branches. Similarly, the Yamabiko pruning device climbs the tree on rubber pneumatic tyres and cuts branches with a vertical chainsaw. However, this style of device does not work well on the rough knobbly stems of New Zealand radiata pine (Wilkes & Bren, 1986). University of Canterbury, New Zealand is attempting to develop a UAV based pruning device that can cut individual branches from Radiata pine stems.

Thinning in New Zealand forests can be ‘commercial thinning’, where the logs are extracted and sold or ‘thinning to waste’ where the felled trees are left where they fall. Mechanised commercial thinning operations have existed in New Zealand for many decades (Grayburn, 1976). However, mechanised waste thinning is uncommon although attempts have been made to successfully implement mechanised operations.

Silvicultural tasks are difficult to mechanise and one of the greatest causes of difficulties is finding a simple and reliable method to move over the broken forest terrain to get to the next tree.

2.3 Acceptance of mechanisation

Bayne and Parker (2012) interviewed 23 New Zealand forestry personnel involved in forestry operations to gain an understanding of their reactions to the potential use of robotics in forestry. Robotics was widely viewed as a natural progression of mechanisation for the industry, and for a third of respondents, seen as essential in order to have an industry that remains competitive in the future. The greatest perceived concerns from robotics implementation include the impact on employment in small rural communities; the ability of robotic devices to cope with the difficult terrain of the New Zealand forest environment; and meeting economic considerations given tree and forest variability.

3. Future Forestry Machines

In the past we were able to cut down a tree with an axe. Tools were then refined so that hand saws and eventually power saws were used to cut down trees. We have now moved to large expensive 40 tonne tracked and wheeled machines felling trees. The ideal would be to have the smallest, cheapest machines that are capable of performing productive forestry tasks.

3.1 Learning from nature

The term biomimetics was first used in a paper by Otto Schmitt (Schmitt, 1969). Biomimetics relates to gaining inspiration from biological structures and processes to solve problems. Our future forest machine development has been inspired by nature.

As forestry professionals designing machinery and forest systems we can learn from nature's forest experts – the animals that live among trees all their lives. Arboreal animals have developed behavioural, structural and physiological adaptations to the forest environment. Some animals move slowly from branch to branch, like the stick insect. Others, such as Gibbons, can move rapidly using brachiation, engaging in the arboreal equivalent of running through the forest canopy. Hands, claws, arms, muscles and other body parts have evolved over time to make movement efficient.

An opportunity exists to use these adaptations in the design and movement of forestry machinery. We can even learn from the behaviour of forest animals to inspire the development of intelligent forest machine control systems. Over millions of years animals have evolved to use the trees of the forest for locomotion. The most impressive are the brachiating Spider Monkey and the Gibbon (Figure 1).



Figure 1 Gibbon displaying brachial swinging locomotion
Source: http://www.gibbons.de/main/introduction/pics/5-1.gif

A robot needs incredible control to brachiate rapidly, moving slowly is more within the capabilities of existing robotics. The robot we developed, which is described below, moves slowly between trees.

4. Possible Forest System

One common feature of forest animals that live in trees is that they avoid the forest floor when possible, preferring to move from tree to tree. They tend to have a low body mass so more tree branches are available for locomotion and there is less energy required for movement. We designed and built a prototype forest locomotion machine inspired by forest animals. It is designed to always stay above ground moving from tree to tree and to be as light weight as practically possible. The machine is designed to eliminate the problem of soil disturbance and movement on steep terrain. Additionally, by not interacting with the ground surface, navigation and traction are much easier – slippery soil, slopes, rocks, holes, fallen logs and other barriers to terrestrial locomotion can be ignored.

With funding from Scion, the New Zealand Ministry for Primary Industries and the New Zealand Forest Growers Levy Trust the concept of a tree to tree forestry machine became real (TVNZ, 2015). In 2013, four University of Canterbury Mechanical Engineering and Mechatronics students built a working radio-controlled tree to tree locomotion machine (Figure 2). Their efforts won them the New Zealand Institute of Professional Engineers Ray Meyer Medal for Excellence in Student Design for 2014.



Figure 2 Scion tree-to-tree robot platform

We will present a possible future for forest operations mechanisation where economically valuable forestry tasks are performed by machines inspired by nature. These operations are demonstrated in a video animation found at https://www.youtube.com/watch?v=mzzE70ymuTU&t=5s

4.1 Pruning

The robot attaches to two adjacent trees, removing limbs as it climbs upwards. The limbs fall to the forest floor and the robot then moves to another pair of trees (Figure 3).



Figure 3 Tree to tree robot pruning trees

4.2 Scanning

The robot carries a LiDAR tree scanning device to record the form of trees. The robot moves from tree to tree without disturbing the forest floor (Figure 4).



Figure 4 Robot scanning trees

4.3 Thinning

Trees are cut by the robot which is attached to an adjacent tree (Figure 5). This prevents damage to the forest soil. Planning of the path of the robot through the forest will be important to assure standing trees are always available for locomotion.



Figure 5 Tree to tree robot felling trees

4.4 Extraction

Logs removed from the forest using an aerial ropeway held in place by moveable robots. The logs do not disturb the forest soil. This is one possible scenario and logs could be moved by other means (Figure 6).



Figure 6 Robot system to extract logs to the nearest road

Considerable effort is going into developing machines for forest operations. Lindroos et al. (2017) discuss recent innovations for mechanised timber harvesting. The ideal would be a utopian forest working environment where quiet, small forestry machines perform the tasks – planting, pruning, mensuration, felling and extraction. The machines work in swarms to do the bigger tasks like felling heavily leaning trees or log extraction (Parker, Clinton & Hooper, 2018).

There would be humans on-site, like shepherds, looking after the flock of forestry robots – repairing fallen machines, refuelling and sharpening cutting blades. All the machines would be small enough to be easily transported by light helicopter to the forest location. Because there are many, less expensive machines the economic risk for the contractor is less. If one machine is broken there are others that can continue to work.

5. Conclusions

Nature provides a vast array of potential solutions to the problems that arise in the design of robotic systems for forestry. Animals have developed efficient methods of locomotion in the arboreal environment. Forestry is a high risk industry set in a challenging environment and robots will, in the future, perform those dangerous and difficult tasks. Additionally, we are learning of the importance of the microbiome of the forest soil to tree health and the importance of not disturbing the soil. Robotic systems which can tend and harvest trees without damaging the soil will be essential for the health and wellbeing for our forests.

6. Acknowledgements

The authors acknowledge the financial assistance provided Scion (the New Zealand Forest Research Institute), the New Zealand Ministry for Primary Industries and the New Zealand Forest industry through the NZ Forest Growers Levy Trust.

7. References

Adams, J., Visser, R., and Prisley, S. (2003), "Modelling Steep Terrain Harvesting Risks Using GIS," Paper presented at the Precision Forestry Conference, Seattle.

Baker, J. (2014), "The Environmental Effects of Plantation Forestry: The Ngunguru Catchment, Northland, New Zealand. A Discussion Document," Wellington: Environment and Conservation Organisations of NZ Incorporated (ECO).

Bayne, K., and Parker, R. (2012), "The Introduction of Robotics for New Zealand Forestry Operations: Forest Sector Employee Perceptions And Implications," Technology in Society, 34 (2), 138-148.

Fahey, B., and Coker, R. (1989), "Forest Road Erosion in The Granite Terrain of Southwest Nelson, New Zealand," Journal of Hydrology, 28(2), 123 -140.

Ghafferin, M., Acuna, M., and Ackerman, P. (2012), "Review of New Ground-Based Logging Technologies for SteepTerrain," Tasmania CRC for Forestry.

Grayburn, A.W. (1976), "Kinleith Thinning Operations of N.Z. Forest Products Limited," New Zealand Journal of Forestry Science 6(2): 214-220.

Lindroos, O., La Hera, P. and Häggström, C. (2017), "Drivers of Advances in Mechanized Timber Harvesting – A Selective Review of Technological Innovation," Croatian Journal of Forest Engineering, 38(2): 243-258.

Milne, B., Buchanan, G., Paulin, S., Chen, X.Q., Hann, C., Geldenhuis, A. and Parker, R. (2013a), "Robotic Arm Kinematics and Bilateral Haptic Feedback Over an Ethernet Communications Link," Madison, WI, USA: 2013 IEEE International Conference on Automation Science and Engineering (CASE), 17-20 Aug 2013. 960-965. http://dx.doi.org/10.1109/CoASE.2013.6654005.

Milne, B., Chen, X.Q., Hann, C.E. and Parker, R. (2013b), “Robotisation of Forestry Harvesting in New Zealand - An overview,” Hangzhou, China: 2013 The 10th IEEE International Conference on Control and Automation (ICCA), 12-14 Jun 2013. 1609-1614. http://dx.doi.org/10.1109/ICCA.2013.6564913.

Parker, R.; Clinton, P. and Hooper, B. (2018), “Forestry Automation and Robotics,” New Zealand Journal of Forestry. 63:1, 38-40.

Ringdahl, O. (2011), “Automation in Forestry – Development of Unmanned Forwarders”, (PhD), Umeå University, Umeå: Sweden.

Savage N., D. Ndzi, A. Seville, E. Vilar, and J. Austin. (2003), “Radiowave Propagation Through Vegetation: Factors Influencing Signal Attenuation," Radio Science, 38(5), 1088.

Schmitt O. H., (1969), “Some Interesting and Useful Biomimetic Transforms,” Proceeding of the Third International Biophysics Congress, Boston, Mass., Aug. 29-Sept. 3,1969, p.297.

TVNZ. (2015). Tree Traversing Robot. Series 11, Episode 38. Wellington, New Zealand: Television New Zealand Rural Delivery. Screened Oct 4 2015. Retrieved from https://www.youtube.com/watch?v=kr0XvI0IkyA

Wilkes, P. and Bren, L. J. (1986), “Radiata Pine Pruning Technology,” Australian Forestry 49(3): 172-180.

Young, M. (2002). Clouston’s tree shaver. Blachly-Lane Electric Coop: 4-5.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

ESTIMATING THE NEED FOR PRE-HARVEST CLEARING BY MULTISPECTRAL AIRBORNE LASER SCANNING

Blanca Sanz[1], Jukka Malinen[1], Jussi Heiskanen[2] & Timo Tokola[1]
[1]University of Eastern Finland
School of Forest Sciences
P.O.Box 111, FI-80101 Joensuu FINLAND
[2]Savonia University of Applied Sciences, Varkaus, FINLAND
blanca.sanz@uef.fi

Abstract: *In cut-to-length harvesting, pre-harvest clearing is needed when the forest has many undergrowth stems preventing the visibility to the harvested stems. Pre-harvest clearing eases the harvester operators' work, which increases the productivity and quality of the harvesting operation. The use of electronical marketplaces requires more accurate information on the value of tree stock and productivity of harvesting operations in the stand. Thus, the ultimate goal was to decrease the need of forest visits before harvesting operations utilizing airborne laser scanning (ALS) methodology for pre-harvest assessment of harvesting conditions.*

In the study, methodologies for estimating the need for pre-harvest clearing of understorey vegetation were developed. The field data included 97 field plots, where stems with diameters from 1 to 7 cm were measured. Moreover, all the plots were photographed, and the photos were used in an e-questionnaire that was answered by 66 forest professionals, who were mainly harvester operators. The respondents were asked to classify the sample plots to the five categories, which were: no need for pre-harvest clearing; pre-harvest clearing would help harvesting; pre-harvest clearing recommended; a great need for pre-harvest clearing; and pre-harvest clearing essential. Multispectral ALS data were collected by the Optech Titan sensor. The results showed high variability in the classification of the need for pre-harvest clearing by forest professionals. The ALS-based recognition of the need for pre-harvest clearing proved to be challenging in the cases where the need for pre-harvest clearing was subjective, but the lowest and highest needs could be detected in most of the cases.

Keywords: pre-harvest clearing, productivity, understorey, airborne laser scanning, visibility

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

PLANTERBOT – PLANTING ROBOT

Robert Radics, Linh Duong
Scion Forest Research
10 Kyle Street, Riccarton, Christchurch 8014 New Zealand
Robert.Radics@scionresearch.com

Abstract:

New Zealand government decided to plant 1 billion trees beyond reforestation in ten years. The labour shortage has already been a significant problem for employers, especially in the forestry industry since it needs specific knowledge and the working environment is challenging. Therefore, the already stretched system needs new solutions to handle the challenge.
The study introduces the cost and benefits of applying planting robots (planterbots). Four generations of planterbots were considered from a remote-controlled tractor to autonomous solar-powered small units can process remote sensing information and cooperate on the field.
Discrete event simulation (DES) was applied to analyse the movements in the planting area. Based on the DES information, an economic analysis was developed to calculate the costs and benefits. Sensitivity analysis was used to define the critical factors and identify the important constraints (speed, fuel consumption, cost/unit, etc.) to be competitive with the current manual labour. The identified constraints are the essential inputs for the initial machinery design.
The presentation includes the problem definition, the description of the planned planterbot generations and the thoughts behind the machinery, the method of analysis, and the results.

Keywords: Planting robot, reforestation, afforestation, labour shortage, mechanisation

1. Introduction

Mechanisation studies are used to investigate the impact on the assisting or removal of human labour in favour of a mechanical alternative. Access to a willing and capable human workforce is increasingly difficult in recent years as competition for labour increases. This provides an incentive to consider alternatives to a human capital system. The rationale implies that powered sources can reduce the recruitment and safety issues facing a human workforce while providing at least parity in operational efficiency and cost. Mechanisation has been demonstrated in many industries to increase the speed at which work can be completed and provide a more consistent quality of work. Machines are able to operate in environments unsuitable for the health and safety of workers. The overall objective of a mechanisation of a process is to enhance overall productivity of the process at the lowest possible cost of production.

Mechanisation impacts on a number of logistical factors in a system. Any study must include fine details such as the planting rate, utilisation of resources, and costs associated with these activities. Time must also be accounted for including the operational aspects such as planting time, planting quality, transfer times, shift requirements as well as planned and unplanned downtimes of resources. Novel methods of delivery of inputs to site may be required, the frequency and size of these deliveries may need to be adjusted. How the resources will be moved from site to site must also be included in the analysis.

It is proposed that the logistical impact of mechanisation of the planting system be undertaken by a discrete event simulation model. Discrete event simulation is a mathematical computer model which creates scenario based operational models of a system. Discrete event simulation is a modelling system

where changes to the state of the system occur at discrete periods of time. Discrete event simulation models items as populations of individual entities moving through activities, waiting in queues, and joining with resources. It is the moment of these individual entities from process to process or queue to queue that causes changes to the systems state. Discrete event simulation software provides for variability in the time it takes an entity to undertake an activity and accounts for planned and unplanned downtimes of resources and activities; this ability to fully represent a system's true stochastic nature is vital to predicting the systems response to situational or variable changes. This reduces the time and money spent on situational analysis of the resulting impact on key performance indicators. The models are also easily manipulated, permitting numerous refinements to the system to be examined.

The identified logistical factors are all inputs into a larger economic analysis of the business case for the mechanised system. In addition to the operational factors analysed by the discrete event simulation there are a number of organisation level economic factors that should be considered for a true business case analysis. Many of these factors are influenced by changes in the logistics and as such these models should be intricately linked to enable scenarios to be compared (Figure 1).

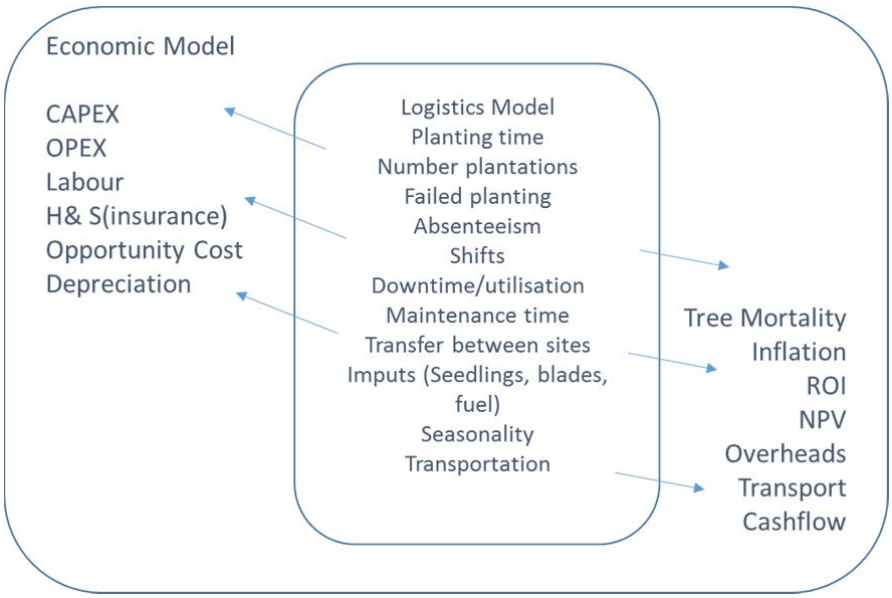


Figure 1. Connections of the logistic and economic models

It is proposed that the outputs of the logistics modelling be linked with an economic impact model which will analyse the capital, operational, financial and opportunity costs of the proposed Planterbot mechanization.

This will result in a model that provides a logistical element identifying the operational efficiencies of the Planterbot as well as an economic element identifying the financial efficiencies. By linking the output of the logistics model to the economic model the research team will be able to run future scenarios to refine or test the Planterbot system design.

2. Methods

The first step of the DES is the process mapping (Figure 2). All the given process phases defined by the time, energy, and labour demands and their variances in the Extendsim DES simulation tool. Considering the seasonality of tree planting we run the model to represent a year.

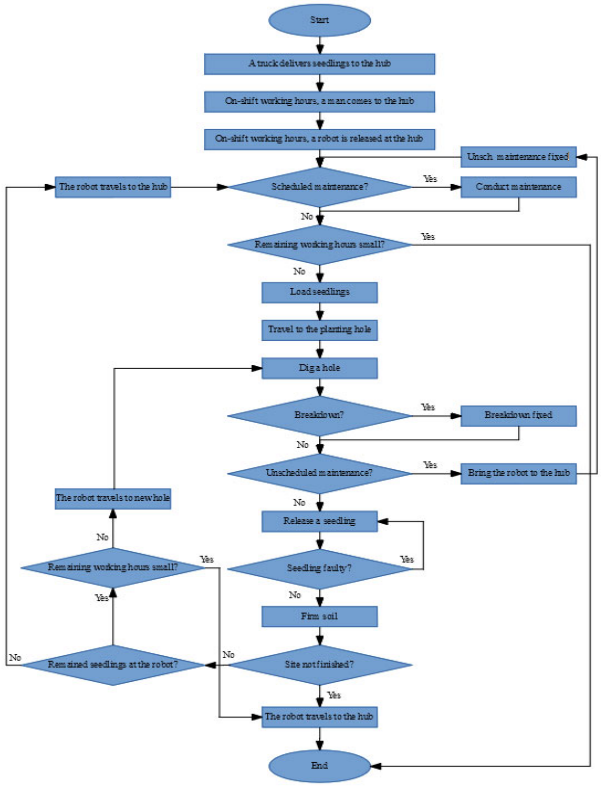


Figure 2. Planting process map

The DES outputs (uptime, labour, energy, planted trees/year) were applied in a spreadsheet economic model to analyse the feasibility, profitability, sensitivity, and tradeoffs. The links between the logistic and economic models and economic inputs and calculated benefits are introduced in Figure 3.

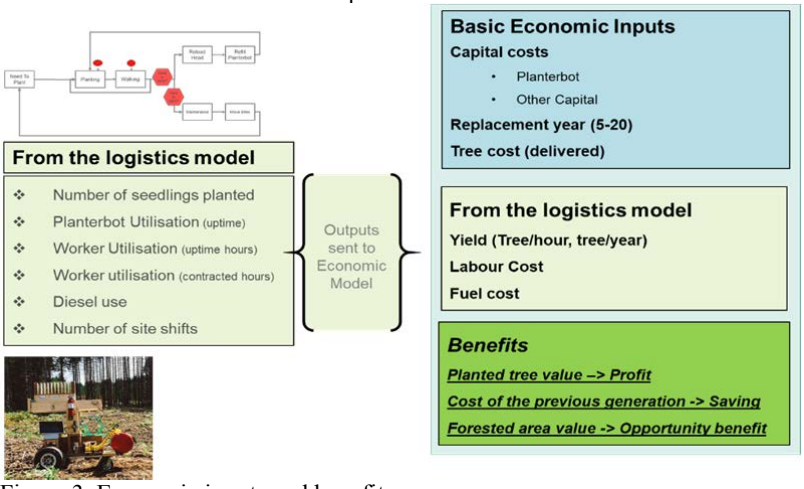


Figure 3. Economic inputs and benefits

3. Results/Conclusions

Based on expert's consensus, we applied a 1.2-2.0 NZD/tree planted cost by manual labour depending on the production site. Sensitivity analysis was performed (Figure 4-7) and we have defined regressions to understands the effects of the main economic factors.

3.1 Sensitivity analysis

The effect of the loading capacity on the cost/tree introduced in Figure 4. Larger loading capacity results in lower cost, however, the effect of the loading capacity on the costs is diminishing. Figure 5 introduces the impact of planting time/tree on costs. A strong positive correlation was found as in the case of fuel consumption (Figure 6) as well. The number of serviced planterbots by a technician has a strong negative correlation with the cost/tree (Figure 7).

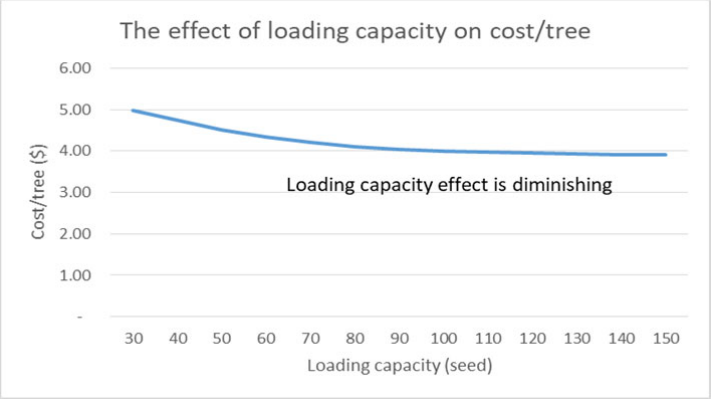


Figure 4. The effect of loading capacity of the planterbot on cost/tree planted

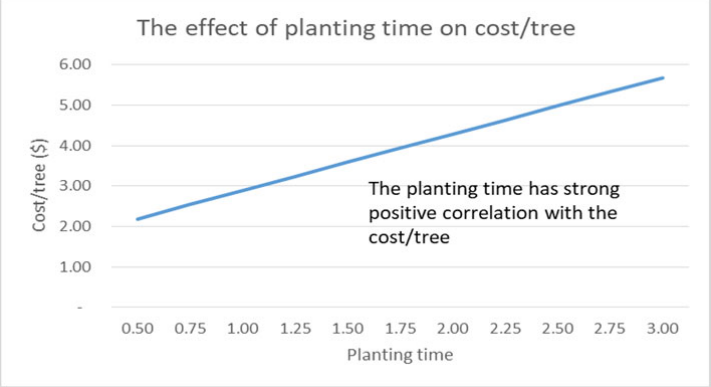


Figure 5. The effect of planting time on cost/tree planted

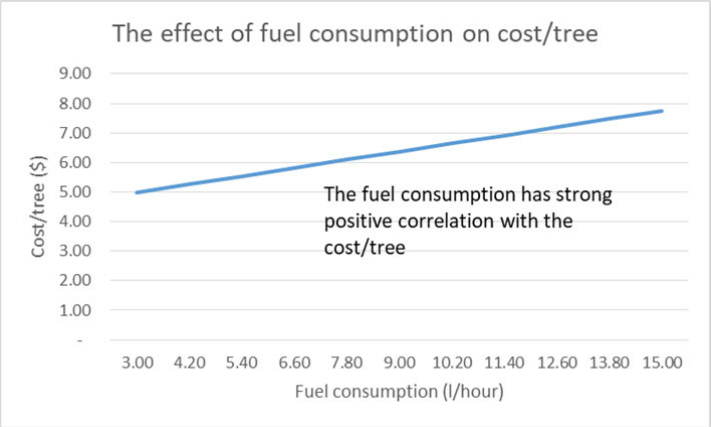


Figure 6. The effect of fuel consumption on cost/tree planted

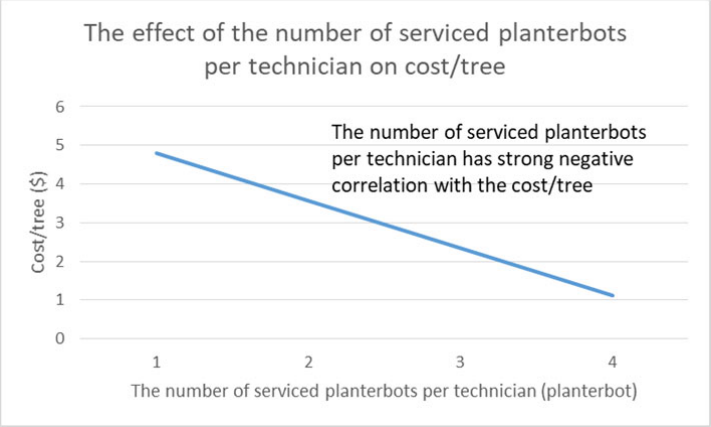


Figure 7. The effect of the number of serviced planterbots by technician on cost/tree planted

3.2. Effect of various factors on the costs

We identified the key regressions to calculate of the feasibility of planterbots in a NZ environment.

Number of seedlings picked up effect:

Cost/tree = 3.859 + 1.465 / (1 + number of seedling picked up at a time / 46.118) ^ 2.837

Planting time effect:

Cost/tree = 1.492 + 1.396 * planting time

Fuel consumption effect:

Cost/tree = 4.300 + 0.230 * hourly fuel consumption

Number of one technician serviced planterbot effect:

Cost/tree = 6.007 – 1.220 * number of serviced planterbots

3.3. Key constraints of a feasible planterbot solution

In conclusion, a feasible planterbot solution has the following key constraints:

- One technician should support at least the planting of ~80,000 tree/year to keep the labour costs down;
- The total fuel consumption should be below 0.25 l/planted tree;
- Planting time should be below 1 minute/tree excluding pickup time, maintenance and all breaks;
- The cost of the planterbot is not a key factor up to 100,000 NZD.

4. Future research

There is a clear limitation of the DES modelling, without experiments involves working planterbots, the numbers cannot be accurate. However, some important constraints and trade-offs were identified during the model building and runs. The collaboration of value chain experts, engineers, economists decreased the risk of the research.

The next step is designing and building the first generation of planterbots and collecting operation data. Based on the data from the working machines we can analyse the design and operation, and finally, we can optimise the planterbot solution.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

A FORECAST OF SILVICULTURE RE-ESTABLISHMENT TECHNOLOGIES OF THE FUTURE IN PLANTATION FORESTRY

[12]Muedanyi Ramantswana, [12]Michal Brink, [1]Keith Little and [3]Raffaele Spinelli
[1]Department of Natural Resource Management
Nelson Mandela University
George, Madiba Drive, 6530
Muedanyi.Ramantswana@mandela.ac.za

[2]Department of Forest Science
University of Pretoria
Hatfield, Lynwood road, 0002

[3]CNR IVALSA
Sesto Fiorentino, ITALY

Extended Abstract:

Technology is moving at a rapid pace and in forestry new innovations are increasingly being integrated in operations such as silviculture re-establishment (regeneration). Globally, re-establishment operations have traditionally been manually orientated except soil preparation techniques that have shown the most progress. The main drivers of mechanisation in re-establishment have been labour shortages, increasing labour costs, need to increase productivity, reduction of exposure to safety risks and improvement of quality and uniformity in forest stands. However, unlike harvesting, re-establishment mechanisation has globally been fragmented due to a wide variability in site factors and the diverse manner in which these practices are conducted. Due to the increasing need to remain competitive and meet growing wood demands, there has been an increased focus on various innovative ways to improve re-establishment activities. However, little is known about new re-establishment technologies that exist in plantation forestry and how they are expected to evolve going into the future. The aim of the study was to identify potential re-establishment technologies and further forecast when they were likely to be adopted in future.

The Delphi technique was used to systematically elicit expert opinion on possible future re-establishment technologies which have the highest probability of being adopted in operations. The technologies were categorized into for broad categories, namely: (i) machine specific developments (ii) material input innovations (iii) machine operator specific innovations and (iv) computerized technology applications. Within these broad technology areas, 18 specific technologies were identified and forecasted. The process involved the distribution of a questionnaire to 24 experts in the field of silviculture re-establishment in plantation forestry. The technology forecasting span over six months and involved three rounds of response analysis and recirculating the questionnaire amongst the experts. Statistical analyses were conducted on the data to determine central tendencies (mode) and percentage change in predictions between Delphi 1 and Delphi 3 iterations.

The Delphi findings indicate that by “2025” there is a high chance that machine specific technologies such as multi-functional machines, advance machine terrain handling enhancements, drones and machine self-diagnosis and maintenance will reach 50% adoption whilst machine automation and robotics may reach 50% adoption about five years later. By “2025” material input technologies such as paper-based pots, optimised chemical applicators, Nano fertilisers and low emission engines will likely reach 50% adoption. The adoption rates of these technologies will be influenced by the availability of infrastructure, social and

environmental pressures as well as legislation imposed by various external stakeholders. Furthermore, the Delphi revealed that the adoption of operator specific technologies is ongoing and progressive. The experts concluded that the adoption of ergonomically friendly cabs had occurred in “2018” and in “2025” the widespread adoption of simulation training and machine learning technologies can be expected. The Delphi results further indicated that by “2025” real time monitoring of operations, stands and operators as well as big data processing technology will reach 50% adoption. Despite several potential future technologies identified in this study, advance human interface technology and remote control technologies were identified as highly unlikely to be adopted in the future. Although one study is insufficient to completely reorient the industry as a whole, this study has exposed key new relevant technologies that forest owners need to be aware of when they plan for the future.

Keywords: Re-establishment, technology, silviculture, forecast

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

MEASURING LOG PILES WITH PHOTO-OPTICAL MONO CAMERA SYSTEMS

Hans-Ulrich Dietz
Kuratorium fuer Waldarbeit und Forsttechnik (KWF); Gross-Umstadt, Germany
hans-ulrich.dietz@kwf-online.de

Abstract: *Determination of the stacked volume of log piles at forest roadside is decisive for further logistics processes in Germany. Manual measuring of log piles is time consuming and precision of volume determination is dissatisfying. Recently the use of mono camera systems on smartphone or tablet devices therefore has been on the rise. According to German regulations measuring devices and their legal use have to be certified by conformity assessment. Reliability and validity of log pile measuring by mono camera systems have to be identified and major factors that might affect accuracy have to be revealed.*

In order to obtain information on the predictable accuracy of these new measurement systems, most common products currently are tested in a round robin test and compared with a reference value. Additionally the log piles will be rechecked by Dralle/AB's stereo camera as a benchmark system. The baseline for the experimental set-up to determine the measurement accuracy has been the draft requirements of the PTB (the National Metrology Institute of Germany) for photo-optical measuring devices for the designation of front areas on log piles. Trial scope, evaluation and results of this test procedure will be presented.

S15 Standards, conversion, measurement
Speak the same language

EUROPEAN STANDARD FOR ROUND AND SAWN TIMBER (METHOD OF MEASUREMENT OF DIMENSIONS) – INFLUENCE ON VOLUME LOSSES

Andreja Đuka [1], Tomislav Poršinsky [2], Tibor Pentek [3], Mirna Sertić [2], Dinko Vusić [1]
[1] Faculty of Forestry University of Zagreb; [2] Croatian Forests Ltd. Zagreb

ELEKTRO WZ – ELECTRONIC CONVERSION FACTORS FOR VOLUME CALCULATION OF STACKED SAWMILL TIMBER

Piotr S. Mederski [1], Krzysztof Rosiński [2], Martyna Rosińska [1], Zbigniew Karaszewski [3], Mariusz Bembenek [1]
[1] Poznań University of Life Sciences, Poland; [2] individual IT contribution, Poland; [3] Wood Technology Institute, Poznań, Poland

DEVELOPMENT AND VALIDATION OF A MEASUREMENT SYSTEM USED TO CALCULATE THE DEBARKING PERCENTAGES OF PROCESSED LOGS

Joachim B. Heppelmann [1,2], Eric R. Labelle [1], Thomas Seifert [3], Stefan Seifert [3], Stefan Wittkopf [2]
[1] Assistant Professorship of Forest Operations, Department of Ecology and Ecosystem Management, Technical University of Munich, Hans-Carl-von-Carlowitz-Platz 2, D-85354 Freising, Germany [2] University of Applied Science Weihenstephan-Triesdorf, Hans-Carl-von-Carlowitz-Platz 3, D-85354 Freising, Germany [3] Scientes Mondium, Ruppertskirchen 5, D-85250 Altomünster, Germany

A PROPOSAL OF NEW FORMULATION ON INVESTMENT AND ACHIEVED COST OR ENVIRONMENTAL LOAD REDUCTION: TRIAL APPLICATIONS ON LOGGING RESIDUE TRANSPORTATION AND INFRASTRUCTURE DEVELOPMENT FOR BROAD-LEAVED TREE HARVESTING

Yasushi Suzuki [1], Tetsuhiko Yoshimura [2]
[1] Faculty of Agriculture and Marine Science, Kochi University, Japan; [2] Faculty of Life and Environmental Science, Shimane University, Japan

GLOBAL SENSITIVITY ANALYSIS OF INTEGRATED HARVESTING COST UNDER VARIOUS STAND CONDITIONS AND MACHINE ATTRIBUTES

Libin T Louis, Anil Raj Kizha, Adam Daigneault
School of Forest Resources University of Maine Orono 5755 Nutting Hall, Orono, Maine, United States

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

EUROPEAN STANDARD FOR ROUND AND SAWN TIMBER (METHOD OF MEASUREMENT OF DIMENSIONS) – INFLUENCE ON VOLUME LOSSES

Andreja Đuka[1], Mirna Sertić[2], Tibor Pentek[1], Dinko Vusić[1], Tomislav Poršinsky[1]
[1] Department of Forest Engineering
Faculty of Forestry University of Zagreb
Svetošimunska 25, 10000 Zagreb, Croatia
aduka@sumfak.hr
[2] Croatian forests Ltd.
Forest Administration Office Karlovac

Abstract: *This paper presents the research of volume losses of processed sessile oak (Quercus petraea (Matt.) Liebl.) butt-logs concerning the use of four different equations for assessment of timber volume. Log volumes were analysed and compared considering Huber's, Smalian's, Riecke-Newton's equation and Centroid sampling as opposed to the volume determined by the sectioning method. The test sample involved 225 butt-logs of sessile oak with the mean diameter ranging between 25 and 70 cm, i.e. 25 pieces in 5 cm diameter classes. The research included: 1) accuracy (and suitability) of the equations for the assessment of butt-log volume, 2) amount and structure of volume loss due to the prescribed method of measuring diameter and length of butt-logs considering EN 1309-2:2006 (E) standard and 3) analysis of volume loss due to undercuts, indicating that measuring butt-logs length from half of the undercut's height is questionable. Smalian's equation overlapped the average gained by the sectioning method by 13.2%, the Centroid sampling was down by 3.8%, Huber's equation downgraded by 6.6%, and Riecke-Newton's equation did not show any deviation from the sectioning method. There was a statistically significant difference between these volume measurement methods.*

Keywords: sessile oak, volume equations, butt-log, diameter rounding, length rounding, EN 1309-2:2006 (E)

1. Introduction

There are many different round wood measurement and volume calculation rules in Europe based on historical influences and traditions. Much sawmilling and forestry data are based on these differing rules. European standards relating to dimensions of round timber date from 27 February 1997 (date of ratification) and were superseded by several others. Today's valid standard for round wood measurement is the EN 1309-2:2006 standard (Round and sawn timber – Method of measurement of dimensions – Part 2: Round timber – Requirements for measurement and volume calculation rules). This standard gives basic principles, which are to be followed when drawing up round wood measurement and volume calculation rules. This standard applies to the rules for measuring hardwood and softwood felled round timber. It does not apply to tropical timber (https://standards.cen.eu, 2019).

In Croatia depending on the method of timber processing usually, tree length or cut-to-length (Fig. 1), scaling of timber is performed either in the stand (cut-to-length method, chainsaw + forwarder) or on the roadside landing site (tree length, half-tree length, chainsaw + skidder). Timber scaling is also regulated by several regulations (by-laws) and standards that prescribe exact information of each produced log: tree species, length, middle diameter, log volume, place (origin) of scaling and person responsible for timber scaling which is in accordance with the EU Timber Regulation i.e. Forest Law Enforcement, Governance and Trade (FLEGT) Action Plan.

As much as 60–85% of the cost of producing wood products can be in the purchase of logs, so it is essential to fully understand the variables of the unit of measure used and to control its consistency and accuracy (Fonseca 2005). According to Čavlović (2010) share of oak (both sessile and pedunculate) is at 23.03%, and they together comprise to 108.75 million m^3 and they present, in economic terms, the most valuable tree species in Croatia.



Figure 1 Timber scaling

In theory, log volume is determined according to its similarity to a geometric 3D shape (Fig. 2) for example cylinder, paraboloid, cone, neiloid that is dependent on tree species (broadleaved or conifers), part of stem, age and management type (Patterson et al. 1993, Husch et al. 2003).

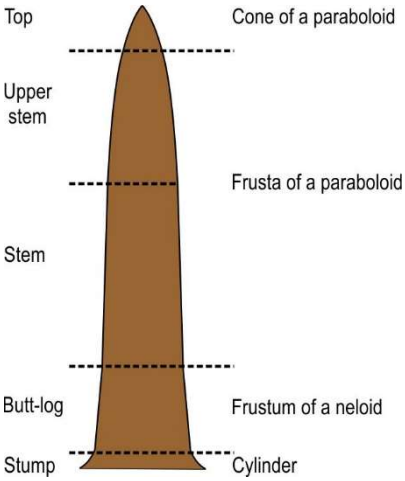


Figure 2 Stem parts with recommended geometrical 3D shapes for volume assessment (Husch et al. 2003)

Given the same basic inputs (diameter, length and wood defects) are used in different scaling methods, one would assume that there is a good level of uniformity and harmonisation of methods; unfortunately, this is not often the case (Fonseca 2005). Most commonly used equations for volume determination are (Fonseca 2005, Sertić 2012):

⇒ Huber's $v = g_s * L = \frac{d^2 * \pi * L}{4}$ (1)

⇒ Smalian's $v = \frac{(G+g)}{2} * L$ (2)

⇒ Riecke-Newton's $v = \frac{L}{6} * (G + 4 * g_s + g)$ (3)

⇒ Bruce's $v = (0{,}25 * G + 0{,}75 * g) * L$ (4)

⇒ Hosfeld's $v = \left(\frac{3 \cdot G_{1/3} + g}{4}\right) L$ (5)

$\Rightarrow$ Centroid sampling $\quad v = g * L + \frac{b_1}{2} * L^2 + \frac{b_2}{3} * L^3 \quad b_1 = \frac{G-g-b_2*L^2}{L}$

$$b_2 = \frac{G-g_c*\frac{L}{e}-g*\left(1-\frac{L}{e}\right)}{L^2-L*e} \qquad e = L - \left[\left[\frac{\sqrt{\left(\frac{D}{d}\right)^4+1}-\sqrt{2}}{\sqrt{2}*\left[\left(\frac{D}{d}\right)^2-1\right]}\right]*L\right] \qquad (6)$$

Where:
v – Volume, m^3
L – Length, m
D – Diameter at large end of log, cm
d – Diameter at small end of log, cm
G – Cross-sectional area at large end of log, m^2
g_s – Cross-sectional area at mid-end of log, m^2
g – Cross-sectional area at small end of log, m^2
$G_{1/3}$ – Cross-sectional area at 1/3 of log length from the large end of the log, m^2
g_c – Cross-sectional area at mid volume of log (m^2) measured at a distance e from the large end of log.

Determination of the volume, according to EN 1309-2:2006 (E) standard is by using Huber's equation. Huber's equation assumes that solid shape of the main bole of a tree or sub-sections of it are frusta of second-degree paraboloids. For forms less than second-degree paraboloid (conoid, neiloid), the negative bias would be expected (Wood and Wiant 1990). On the other hand, many authors (Wood and Wiant 1990, Wood et al. 1990, Wiant et al. 1991, Wiant et al. 1992, Patterson et al. 1993) reported that centroid sampling is applicable to mature tree species of both excurrent (confiers) and deliquescent (broadleaved) habit. Centroid sampling, a variant of importance sampling (Gregoire et al. 1986) developed by Wood, Wiant, Loy and Miles in 1990 is more costly than Huber's or Smalian's because it requires three diameter measurements – one at each end and one at the centre of volume (centroid), but is no more costly than Riecke-Newton's, Hosfeld's (Yavuz 1998) or Bruce's volume determination.

2. Materials and Methods

European standard EN 1309-2:2006 (E) defines measurements of length, diameter (over bark), weight (round wood and stacks) and calculation of volume (round wood and stacks).
It prescribes the measure of the shortest length (accuracy of at least one centimetre), as the distance between two parallel planes, one at each end of round wood where the full cross section is enclosed and perpendicular to the longitudinal axis. Timber with an undercut or butt trimming should be measured from the middle of the undercut or the butt trimming surface. The length is expressed in meters to one place of decimal rounded down. If nominal length is required the length shall be rounded down to the nearest nominal length.
The diameter should be measured at mid-length to an accuracy of at least one centimetre. The diameter under bark should be measured. In case of over bark measure, conversion to a diameter under bark is necessary. Measurements of diameter, expressed in centimetres, are rounded down to the nearest centimetre. The arithmetic mean of two measurements is calculated and expressed in centimetres, rounded to the nearest centimetre according to the arithmetical rounding rule.
Volume is calculated by Huber's equation and expressed in cubic meters to two or three places of decimal. Ludolf's number (π) is rounded to four places of decimal (3.1416).
Butt-log is the portion of a felled tree from the butt to the first bucking cut. It is of largest diameter in comparison to subsequent logs, in broadleaved species usually with expressed butt swelling and consecutive taper. The research was conducted on 225 butt-logs of sessile oak (*Quercus petraea* (Matt.) Liebl.) ranging in diameter classes from 27.5 cm to 67.5 cm in Forest Administration Office (FAO) Karlovac in the central part of Croatia. The research was conducted in even-aged forests on the area of 179.77 ha with a rotation period of 120 years in eight different sub-compartments. The most common tree species in this FAO is European beech (*Fagus sylvatica* L.) at 50%, follow sessile oak at 13% and pedunculate oak (*Quercus robur* (Matt.) Liebl.) at 12%, the share of conifers is at 7%.
On each butt-log, the following characteristics were measured:

1. Log length (*L*), expressed in metres and two places of decimal. Length was measured with a Stihl forest measuring tape.

2. Two diameters over bark at small end (d_1, d_2), large end (D_1, D_2), mid-length (d_{s1}, d_{s2}), at the centre of volume (centroid) and on mid-length of each log section ($d_{25\text{-}1}$, $d_{25\text{-}2}$…), expressed in centimetres and one place of decimal. Diameters were measured with a digital calliper Haglöf Sweden AB Digitech Professional.

For estimating log volume, four equations were used: Huber's (1), Smailan's (2), Riecke-Newton's (3) and Centroid sampling (6).

Control group was defined with a sectioning method, where each butt-log was divided into sections of 50 cm length where two diameters were measured at mid-length. Volume was then calculated by Huber's (1) equation.

Statistical analysis was done in Statistica 13.4.0.14 software and figures were edited in CorelDRAW X7 programme package.

3. Results

3.1 Butt-log length measurements

Minimal length of butt-logs was at 2.11 m and maximal at 7.98 m. The median value was at 4.02 m, which is in accordance with previous research (Stankić 2010).

Figure 3 shows that with the growth of mid diameter, butt-log length increased. The exceptions are diameter classes 62.5 cm and 67.5 cm, which were from older forest stands (age 115 to 140 years) with many wood defects (ring shake, heart shake, rot) and butt-logs were bucked and cut to shorter lengths so that second logs could be classified in higher assortment classes. Maximal lengths were 6 and 8 m due to forest truck and trailer loading area length respectively. One-way ANOVA showed a statistically significant difference in some diameter classes ($F = 6.9$, $df = 8$, $p < 0.001$) and Tukey post-hoc test confirmed that the biggest differences were in diameter classes 32.5 cm and 57.5 cm.

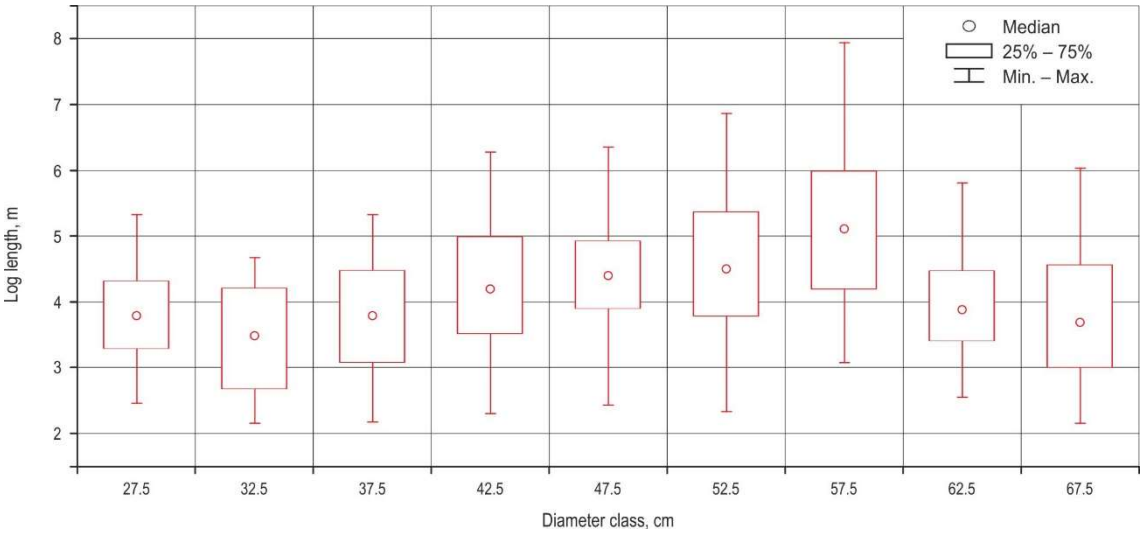


Figure 3 Box-whisker of butt-log length values in all diameter classes

Taper of processed butt-logs ranged from 0.0 to 2.5 cm/m, with median value for all 255 logs at 0.9 cm/m. mild increase is evident from smaller to larger diameter classes i.e. 0.7 cm/m at 27.5 cm diameter class to 1.3 cm/m at 62.5 cm diameter class. In diameter class 67.5 cm, the median value of taper was at 0.8 cm/m due to the interaction of diameter and lengths of butt-logs.

3.2 Losses due to used equations for volume

Comparing volume values according to different equations and the sectioning method (Fig. 4) shows:

- ⇒ Huber's equation gives the lowest negative values (average -6.0% ± 3.6 standard deviation, median at -6.0%),
- ⇒ Smailan's equation gives the highest positive values (average 13.2% ± 5.9 standard deviation, median at 11.8%),

⇒ Centroid sampling equation gives slightly higher values (average 3.8% ± 3.1 standard deviation, median at 3.3%)

⇒ Riecke-Newton's equation is the most accurate (average 0.0% ± 2.1 standard deviation, median at -0.0%) in comparison to the sectioning method.

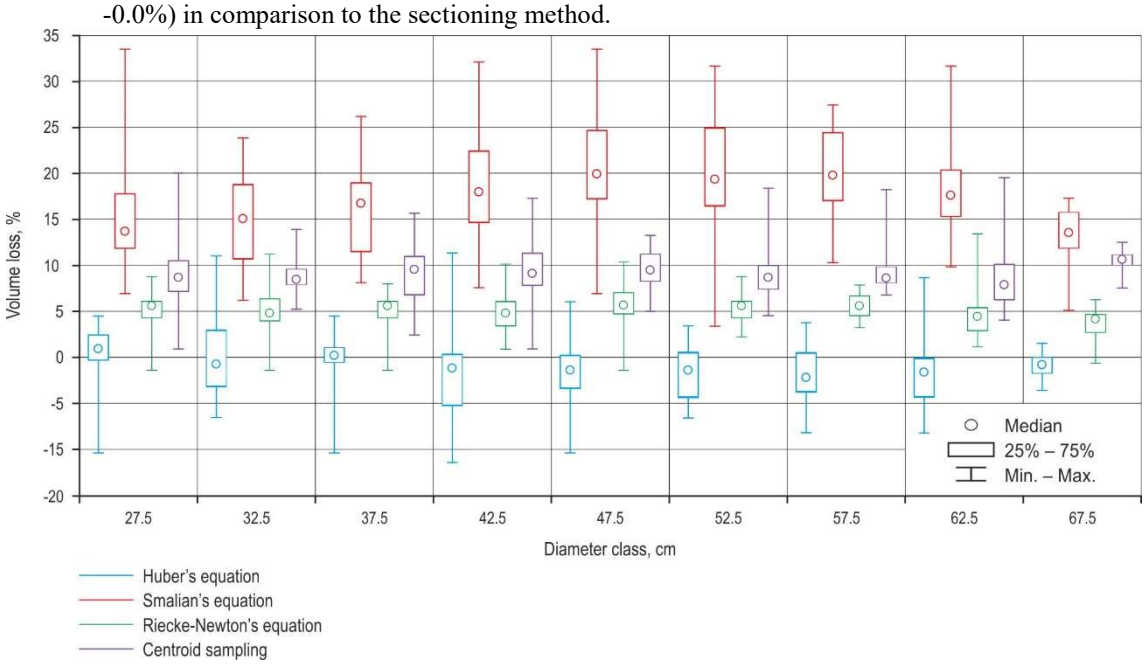


Figure 4 Distinction in volume of butt-logs according to different equations

The discrepancy in gross volume of 225 processed sessile oak butt-logs from volume gained by the sectioning method is shown in figure 5. A strong relationship between dependent and independent variable ($R^2 > 0.99$) is evident. Root mean square error (RMSE) varied from 0.01 to 0.15, again being the most favourable in Riecke-Newton's equation. Repeated variance analysis showed statistically significant difference ($F = 339.86$, $df = 4$, $p < 0.001$) between several volume equations. Tukey post-hoc test showed that there was no difference between Riecke-Newton's equation and sectioning method in volume of 225 oak butt-logs, while all other volume equations were significantly different.

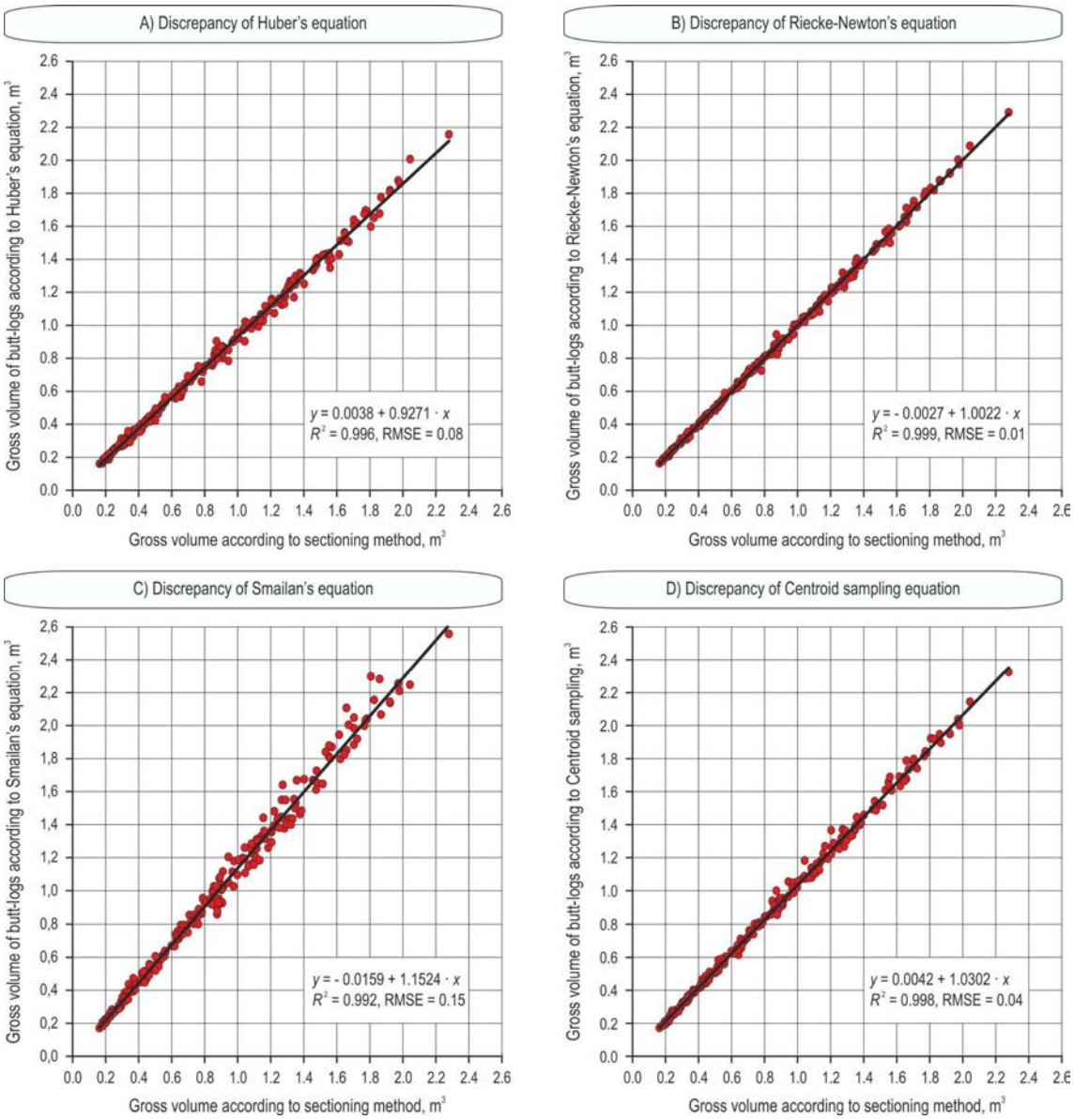


Figure 5 Discrepancy in gross volume of 225 processed sessile oak butt-logs

3.3 Volume losses due to the prescribed diameter measurements

Measurements of diameter according to EN 1309-2:2006 (E) are rounded down to the nearest centimetre that also showed its influence on volume losses:

- ⇒ In Huber's equation loss in volume ranges from -5.1% in diameter class 27.5 cm to -2.0% in diameter class 67.5 cm i.e. -2.9% ± 1.3% and with median value at -2.6% for the entire measuring sample.
- ⇒ In Smailan's equation loss in volume ranges from -4.2% in diameter class 27.5 cm to -1.7% in diameter class 67.5 cm i.e. -2.6% ± 1.3% and with median value at -2.3% for the entire measuring sample.
- ⇒ In Riecke-Newton's equation loss in volume ranges from -4.6% in diameter class 27.5 cm to -1.8% in diameter class 67.5 cm i.e. -2.8% ± 1.4% and with median value at -2.7% for the entire measuring sample.
- ⇒ In Centroid sampling loss in volume ranges from -3.8% in diameter class 27.5 cm to -1.9% in diameter class 67.5 cm i.e. -2.9% ± 1.2% and with median value at -2.9% for the entire measuring sample.

Repeated ANOVA analysis showed a significant difference between volume losses due to the prescribed diameter measurements ($F = 6.2$, $df = 3$, $p < 0.001$).

3.4 Volume losses due to the prescribed length measurements

Measurements of the length according to EN 1309-2:2006 (E) of timber with an undercut or butt trimming should be measured from the middle of the undercut or the butt trimming surface. The length is expressed in meters to one place of decimal rounded down. Losses due to prescribed length measurements are classified into three categories:

- ⇒ Length loss due to the measurement from the middle of the undercut or the butt trimming surface for the entire sampling group was 4.8 ± 2.9 cm, with median value at 4.0 cm and mod value at 3.0 cm.
- ⇒ Length loss due to decimal round down for the entire sampling group was 4.6 ± 2.9 cm, with median value at 5.0 cm and mod value at 6.0 cm.
- ⇒ Length loss due to prescribed length measurement of butt-logs for the entire sampling group was 9.4 ± 3.9 cm, with median value at 9.0 cm and mod value at 9.0 cm.

The average loss in volume due to the prescribed measurement of butt-log length for the entire sample was the highest at Centroid sampling at -2.6 ± 1.4%, median at -2.7% and for the other three methods was -2.3 ± 1.2%, median at 2.3%.

4. Discussion

In most cases, butt-log is the most valuable log of a felled tree (when minimal dimensions define assortment classes) which usually corresponds to "A" class of European standards or as it in Croatian case I or II class of veneer (according to national standards still in use). On Croatian timber market, pedunculate oak and sessile oak I and II classes of veneer together account to 42.48% of all veneer assortments together. According to timber products' price list of the national company (www.hrsume.hr) which manages over 80% of national forests (Franjević et al. 2016), I. class veneer logs of pedunculate and sessile oak are 3.15 times more costly than European beech (the most common tree species in Croatia), 1.52 time more costly than narrow-leaved ash and other ash species (*Fraxinus angustifolia* L. and other) and 4.33 time more costly than hornbeam (*Carpinus betulus* L.).

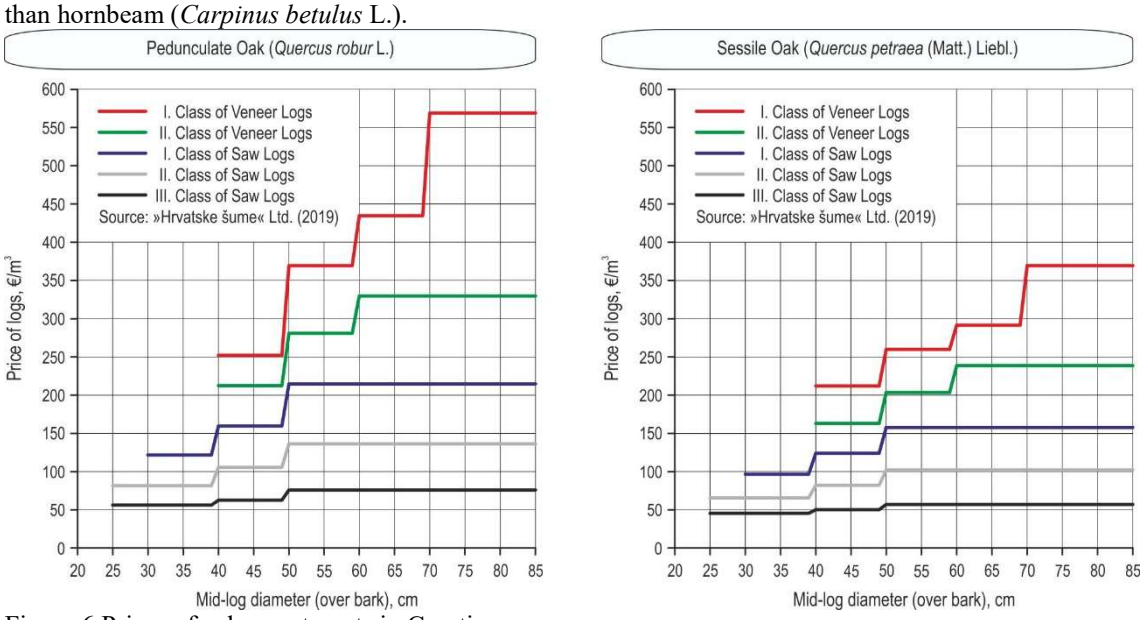


Figure 6 Prices of oak assortments in Croatia

In 2007 Poršinsky and Vujeva wrote about volume losses in European spruce (*Picea abies* (L.) Karsten) due to the prescribed method of diameter and length measurements, Huber's equation and bark deductions. The authors expressed their hope that the Croatian Standards Institute will revise new European standards for Round and sawn timber – Method of measurement of dimensions in their application in Croatian forestry, but unfortunately, until today this has not happened. Nevertheless, it should be mentioned that even currently used national standards contain the same principles regarding methods of measurements with one exception. According to Croatian national standards, diameter measurements are expressed in

centimetres, rounded down to the nearest centimetre, and their arithmetic mean of two measurements is also rounded down to the nearest centimetre – which leads to even more volume losses.
Even though some authors argue that Centroid sampling is a useful and more accurate alternative to other standard volume equations (Wood and Wiant 1990, Wood at al. 190, Wiant et al. 1991, Wiant et al. 1992, Yavuz 1998), this research indicated that Riecke-Newtons' equation is the most precise in terms of oak butt-logs of approximately 4 m length. When comparing volume values according to different equations and sectioning method (length of each section was 50 cm) Riecke-Newton's equation showed to be the most accurate (average 0.0% ± 2.1 standard deviation, median at -0.0%) in comparison to the sectioning method with $R^2 = 0.998$. The reason why Riecke-Newton's proved to be better in this research is probably in the average length of oak butt-logs (4.02 m) as oppose to logs in research of Wood and Wiant (1990), Wood et al. (1990), Wiant et al. (1991), Wiant et al. (1992), Yavuz (1998) where average log length was 6 meters and more.
One might argue that these losses are minimal and should be ignored, for what is 9.4 ± 3.9 cm of length losses in butt-log measurements, -2.9 ±1.3% volume losses due to diameter measurements or -0.3% to -16.9% volume losses due to the use of Huber's equation. However, if we take into account the law of large numbers, the probability of butt-logs to be the most valuable logs of the tree and the most important commercial species, if not all, these "small" losses in diameter, length and volume gain in significance.

5. Acknowledgements

This research was an integral part of the research conducted by Mirna Serić, MSc. in the national company Hrvatske šume Ltd. during her postgraduate master study at the Faculty of Forestry University of Zagreb, and under the mentorship of prof. Tomislav Poršinsky.

6. References

Čavlović, J., (2010), "The first national forest inventory in the Republic of Croatia", Ministry of regional development, forestry and water management, ISBN 978-953-292-016-1, 296 p.

EN 1309-2:2006 (E) Round and sawn timber – Method of measurement of dimensions – Part 2: Round timber – Requirements for measurement and volume calculation rules, Croatian Standards Institute, 13 p.

Fonseca, M. A., (2005), "The Measurement of Roundwood: Methodologies and Conversion Ratios", CABI Publishing, 1-26.

Franjević, M., Poršinsky, T. and Đuka, A., (2016): "Integrated oak timber protection from ambrosia bark beetles: Economic and ecological importance in harvesting operations", Croatian Journal of Forest Engineering, 37(2), 353-364.

Gregoire, T. G., Valentine, H. T, Furnival, G. M., (1986), "Estimation of bole volume by importance sampling", Canadian Journal of Forest Research, 16, 554-557.

https://standards.cen.eu, 2019

Husch, B., Beers, T.W., Kershaw, J.A.Jr., (2003), "Forest Mensuration", Fourth Edition. John Wiley & Sons, Inc., Hoboken, New Yersey: 1-125.

Patterson, D. W., Wiant, H. V. Jr., G. B. Wood, (1993a), "Comparison of the centroid method and taper systems for estimating tree volumes", North. J. Appl. For., 10(1), 8-9.

Patterson, D. W., Wiant, H. V. Jr., Wood, G. B., (1993b), "Log volume estimations-the centroid method and standard formulas", J. For, 91(8), 39-41.

Poršinsky, T., and J. Vujeva, (2007), "Volume losses of processed spruce roundwood due to prescribed method of scaling", Nova meh. šumar., 28, 37-47.

Sertić, M., (2012), "Volume Losses of Processed Sessile Oak But-logs due to Prescribed Method of Scaling", Master thesis, Faculty of Forestry University of Zagreb, 1-107.

Stankić, I., (2010), “Multi-criterial planning of timber forwarding in Croatian lowland forests”, Dissertation, Faculty of Forestry University of Zagreb, 1-123.

Wiant, H. V., G. B. Wood, and G. M. Furnival (1992), “Estimating log volume using the centroid position”, Forest Science, 38(1), 187-191.

Wiant, H. V., G. B. Wood, and R. R. Forslund, (1991), “Comparison of Centroid and paracone estimates of tree volume”, Canadian Journal of Forest Research, 21, 714-717.

Wood, G. B., and H. V. Wiant, (1990), “Estimating the volume of Australian hardwoods using Centroid Sampling”, Australian Journal of Forestry 53, 271-274.

Wood, G. B., H. B. Wiant, R. J. Roy, and J. A. Miles, (1990), “Centroid Sampling: a variant of Importance Sampling for estimating the volume of sample trees of radiata pine”, Forest Ecology and Management, 36, 233-243.

www.hrsume.hr

Yavuz, H., (1999), “Comparison of the Centroid Method and Four Standard Formulas for Estimating Log Volumes”, Tr. J. of Agriculture and Forestry, 23, 597-662.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

ELEKTRO WZ – ELECTRONIC CONVERSION FACTORS FOR VOLUME CALCULATION OF STACKED SAWMILL TIMBER

Piotr S. Mederski [1], Krzysztof Rosiński [2], Martyna Rosińska [1], Zbigniew Karaszewski [3], Mariusz Bembenek [1]
[1] Poznań University of Life Sciences, Poland; [2] Individual IT contribution, Poland; [3] Wood Technology Institute, Poznań, Poland
piotr.mederski@up.poznan.pl

Abstract: *Calculation of the volume of stacked round timber requires the measurement of stack dimensions: the length, width, and height, as well as the use of a conversion factor (CF). CF use is necessary in order to obtain the cubic metres (m3) of solid wood without bark and air in the stack.*
Another way of calculating volume is to measure the top log diameter and the log's length. Based on these measurements, and with use of a formula, the log volume is obtained, ie. the sum of all the logs in the stack giving the total volume, m3, under bark. This method is precise, however very time consuming.

The value of the CF mainly depends on tree species, and in general, is bigger when there is/are:
1) wood with larger diameters in the stack,
2) thinner bark,
3) dense stacking,
4) little crookedness,
5) accurate delimbing.

The value of the CF can also depend on tapering, snow and ice between the logs, logging waste (debris) in the stack and the height of the stack.

Taking into consideration the above-mentioned parameters, the use of a standard CF for particular timber assortment may not be accurate enough. Therefore, for each timber stack, an individual CF should be used.

The aim of this project was to develop a new application, Elektro WZ, which can be downloaded on a smartphone and used in the forest for a quick evaluation of the CF for each individual stack. The application was built for the android system (Google Tango platform). The CF calculation is based on a picture of the front of the stack showing the top surfaces of the logs. The individual CF is calculated as the sum of the top logs' surface areas divided by the area within the picture frame.

The Elektro WZ application was developed in the spring of 2018 within the Elektro project financed by the State Forests in Poland. In that time this product was probably the earliest development of individual CFs calculated by an electronic device.

The widespread use of Elektro WZ should, in the future, improve the accuracy of stacked timber volume calculation.in format is a desired attribute for papers included in the Proceedings of this conference. This paper is written in the recommended format. It outlines the required page length, spacing, margins, font sizes, headings, references, quotations and other aspects that lead to an appealing visual image.

FORMEC 2019 – Exceeding the Vision: Forest Mechanization of the Future

October 06th -10th, 2018. Hungary | Austria, Sopron | Forchtenstein

DEVELOPMENT AND VALIDATION OF A MEASUREMENT SYSTEM USED TO CALCULATE THE DEBARKING PERCENTAGES OF PROCESSED LOGS

Joachim B. Heppelmann[1,2], Eric R. Labelle[1], Thomas Seifert[3], Stefan Seifert[3], Stefan Wittkopf[2]

[1]Assistant Professorship of Forest Operations
Department of Ecology and Ecosystem Management
Technical University of Munich
Hans-Carl-von-Carlowitz-Platz 2
D-85354 Freising
Germany

[2]University of Applied Science Weihenstephan-Triesdorf
Hans-Carl-von-Carlowitz-Platz 3
D-85354 Freising
Germany

[3]Scientes Mondium
Ruppertskirchen 5
D-85250 Altomünster
Germany

joachim.heppelmann@hswt.de

Within an associated research project, the applicability and performance of modified harvesting heads during the debarking of coniferous species was investigated, in order to evaluate the actual debarking percentage of processed logs. As the monitoring and measurement campaigns needed to be imbedded within economic and productive harvesting operations, off-site measurement systems (Laser-, X-Ray-, CT – based, etc.) were not suitable. Therefore, a computer-based photo-optical measurement system designed to assess debarking percentage was developed and offered the ability of processing large amounts of data within a relatively short period of time. During live field operations, processed logs from a modified debarking head were transported and placed on the forest road where a single picture per log was taken with a reflex camera. The length and diameter of each log was also manually measured. With the single log pictures as input, the photo-optical system calculated the overall debarking percentage by further estimating the un-displayed part of the log surface. For the debarking measurements, polygons were defined representing the different shares of the log surface (wood, outer-bark, inner-bark, covered, not measureable). Those polygons were measured and translated to the log surface. By calculating average debarking percentages of multiple log surfaces, a precise average debarking result was obtained.

Within the project, the system was used to evaluate the debarking results on 1720 single coniferous logs. However, to test the precision of the developed measurement system, laboratory tests with a defined artificial log and defined presented surface shares (75% wood and 25% bark) were carried out on an additional 480 log measurements. The standard deviation was calculated for multiple average debarking percentages based on increasing sample sizes (n=12, n=24; n=48, n=96). For all tested sample sizes, the standard deviations of average debarking percentages remained within a 4% variation. By increasing the sample size, the standard deviation was lowered resulting in a standard deviation less than 1% for n=96.

The results also indicated a conservative calculated debarking percentages within the project were for summertime, underestimating the achieved debarking percentages by 1.25%. Thus, laboratory tests approved the validity and robustness of the 1,720 gathered field data and calculated debarking percentages.

Keywords: debarking, debarking percent, debarking harvesting heads, photo optical measurement, European forestry

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

A PROPOSAL OF NEW FORMULATION ON INVESTMENT AND ACHIEVED COST OR ENVIRONMENTAL LOAD REDUCTION: TRIAL APPLICATIONS ON LOGGING RESIDUE TRANSPORTATION AND INFRASTRUCTURE DEVELOPMENT FOR BROAD-LEAVED TREE HARVESTING

Yasushi Suzuki
Faculty of Agriculture and Marine Science
Kochi University
B200 Monobe, Nankoku, Kochi 783-8502, Japan
ysuzuki@kochi-u.ac.jp

Tetsuhiko Yoshimura
Faculty of Life and Environmental Science
Shimane University
1060 Nishikawatsu, Matsue, Shimane 690-8504, Japan
t_yoshimura@life.shimane-u.ac.jp

Abstract: *We propose a simple formulation on investment and achieved improvement with regard to unit amount of work. Two trial approach is presented. The first one tried to formulate the relationship between unit cost or environmental load such as CO_2 emissions and energy consumption per amount of logging residue and transportation distance. Generally larger scale transportation modes have an advantage over smaller scale transportation modes. The mode transfer from smaller scale to larger scale can be accomplished with an investment such as a setting of intermediate landing. In a case study, four transportation modes were considered, i.e., light truck, 2t truck, 4t truck and 10t truck, with a loading by a grapple loader at a landing. Results showed that the smallest mode (light truck) should be transferred to larger scale modes less than 2 km while middle scale mode still has similar advantage as the largest mode till around 10 km of transportation distance. The obtained formulation is then applied to the second trial, which is on infrastructure development, i.e., improvement and/or construction of forest road network, and broad-leaved tree harvesting. Three mode of extraction was set: manual, winching, and simple cable system. The levels of infrastructure development were assumed as two: one with 2.5 m width road network for small-scaled system for mini-forwarders and 0.25 m^3 bucket-size class excavator-based machines, and the other with 3.0 m width road network for 0.45 m^3 bucket-size class excavator-based machines. In this case, investment is construction of forest road network and unit of work is evaluated with logged tree volume per ha. An application of the formulation suggested appropriate thresholds between the proposed systems.*

Keywords: broad-leaved tree, logging residue, modal selection threshold, transportation, woody biomass

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

GLOBAL SENSITIVITY ANALYSIS OF INTEGRATED HARVESTING COST UNDER VARIOUS STAND CONDITIONS AND MACHINE ATTRIBUTES

Libin T Louis, Anil Raj Kizha, Adam Daigneault
School of Forest Resources University of Maine Orono 5755 Nutting Hall, Orono, Maine, United States
libin.thaikkattil@maine.edu

Abstract: *Harvest operations is one of the most expensive and crucial parts of forest management. The cost of operational phases within an integrated harvesting system can vary depending on several stand characteristics and machine attributes. Moreover, these factors typically drive the choice of machinery to be employed. The main objective of this study was to identify the impacts of key factors that influence the operating costs in different harvesting phases. The data was gathered from selected scientific studies conducted in Europe and North America from the past 30 years. A total of ten studies and a minimum of fifteen observations were utilized to generate regression models on major forest machineries including feller-buncher, skidder, processor, slasher, and loader. This study attempts to review and analyze factors affecting the cost of harvesting machines utilizing global sensitivity analysis with Monte Carlo simulation and estimation of Sobol's first order and total indices. Stand parameters such as density (trees ha-1), age (years), height (m), diameter at breast height (DBH) (cm), harvest area (ha) were considered independent variables. Additionally, analysis was conducted to understand the impacts on costs from machine attributes including purchase prices (US$), salvage values, economic life (years), utilization rate (%), and fuel cost ($/l). The cost of all machines were discounted to present value. Preliminary results show DBH as the most influencing factor impacting the felling cost amongst stand characteristics. Stand age was also found to have a significant but relatively less effect on harvest costs. Among the machine attributes, economic life and purchase price were the most significant factors but had minimal impact on the overall harvesting cost. The results from the study are expected to provide stakeholders with robust techniques to estimate harvest costs across a broad range of stand and site characteristics, thereby developing a management tool for better decision-making and higher financial returns.*

S16 Machine-Soil-Interaction
Digging up the dirt

HOW DOES SOIL COMPACTION INFLUENCE THE GROWTH OF SPRUCE SEEDLINGS?
Eric R. Labelle, Max Kammermeier
Assistant Professorship of Forest Operations, Department of Ecology and Ecosystem Management, Technical University of Munich, Germany

CONTAMINATION OF WOOD CHIPS WITH MINERAL SOILS – FUEL QUALITY AND COMBUSTION BEHAVIOUR
Carina Kuchler [1], Daniel Kuptz [1], Elisabeth Rist [1], Robert Mack [1], Claudia Schön [1], David Zimmermann [2], Elke Dietz [2], Markus Riebler [2], Uwe Blum [2], Herbert Borchert [2], Hans Hartmann [1]
[1] Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ), Schulgasse 18, D-94315 Straubing/ Germany, Tel.: (+49) 9421-300-121, Fax: (+49) 9421-300-211, E-Mail: carina.kuchler@tfz.bayern.de [2] Bavarian State Institute of Forestry (LWF), Hans-Carl-von-Carlowitz-Platz 1, D-85354 Freising/ Germany

NUTRIENT SAVING EFFECTS OF ROUGHLY DELIMBED ENERGY ROUNDWOOD IN COMPARISON TO BIOMASS SUPPLY OF WHOLE CONIFEROUS CROWNS CAUSED BY HARVESTING METHOD AND BUCKING
Elke Dietz, Markus Riebler, Herbert Borchert
Bavarian State Institute of Forestry, Freising, Germany

SOIL FAILURES UNDER TRACKED FORESTRY MACHINES AS A FUNCTION OF SLOPE AND SOIL WETNESS
D H McNabb
ForestSoil Science Ltd. Edmonton, Alberta Canada

MECHANIZED PRE-COMMERCIAL THINNING BY UPROOTING
Karri Uotila
Natural Resource Institute Finland, Kuopio, Finland

GROUND-BASED FOREST MACHINERY AND TACTICS IMPROVING WILDLAND FIRE SUPPRESSION OPERATIONS IN WESTERN NORTH AMERICA
Chris Bielecki [1], Obie O'Brien [2]
[1] Supervisory Civil Engineer, USDA Forest Service; [2] Logging Engineer and Owner of Forest Operations Engineering LLC. Retired Logging Engineer, USDA Forest Service.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

HOW DOES SOIL COMPACTION INFLUENCE THE GROWTH OF SPRUCE SEEDLINGS?

Eric R. Labelle, Max Kammermeier
Assistant Professorship of Forest Operations
TUM School of Life Sciences Weihenstephan
Technical University of Munich
Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany
eric.labelle@tum.de

Abstract: *Soil bulk density, commonly measured with soil cores and expressed in g/cm^3, has been the preferred method of quantifying the physical impacts on soils caused during mechanized harvesting. Due to inherent soil properties at the time of impact, extrapolating specific study results is difficult. To circumvent this problematic, the use of relative bulk density (RBD), where field bulk densities are divided by a maximum bulk density (obtained by the well-known standard Proctor test), is gaining popularity. RBD can be used as a qualitative measure of the level of compaction. Since the field bulk densities collected from the test sites are referenced to a standard, the results are normalized and can be compared between test sites. Furthermore, a RBD threshold of 0.80 or 80% of the maximum bulk density, has already been established as growth impeding for certain agricultural crops and seedlings of Douglas fir and sessile oak.*

Because of the economic importance of Norway spruce (Picea abies (L.) H. Karst), we assessed the impact of four RBD levels (0.67, 0.72, 0.77, and 0.82) on the above- and below-ground biomass response of Norway spruce seedlings. The experiment consisted of using a customized seedling growth-monitoring system comprised of 24 individual chambers (internal dimensions of 30.6 cm in length, 8.2 cm in width, and 42.0 cm in height for a total volume of 10.5 liters) each having one side constructed from 4 mm thick glass to allow the visualization of the root system. Soil collected from a forest stand near Freising, Germany, was used as testing substrate for the standard Proctor test and also within the chambers where the material was compacted to the respective RBD levels in three equal layers. The soil moisture and density relationship, expressed through the standard Proctor test, showed a maximum soil dry density of 1.611 g cm^{-3} (dry unit-weight of 15.80 kN m^{-3}) achieved at an optimum moisture content of 18.9%. From this maximum dry density, the following dry densities 1.08, 1.16, 1.27, and 1.32 g cm^{-3} were targeted for RBD levels of 0.67, 0.72, 0.77, and 0.82, respectively. Once compacted, five seeds of Norway spruce were sown in each chamber (total of 120 seeds) and growth was monitored for 156 days under controlled light and water conditions. Following the monitoring period, 102 seedlings were extracted and analyzed.

Statistically lower root (48%), shoot (43%), and needle (43%) mass per seedling for seedlings growing on the RBD 0.82 as compared to those growing on the RBD 0.67 were reported, thus indicating a clear trend of negative growth impact as soil compaction increases. In general, the two lowest RBD levels revealed no statistical differences, whereas statistical differences were observed as the RBD levels increased to 0.77 and 0.82. Given the importance of Norway spruce within the German forestry sector and the increased rate of mechanized forest operations, results from the study highlight the need for additional research into the complex machine/soil/plant interactions. This research also reiterates the need for controlled traffic through pre-defined machine operating trails, in order to limit the spatial extent of soils exposed to high RBD levels.

Keywords: root growth, soil compaction, soil health, standard Proctor test, sustainability

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

CONTAMINATION OF WOOD CHIPS WITH MINERAL SOILS – FUEL QUALITY AND COMBUSTION BEHAVIOUR

Carina Kuchler*[1], David Zimmermann[2], Dr. Daniel Kuptz[1], Dr. Elke Dietz[2], Elisabeth Rist[1], Markus Riebler[2], Claudia Schön[1], Robert Mack[1], Dr. Uwe Blum[2], Dr. Herbert Borchert[2], Dr. Hans Hartmann[1]

[1]Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ), Schulgasse 18, D-94315 Straubing, Germany,
Tel.: (+49) 9421-300-121, Fax: (+49) 9421-300-211,
carina.kuchler@tfz.bayern.de

[2]Bavarian State Institute of Forestry (LWF), Hans-Carl-von-Carlowitz-Platz 1, D-85354 Freising, Germany

Abstract: *Due to careless operation during fuel production, considerable shares of mineral soil might be added to wood chips leading to contamination of the biofuels. This can result in elevated gaseous and particle emissions, corrosion or slag formation during combustion. To investigate this effect, ten wood chip fuels were partly contaminated with mineral soil or were mechanically upgraded by screening or washing using forest residues of coniferous wood. Contamination was done using three typical forest soils in Bavaria (soil A to C). Total particulate matter (TPM) emissions increased for wood chips that were contaminated with soil A and C compared to the reference fuel, while the emissions for wood chips contaminated with soil B remained constant. For NO_X emissions, no clear trend was detected. CO and OGC emissions decreased for contaminated fuel assortments. Overall, the contamination of woody biomass had a noticeable effect on pollutant emissions and should be therefore avoided.*

Keywords: wood chips, fuel quality, contamination, combustion, emissions

1. Introduction

The contamination of woody biomass with mineral soil might have a substantial impact on the combustion behaviour of the fuels due to an unsuitable chemical fuel composition. Chemical elements that are considered critical for combustion of woody biomass are, for example, nitrogen (N), sulphur (S) and chlorine (Cl). These elements can cause increased emissions of NO_X, SO_X or HCl. Other elements such as potassium (K), sodium (Na), lead (Pb), zinc (Zn) and to a certain degree S and Cl influence the amount of aerosols formed during the combustion process. Chemical elements are also critical in terms of high temperature corrosion (S, Cl) or slagging (K, silicon (Si)) (Dietz, 2016b; Obernberger, 2015; Schön, 2014; Sommersacher, 2012). The concentration of these elements is typically low in wood as they mainly occur in other organic (e. g. needles, bark) or inorganic sources (e. g. mineral soil) (Dietz, 2016b). Due to careless operation during fuel production, high levels of mineral soil may be added to the fuels, e. g. during the logging process, transportation, storage or fuel processing after storage (Kuptz, 2019; Zeng, 2019). Current studies reported up to 10 w-% of mineral soil in woody biomass (Dietz, 2016a). This may lead to unwanted effects during combustion which can even result in a boiler shutdown. Mineral soils in woody biomass could also be an economic disadvantage for the combustion plant operator if the accounting of the delivered fuels is based on fuel mass (Dietz 2016b) or if more ash has to be disposed. Furthermore, soil adhesion to the fuel will also raise mechanical stress in moving parts of the boiler and will thus increase mechanical wear. The aim of this research was therefore to evaluate the combustion behaviour of coniferous wood chips, which were contaminated with 5 and 10 w-% of mineral soil (dry

basis, d. b.). The study included the identification and evaluation of potential damage to boilers (e. g. slagging,) and of the environmental impact (e. g. emissions).

2. Material and Methods

2.1 Selection of mineral soils and wood

The project area was focussing on the state of Bavaria in Germany. Three different types of mineral soil (soil A, B and C) were selected in order to represent large Bavarian forest growing regions of spruce with high wood chip production (Figure 1, left).

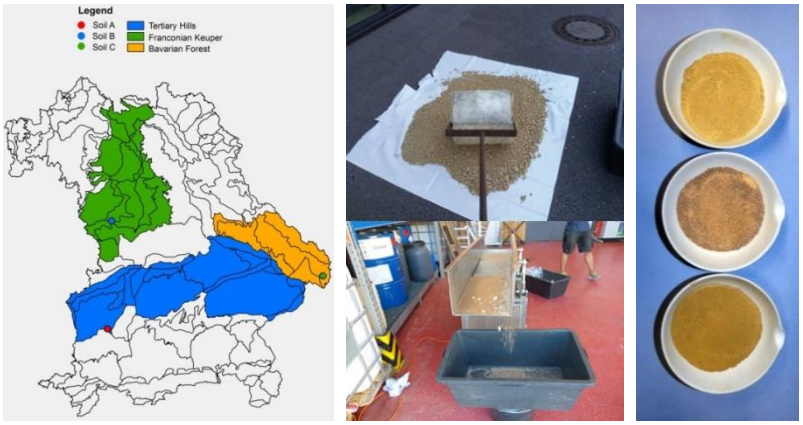


Figure 1: Left: Location of three different soil types. Each soil is representative for the considerable parts of the region (Zimmermann; 2019); centre top: crushing with a concrete roller; center bottom: screening at 2 mm with a self-constructed vibration screen; right, from top to bottom: soils A, B and C;

Forest regions with a high amount of rocks were excluded because contamination with mineral soil is not very likely in these areas. The following soils / regions were selected:

- Soil A: waterlogged loess/clay from tertiary hills
- Soil B: podsol brown soil above sandy-loam Franconian Keuper from northwest Bavaria
- Soil C: brown earth from weathered granite and gneiss substrates from the Bavarian Forest

The mineral soils were taken from the upper 30 cm, excluding the layer of humus. After sampling, each soil was air-dried indoor at room temperature. After drying, each soil was homogenized manually. A representative subsample of every soil was obtained by sample reduction. The respective subsamples were crushed manually using a concrete drum (Figure 1 centre top). The drum was wrapped in cling film to avoid contamination and rolling was done on a tarpaulin. Each soil was then screened mechanically to a grain size of 2 mm using a self-made vibrating screen (Figure 1 centre bottom). This diameter corresponds with the geological fraction-limit between fine soil and coarse soil fraction (Sponagel, 2005). The screened and dried soils can be seen on the right in Figure 1.

The wood fuel was forest residue chips (FRC) of coniferous wood of Norway spruce (*Picea abies*) from the same region as the mineral soil A. Every wood fuel used in the trials was produced from the same raw material batch.

2.2 Mechanical upgrading and washing of wood chips

Three different methods for upgrading the fuel quality were performed on the wood chips prior combustion. Two batches (moisture content: 15 w-%) of wood chips were screened with a self-

constructed drum screen. One fuel portion was screened with a round hole diameter of 8 mm, the second with a round hole diameter of 16 mm. A third fuel portion was washed to reduce mineral soil. The washing was performed following the principle as used in the laboratory method of the BioNorm2-project (Jensen, 2010), but the apparatus was drastically upscaled by constructing a large washing box (1 m × 0.725 m × 0.715 m) of stainless steel. The cover and bottom plate of the washing box is completely formed by a 2 mm round hole screen (Figure 2, left). An IBC tank with removed cover plate was used as a water tank. The fuel portion was washed in three washing steps with 750 liters of tap water by submerging and lifting the washing box into and out of the IBC tank using a fork lift (Figure 2, right).



Figure 2: Washing woodchips; left: washing box with FRC; right: lifting the washing box into and out of the IBC tank;

2.3 Contamination of wood chips with soil

By means of preliminary tests, different types of contamination of wood chips were evaluated. These pre-tests revealed that the best reproducible method was to add the mineral soil to the wood chips immediately before combustion by using a separate dosing screw (Figure 3), which feeds the soil into the horizontal conveyor screw between storage tank and boiler. The dosing screw was placed on a scale to adjust the soil dosing rate in accordance to the desired mixing ratio of soil material and wood chips. Two different contamination levels (5 and 10 w-%) were consistently realized. In total ten different fuel qualities were thus created and tested in the wood chip boiler (Table 1).

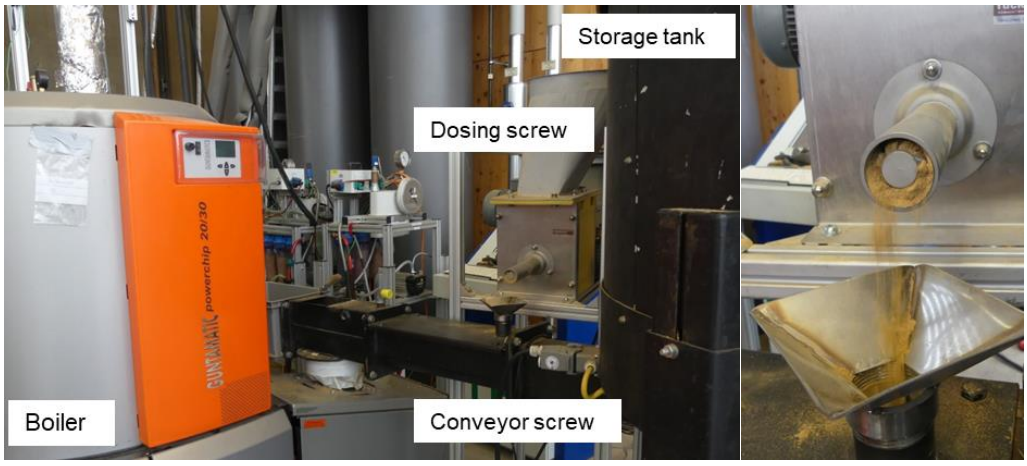


Figure 3: Left: contamination of wood chips with a dosing screw into the screw conveyor. Right: closeup view of dosing screw

Table 1: Nomenclature used for tested fuels

Fuels	Mechanical treatment / contamination
FRC-RS	Reference fuel, no treatment
FRC-W	Washed
FRC-S8	Screened 8 mm
FRC-S16	Screened 16 mm
FRC-A5	5 w - % mineral soil A
FRC-A10	10 w - % mineral soil A
FRC-B5	5 w - % mineral soil B
FRC-B10	10 w - % mineral soil B
FRC-C5	5 w - % mineral soil C
FRC-C10	10 w - % mineral soil C

2.4 Fuel properties

Before combustion, fuel properties were determined according to international standards for solid biofuels. Fuel moisture content was determined gravimetrically according to DIN EN ISO 18134-2 using a drying cabinet (n = 3) (FED 720, Binder GmbH) immediately prior to the combustion tests. Determination of particle size distribution was done according to DIN EN ISO 17827-1. Ash content (n = 3) was determined according to DIN EN ISO 18122 in a muffle furnace (Nabertherm GmbH). Bulk density (n = 3) was determined according to DIN EN ISO 17828 prior to storage. Net calorific value was determined using a calorimeter (C 2000 basic, IKA) according to DIN EN ISO 18125. All chemical analyses were done by a pre-calibrated portable EDXRF device (Epsilon 1, Panalytical). The samples were taken directly from the screw conveyor of the boiler immediately before and after the respective combustion trial, and then homogenised to get a representative sub-sample for the whole batch. For ash content, net calorific value and EDXRF-analysis, the samples were milled to a diameter of < 0.5 mm using a cutting mill (Pulverisette 19, Fritsch GmbH) with heavy metal-free cutting tools. Based on the element concentrations, specific fuel indexes were calculated in order to predict the ash melting behaviour (molar (Si+P+K)/(Ca+Mg)-ratio), the theoretical risk for aerosol formation (Σ(K, Na, Pb, Zn), NO_X-emissions (N-content of the fuel) and K-release (molar Si/K-ratio) (Sommersacher, 2011).

2.5 Test stand and combustion trials

In total, ten different wood chip fuels were combusted (Table 1) in a moving grate boiler (GUNTAMATIC Heiztechnik GmbH, Powerchip 20/30, constructed in 2010) which has a lateral fuel insertion (Figure 4, left). The combustion tests lasted for at least 8 hours including a pre-heating phase lasting for about 2 hours, which was followed by a 6 h full load operation before shutdown. The ash is removed via the moving grate to a screw conveyor which transports the ashes into the ash box. A round storage tank with a flat spring agitator and a screw conveyor was used as fuel feeding systems. To determine the fuel consumption during combustion, the storage tank was placed on a platform scale (Mettler-Toledo GmbH, MT KD600) with a resolution of 0.005 kg. Figure 4 (right) shows a schematic drawing of the test rig and the arrangement of the measurement devices. The heat consumption was permanently regulated to a nominal load of 30 kW following DIN EN 303-5. The gaseous components CO, CO_2 and O_2 were determined using a single component analyser (ABB Automation GmbH ABB AO2020), NO_X by a chemiluminescence detector (Eco Physics GmbH CLD 822 Mhr Analysator) and for water vapour content, SO_X, HCl and CH_4 an FTIR-analyser (Ansyco GmbH FTIR DX4000N) was used. The recording interval for the continuous measurement was set to 10 seconds. The total particulate matter (TPM) was measured following VDI 2066-1 applying a filtration temperature of 160 °C during sampling and filter post-treatment. The boiler was operated at constant flue gas draught of -15±2 Pa as it is suggested by the boiler manufacturer. The diameter of the flue gas duct and the connecting pipe was 150 mm. Flue gas velocity was continuously measured using a vane anemometer (Höntzsch GmbH, ZS25/25-ZG4) positioned in a narrowed stretch of the measurement section with a diameter of 100 mm (Figure 4, right). Prior to each trial, the combustion chamber, the heat exchanger and the fuel feeding

system were completely cleaned using a vacuum cleaner, a brush and pressurized air. The storage tank was filled with sufficient amount of fuel and the boiler was started and heated up to steady state operation at nominal load (30 kW) within approx. 2 h. Then the measurements were performed over 6 h at nominal load operation. Within this time period, the gaseous emissions were continuously recorded, but were evaluated only for the duration of the TPM measurements. Five TPM measurements were performed evenly distributed over the whole duration of 6 h each lasting for 30 minutes. All reported emissions refer to dry flue gas at 0 °C and 1,013 hPa and are based on 13 % O_2. All residues of the combustion tests were carefully removed from the boiler and will soon be assessed regarding slag formation.

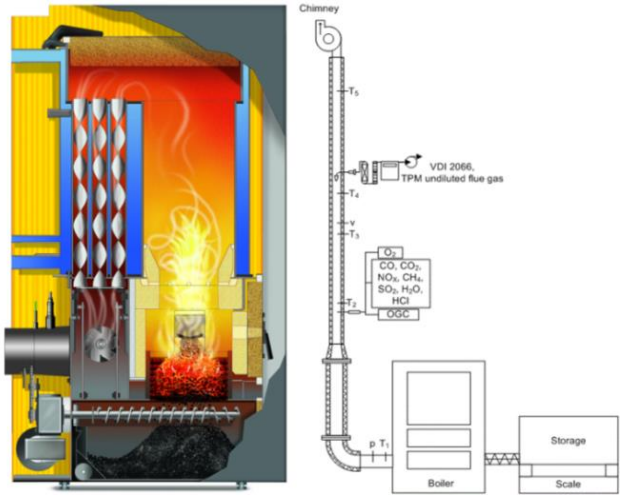


Figure 4: Schematic drawing of the boiler (source: Guntamatic, left) and a schematic drawing of the test stand (right). T1 – T5=temperature measurement points, v=velocity measurement, p=pressure measurement.

3. Results and Discussion

3.1 Fuel properties

The results on physical fuel properties are summarized in Table 2.

Table 2: Physical fuel quality parameters of the produced wood chips
(a. r. - as received, d. b. - dry basis, SD - standard deviation, n. c. – no classification)

Fuel	Moisture content	Bulk density	Ash content	Net calorific value	Particle size distribution	Mineral soil addition
	w-%	kg/m³, a. r.	w-%, d. b. (± SD)	MJ/kg, a. r.	DIN EN ISO 17225-4	w-%, d. b.
FRC-RS	16.48	270	1.95 (± 0.22)	17.97	n. c.	0
FRC-W	15.62	260	1.73 (± 0.15)	17.66	n. c.	0
FRC-S8	14.79	240	1.35 (± 0.27)	17.82	P31s	0
FRC-S16	14.16	240	1.02 (± 0.02)	17.74	P31s	0
FRC-A5	13.13	270	5.35 (± 0.77)	17.64	P45s	3.3
FRC-A10	15.06	280	10.53 (± 0.35)	16.96	n. c.	8.8
FRC-B5	15.00	270	5.13 (± 0.99)	17.58	n. c.	5.0
FRC-B10	15.58	280	9.42 (± 0.31)	17.27	n. c.	8.8
FRC-C5	15.36	280	6.15 (± 0.47)	16.74	n. c.	4.0
FRC-C10	14.93	280	9.40 (± 1.84)	16.52	n. c.	8.6

Due to the previously performed technical drying of all wood chips, the moisture content of the wood fuel used in the combustion trials was in a narrow range between 13.1 w-% (FRC-A5) and 16.5 w-% (FRC-RS). All fuels largely differed in ash content. For the reference fuel, the ash content was 1.95 w-% (d. b.). After mechanical upgrading, the ash content of the washed fuel portion (1.73 w-%) and of the 8 mm (1.35 w-%) and 16 mm (1.02 w-%) screened fuel portion were significantly lower compared to the reference fuel ($p \leq 0.05$, Student's T-Test) due to the reduction of bark, needles or already present impurities in the fuel. At the same time, the ash content of the reference fuel was significantly lower compared to the contaminated wood chips ($p \leq 0.05$, single ANOVA (Tukey)). The actual share of added mineral impurities in the fuels ranged from 3.3 to 8.8 w-% (d. b.). As expected, the ash content of contaminated fuels was in the range of 5.13 to 10.53 w-% (d. b.) due to the addition of inert mineral soil and, thus, much higher than the reference and the mechanically upgraded fuel portions. The bulk densities of the mechanically treated fuel portions were significantly lower compared to the reference fuel due to a higher porosity of the bulk material by removing small particles ($p \leq 0.05$, Student's T-Test). The bulk densities of FRC-B10 and FRC-C5 were significantly higher than the reference fuel ($p \leq 0.05$, single ANOVA (Tukey)). The bulk density of the other contaminated fuel portion was constant or higher. The net calorific value for the reference fuel (17.97 MJ/kg, a. r.) was higher than for all other fuels (16.52 to 17.82 MJ/kg, a. r.) due to no adding of inert material to the fuel (contamination) or due to no separation of fine fuel particles with a predominantly higher net calorific value compared to wood (e. g. bark, needles) by the mechanical treatments. All values of the reference fuel and the washed fuel portions met the requirements of DIN EN ISO 17225-4 fuel class B1. Due to screening, ash content and bulk density were decreased in the fuels FRC-S8 and FRC-S16. Thus, these fuels met requirements of fuel class A2. The contaminated wood chips cannot be assigned to any class of the mentioned standard due to high ash content. The results on the concentration of minor and trace elements and on fuel indexes are given in Table 3 and Table 4.

Table 3: Concentration of minor- and trace-elements in all fuels (d. b. = dry basis)

Fuel	Al	Ca	Cl	K	Mg	Si	P
	mg/kg, d. b.	mg/kg, d. b.	mg/kg, d. b.	mg/kg, d. b.	mg/kg, d. b.	mg/kg, d. b	mg/kg, d. b.
FRC-RS	799	4,529	183	1,518	493	5,125	377
FRC-W	506	4,131	153	1,067	409	3,534	332
FRC-S8	306	3,350	116	1,073	349	1,630	245
FRC-S16	214	2,669	91	977	330	1,063	200
FRC-A5	2,353	3,830	177	1,601	535	10,556	347
FRC-A10	6,024	4,322	179	2,171	600	24,771	384
FRC-B5	1,035	3,837	168	1,417	488	5,319	325
FRC-B10	2,577	4,251	173	1,945	528	10,474	351
FRC-C5	5,037	4,368	159	1,794	592	15,585	355
FRC-C10	5,953	4,256	171	1,933	615	18,368	370

One important fuel index regarding the combustion performance is the ash melting tendency which can be estimated from the molar ratio of (Si+P+K)/(Ca+Mg+Al), the "slagging index". The indexes which are usually used for pure wood fuels and the Al concentration in the soil of the contaminated wood chip might be very high while ash melting temperatures might be increased. With regard to the Al-content of the soils (soil B: 46,630 mg/kg to soil C: 82,220 mg/kg) the (Si+P+K)/(Ca+Mg+Al)-ratio might be preferred for predicting ash melting behaviour of such fuels (Mack, 2019). This index should be low in order to avoid severe slagging (Sommersacher, 2013; Brunner, 2015; Mack, 2019). The index decreases with washing and screening. For contaminated wood chips the index is somewhat higher than for the reference fuel, but differences are not extreme. However, this indicates that slagging problems during combustion of contaminated fuel should be higher in tendency. For every soil the slagging index of 10 w-% contamination is higher than for the 5 w-% variant. A lower ash melting temperature is expected with increasing contamination.

Regarding the K-release, the contaminated wood chip fuels showed distinctly decreased molar Cl/Si ratios compared to reference and to the mechanically treated wood chips. All tested soils have a high

content of Si, so this effect was expected (Brunner, 2015). Thus, the total particle emissions of contaminated fuels were expected to be reduced.

Regarding the part of sum of aerosol forming elements (K and Zn only, since element contents of Na and Pb are too low to be detected by EDXRF) the reference fuel contained 1,561 mg/kg. The mechanically treated fuels are in the range of 977 to 1,073 mg/kg. The contaminated fuels were partly in the same range as the reference fuel and partly considerably higher. Therefore, the prospective total particle emissions from the mechanically treated fuels should be the lowest, followed by the reference fuel and the 5 w-% mineral soil variant. The highest TPM emissions are expected from the 10 w-% contaminated fuels (2,171 mg/kg FRC-A10). Since only two elements are considered, only an initial assessment can be made.

To detect mineral soil in wood chips the Al/200 or Fe/Mn index was used (Dietz, 2016b). If the indexes are > 1, presence of mineral soil is suspected. Following the Al/200 index, every fuel appears to have been contaminated with mineral soil. One explanation might be, that Al is a lightweight element and hard to measure with an EDXRF. On the other hand, there is a clear upward trend in contaminated fuels. So it has to be considered, that the raw material (FRC-RS) has been slightly contaminated with mineral soil from the beginning and therefore a higher Al-content. For further conclusions, the results from the also performed ICP element analyses need to be evaluated (still due). Compared to the Al/200-index the Fe/Mn-index seems in this case better suitable to detect mineral soil impurities. The reference fuel, the washed and the screened fuels are all < 1, while the contaminated wood chips are > 1. One exception is FRC-B5. An increase and partly doubling can be seen by 10 w-% contamination.

Table 4: Fuel indexes calculated for all fuels (d. b. = dry basis)

Parameter	(Si+P+K)/(Ca+Mg+Al)	Cl/Si	Σ (K, Zn)[1)]	Al/200	Fe/Mn
	mol/mol	mol/mol	mg/kg. d. b.	mg/mg	mg/mg
FRC-RS	1.4	0.03	1,561	4.0	0.5
FRC-W	1.2	0.03	1,067	2.5	0.3
FRC-S8	0.9	0.06	1,073	1.5	0.2
FRC-S16	0.8	0.07	977	1.1	0.2
FRC-A5	2.1	0.01	1,601	11.8	1.3
FRC-A10	2.7	0.01	2,171	30.1	3.3
FRC-B5	1.5	0.03	1,417	5.2	0.5
FRC-B10	1.9	0.01	1,945	12.9	1.1
FRC-C5	1.9	0.01	1,840	25.2	3.8
FRC-C10	2.0	0.01	1,981	29.8	5.0

[1)] Na and Pb cannot be detected by EDXRF

3.2 Combustion trials

3.2.1. Gaseous emissions

CO is the leading indicator for incomplete combustion. These emissions from the use of reference fuel were approx. 134 mg/m³ (Figure 5, left top). Highest CO emissions were recorded for the 16 mm screened fuel with 222 mg/m³. No effect from fuel washing was found. For both screened fuels, CO emissions were significantly increased compared to the reference fuel ($p \leq 0.05$, Student's T-Test). The lowest values were measured using the fuel which was contaminated with 10 w-% mineral soil A (19 mg/m³). All contaminated fuels had lower CO emissions as the reference or the mechanically upgraded fuels (mean 19 – 94 mg/m³). Thereby, increasing levels of contamination of every soil had a decreasing effect on the CO emissions.

The emissions of the organic gaseous carbon (OGC) are shown in Figure 5 (right top). The highest OGC emissions were detected for FRC-S16 (2.7 mg/m³). The lowest value was measured for wood chips contaminated with 5 w-% of soil A (FRC-A5: 0.3 mg/m³). Washing significantly decreased the OGC

emissions compared to the reference fuel ($p \leq 0.05$, Mann-Whitney-U-Test). For the contaminated wood chips, no clear trend was observed between the 5 or 10 w-% contaminated fuels or the different soils. This was also due to the generally very low level of OGC as it is typical for automatically fed boilers. The values are in the bottom range of the FID.

NO_X emissions were between 187 mg/m³ and 276 mg/m³ on average (Figure 5, left bottom). The highest NO_X emissions were detected for FRC-A10. The emissions decreased with screening compared to the reference fuel ($p \leq 0.05$, Student's T-Test) as needles and bark particles that are generally rich in nitrogen compared to wood were removed. For the contaminated wood chips, no clear trend could be observed between 5 or 10 w-% contaminated fuels or the different soils.

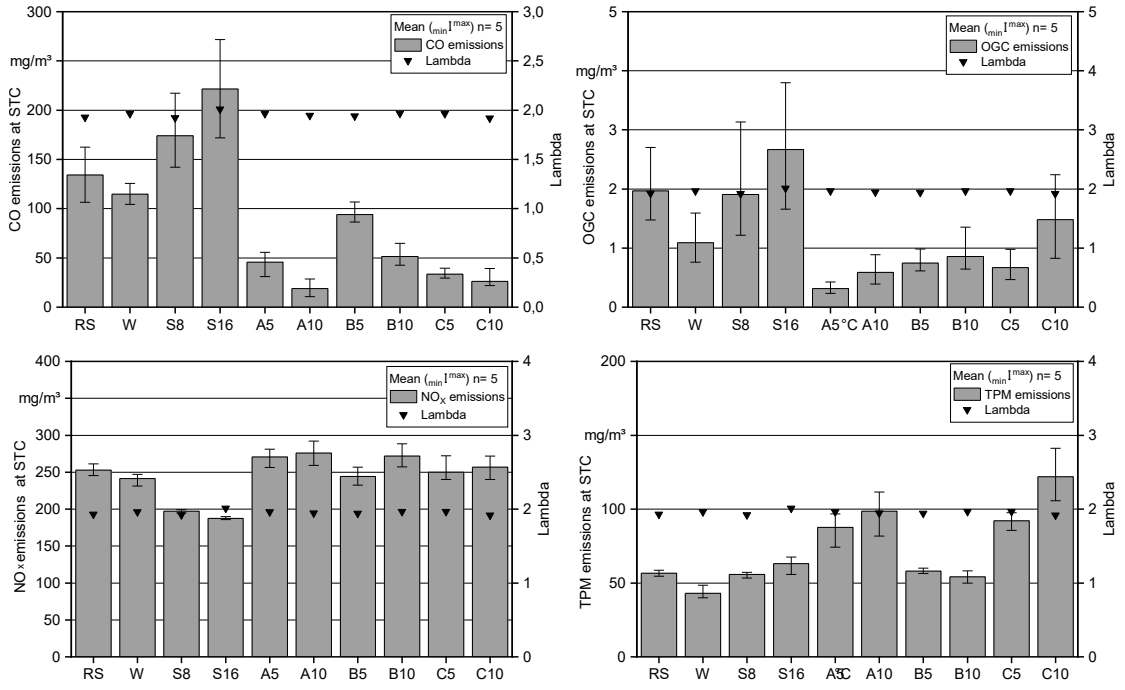


Figure 5: Combustion trials; left top: CO emissions; right top: Org.-C emissions; left bottom: NOx emissions; right bottom: total particle matter (TPM) emissions. Whiskers indicate the range of minimal and maximal values for the measurements. STC = standard test conditions.

3.2.2. Total particulate matter emissions (TPM)

Total particulate matter (TPM) emissions are summarized in Figure 5 (right bottom). The reference fuel led to 58 mg/m³ of TPM during full load operation. These values exceed the German threshold of 20 mg/m³, for TPM emission as defined in the 2nd stage of 1. BImSchV (BMJV, 2010). The highest TPM emission were detected for wood chips contaminated with 10 w-% soil C (122 mg/m³) and the lowest for the washed fuel (43 mg/m³). The TPM emissions of the washed fuel were significantly lower than the reference fuel ($p \leq 0.05$, Student's T-Test) but still above the limiting value of 20 mg/m³. For contaminated wood chips, no clear trend was observed. The emission of FRC-A5, FRC-A10, FRC-C5 and FRC-C10 were higher than the reference fuel. In contrast, the TPM emissions of FRC-B5 and FRC-B10 were on a similar level or lower than the reference fuel. As shown in Table 4, the preliminary index for aerosol forming elements decreases with mechanical treatment. Also the effect of increasing TPM emission for soil A and soil C was also indicated by the index. Regarding the Cl/Si index, the results are indifferent. For further interpretation the ICP values of all elements of the wood chips and the mineral soil need to be seen.

4. Summary and conclusion

The following conclusions can be drawn from this investigation:

- Washing and screening yielded in significantly reduced fuel ash contents, while on the other side the deliberate contamination by soil raised the ash content, as expected. Contamination also showed effect on the calculated fuel indexes which are commonly used for predicting fuel related combustion hazards. Other differences were observed for the concentration of chemical elements in the fuels due to mixing of wood with mineral soil, especially for values for silicon, aluminum and potassium. The highest net calorific value was measured for the reference fuel.
- Washing significantly reduced OGC and TPM emissions while there were no other improvements by washing on CO or NO_x emission compared to the reference fuel.
- Careless operation during fuel production, e. g. during logging, chipping or transportation, might lead to contamination of wood chips and, thus, to problems during combustion. All trials with wood chips that were contaminated with mineral soil resulted in a high amount of boiler ash and, according to the indexes, elevated slag formation is expected (data not shown). The boiler provided 30 kW constant full load operation during every trial. However, severe slagging and too high shares of ash might cause problems for other boilers without a moving grate and can even result in a boiler shut down.
- The CO emissions decrease with addition of mineral soil. No clear trend could be identified regarding NO_X emissions for contaminated wood chips but a reduction was observed for mechanically upgraded wood chips via screening. For CO, the legal requirements of the current national emission thresholds of the German Federal Emission Control Act (1. BImSchV) were met.
- The TPM emissions increased with soil contamination (soil A and C) or remained constant. To date it remains unclear whether this effect is completely caused by thermochemical effects in the fuel conversion process or if it might also be explained by any direct entrainment of soil particles into the flue gas stream.

5. Outlook

Several analyses and trials in the research are still ongoing. The following specific cases and open points will be analysed and published in a scientific paper:

- Complete chemical analyses of the soil and interpretation of chemical reactions in relation to the emissions, including a stoichiometric calculating of the mass fraction.
- Quantification of the ash of the combustion trials, including the amount of slag formation and slag characterization by granulometric analysis.
- Comparison of slagging degree, sintering phenomena and pollutant emissions with fuel indices.
- Combustion trials with energy round wood chips according to the same experimental design.
- Combustion trials with beech and spruce pellets from stemwood in a separate boiler (15 kW).
- Identification of reasons and origin of elevated TPM emissions via particle composition analysis.

6. References

Brunner, T., Wohlmuther, M., Kanzian, W., Obernberger, I., Pichler, W.: Additivation Guideline - How to Utilise Inorganic Additives as a Measure to Improve Combustion Related Properties of Agricultural Biomass Fuels. ETA-Florence Renewable Energies; (2015).

Bundesministerium der Justiz und für Verbraucherschutz (BMJV): Erste Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung über kleine und mittlere Feuerungsanlagen – 1. BImSchV), (2010).

Dietz, E., Kuptz, D., Blum, U., Schulmeyer, F., Borchert, H.,; Hartmann, H.: Qualität von Holzhackschnitzeln in Bayern. Gehalte ausgewählter Elemente, Heizwert und Aschegehalt, Berichte aus dem TFZ, Nr. 46, (2016a).

Dietz, E.; Kuptz, D.; Blum, U.; Schulmeyer, F.; Borchert, H.; Hartmann, H.: New Indexes for the contamination of wood chips with mineral soil. In: EU BC&E 2016. 24th European Biomass Conference. Amsterdam Exhibition and Convention Center, Amsterdam, Netherlands, June 6-9. Florence, Italy: ETA-Florence Renewable Energies, (Eds.), Florence, Italy, (2016b), p. 630–633.

Jensen, P. D.; Bech, K. S.; Hartmann, H.; Hinterreiter, S.; Lazdins, A.; Bardule, A. at al.: Methods for determining impurities in solid particulate biofuELS. IN: R. Wirkner, J. Witt und U. Seyfert (Hg.): BioNorm II - Pre-normative research on solid biofuels for improved European standards, Specific Targeted Research or Innovation Projekt, Leipzig: German Biomass Research Centre (DBFZ), European Commission (EC), (2010), p. 27–36.

Kuptz, D., Schreiber, K., Schulmeyer, F.; Lesche, S.; Zeng, T., Ahrens, F. et al.: Evaluation of combined screening and drying steps for the improvement of the fuel quality of forest residue wood chips - results from six case studies. In: Biomass Conversion and Biorefinery 8, (2019), p. 1-16.

Mack, R., Kuptz, D.; Schön, C., Hartmann, H.: Combustion behaviour and slagging tendencies of kaolin additivated agricultural pellets and of wood-straw pellet blends in a small scale boiler, Biomass and Bioenergy, Vol. 125, (2019), p. 50-62.

Obernberger, T., Brunner, T.: Advanced characterisation methods for solid biomass fuels. International Energy Agency (IEA); Report of the IEA Bioenergy Task 32 project. Graz: University of Technology, (2015).

Schön, C., Hartmann, H., Schwabl, M., Feldmeier, S., Dahl, J., Rathbauer, J., Vega, D., Boman, C., Öhman, M.: New evaluation strategies regarding slag prediction in pellet boilers, In: EU BC&E 2014. 22nd European Biomass Conference & Exhibition - From Research to Industry and Markets. Hamburg, Germany, 23-26 June 2014. ETA Renewable Energies (Eds.), Florence, Italy, (2014), p. 368–372.

Sommersacher, P., Brunner, T., Obernberger, I., Kienzl, N., Kanzian, W.: Application of Novel and Advanced Fuel Characterization Tools for the Combustion Related Characterization of Different Wood/Kaolin and Straw/Kaolin Mixtures. Energy Fuels 2013;27(9):5192–206.

Sommersacher, P., Brunner, T., Obernberger, I.: Fuel indexes: A novel method for the evaluation of relevant combustion properties of new biomass fuels. Energy & Fuels, Jg. 26, Nr. 1, (2012), p. 380–390.

Sponagel, H., Grottenthaler, W., Hartmann, K.-J., Hartwich, R., Janetzko, P., et al.: Bodenkundliche Kartieranleitung, Hannover: Bundesanstalt für Geow. und Rohstoffe, (2005), p. 141.

Zeng, T., Kuptz, D., Schreiber, K., Schön, C., Schulmeyer, F.; Zelinski, V. et al.: Impact of adhering soil and other extraneous impurities on the combustion and emission behavior of forest residue wood chips in an automatically stoked small-scale boiler. In: Biomass Conv. Bioref. 5 (1), (2019), p. 1–18.

Zimmermann, D.: Own representation with ArcGis (2019)

7 Acknowledgments

This study was funded by the Bavarian State Ministry of Food, Agriculture and Forestry (BayStMELF) under the grant number “KS/17/03”. This study was conducted in close cooperation with the Bavarian State Forest Enterprise (BaySF).

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

NUTRIENT SAVING EFFECTS OF ROUGHLY DELIMBED ENERGY ROUNDWOOD IN COMPARISON TO BIOMASS SUPPLY OF WHOLE CONIFEROUS CROWNS CAUSED BY HARVESTING METHOD AND BUCKING

Elke Dietz, Markus Riebler, Herbert Borchert
Bavarian State Institute of Forestry,
Hans-Carl-von-Carlowitz-Platz 1, 85354 Freising, Germany
Elke.Dietz@lwf.bayern.de

Abstract: *During the past years, energy revolution has been a controversial subject of discussion even in general public, as wood chips of forest biomass are still an important part for heat and power production in Bavaria. The aim of our research was to quantify the effects of biomass-harvesting methods on nutrient and biomass exports. The idea is to decide during the planning process of logging which harvesting method is the most suitable for each site with regard to nutrient saving and biomass gain. We tested two approaches. The quantification of nutrient and biomass export and saving on wood chip samples and on tree based mass sum curves of tree compartments. Mass sum curves of tree compartments can be used if element concentrations of tree compartments, as branches and brushwood, are available for the particular stand or the region of interest. Frist results and the use case indicate that this method is a promising approach. The quantification of nutrient and biomass export and saving calculated on wood chip samples allow a relative comparison of harvesting methods and bucking. The disadvantage is that chemical analyses of the wood chips have to be available. Whenever we produced wood chips of roughly delimbed energy round wood instead of supplying wood chips of whole coniferous crowns, we observed a reasonable nutrient saving effect. Our data make us conclude, that the choice of harvesting method leads to a considerable nutrient savings potential.*

Key words: biomass export, nutrient export, harvesting method, roughly delimbed energy roundwood, forest residues

1. Introduction

During the past years, energy revolution has been a controversial subject of discussion even in general public, as wood chips of forest biomass are still an important part for heat and power production in Bavaria. A considerable issue that is often referred to biomass supply from forest biomass of whole spruce crowns is the sustainability of nutrients. To answer various questions about this controversy, the Bavarian State Institute of Forestry has launched a research project called “Nutrient preservation using the technique of roughly delimbed energy roundwood” (Schulmeyer et al ,2016, Dietz et al., 2018 unpublished). Experienced practioners developed this process for poorer sites to leave more branches on the site to maintain nutrient sustainability. The aim of our research was to quantify the effects of biomass-harvesting methods on nutrient and biomass exports. The idea is to decide during the planning process of logging which harvesting method is the most suitable for each site with regard to nutrient saving and biomass gain. We tested two approaches. The first approach is to get information about the biomass export for different harvesting methods like full mechanized harvesting and motor-manual harvesting for forest residues and roughly delimbed energy round wood referring to different bucking diameter. Therefore we used mass output of wood chip production and carried out element analysis. The second approach is to use tree based mass sum curves of tree compartments to detect the expected biomass and nutrient export.

2. Material and Methods

We examined four spruce-dominated stands in Bavaria representing conditions with low nutrient levels (Table 1). At three of the site harvesting operations took place (Zusmarshausen = Zus, Silberbach = Silb , Lauenstein = Lau).

Table 1: Areas of investigations representing Bavarian sites with low nutrient levels.

geology/soil	soil	site	area [ha]	pro rata of forest area [%]
molasse	cambisol loamy-sandy	Zusmarshausen (Zus)	46.200	1,7
foundation rock, granite, gneiss	cambisol loamy -sandy	Silberbach (Silb)	17.600	0,7
foundation rock granite, top layer	cambisol sandy, silty	Wappenberg (Wap)	21.000	0,8
foundation rock schist, graywacke	cambisol silty, sandy	Lauenstein (Lau)	17.500	0,7

We carried out a precise biomass inventory on each stand. Two different approaches of nutrient saving were tested. Firstly, quantification of nutrient export respectively nutrient saving, investigating wood chip quantities and element content of testing areas. Secondly, quantification of nutrient export respectively nutrient saving regarding representative reference trees representing site, stand und removals.

2.1 Quantification of nutrient and biomass export and saving on wood chip samples

2.1.1. Wood chips production and sampling

The wood chips used for investigation were produced at the forest road from roughly delimbed energy round wood and forest residues (whole crowns). At each of the three sites comparable individual harvesting areas for producing the above mentioned assortments were marked. At Silberbach motor-manual harvesting was used, at Lauenstein and Zusmarshausen full mechanized harvesting took place. The diameter of breast height (dbh) of all trees marked for felling was measured. Tree height and crown starting point was registered for every fifth tree (using Haglöf Vertex III bzw. Vertex IV). Bucking limits diameter (bld) from sites with motor-manual harvesting often differ from those of full mechanized harvesting. During the chipping process representative wood chip samples were taken.

2.1.2. Sample preparation

Wood chip samples from roughly delimbed energy round wood as well as from forest residues were collected form the sites Zusmarshausen and Silberbach and were brought to our laboratory for chemical analysis and water content measurement. The samples were dried at 60°C (Kap. 1.2.1 König, 2014) and then sample division (DIN EN ISO 14780 modified Kuptz et al 2018) took place so that four subsamples were obtained. One subsample was used to quantify water content, one for chemical analysis, one to be washed applying BioNorm 2 (Daugbjerg-Jensen et al 2010, Dietz et al., 2016) and one used as retain sample. Washing of wood chips (BioNorm2, Daugbjerg-Jensen et al 2010) intends to remove contamination with mineral soil from the wood chips. After washing, the sample was dried again at 60°C. The dried sample was shredded and milled (Kap. 1.3.1 König 2014). Digestion with microwaves (µPrep-A, Fa. MLS Mikrowellen-Labor-Systeme, Leutkirch) was carried out according to Kap. 3.2.3 König (2014) to get the chemical content of the wood chips. Finally the element content (major- and trace elements) was measured using ICP- AES (Optima 4300 DV, Fa. Perkin Elmer, Rodgau) or ICP-MS (7500i, Fa. Agilent, Waldbronn).

2.1.3. Evaluation and Calculation

At none of the investigated sites the two harvesting methods full mechanized and motor-manual were carried out concurrent. Regular logging operations had to be observed without any influence of the applied harvesting method. Consequently, different bucking limits for each harvesting method occurred for each stand. To compare the theoretical values of motor-manual and full mechanized logging at the same site wood chip mass for each particular harvesting method had to be calculated. At Silberbach full mechanized, at Zusmarshausen and Lauenstein motor-manual harvesting output had to be calculated using the same bucking limit (Silberbach 18 cm, Zusmarshausen 14 cm). For the calculation technical additional delimbing (Riebler et al, 2019) was considered as well. It was expressed as percentage biomass per crown biomass. In the case of harvesting whole crowns (forest residues) for conversion form full mechanized to motor-manual, in the terms of figures, the biomass of the technically caused additional delimbing mathematically has to be left at the stem (3). For the reverse calculation, this biomass has to be removed from the stem by way of calculation (4). In the case of roughly delimbed energy round wood it is necessary to consider the remaining branch and twig biomass on the bottom side of the stem, since it is not turned if delimbing manually. As consequence this biomass has to be added to convert biomass output from full-mechanized to motor-manual harvesting (1). For reverse calculation it has to be removed (2). The technical additional delimbing could be neglected because it is assumed that the spindle breakes at 5 or 3 cm and might not be overrun by the harvest head. This had not yet been tested and therefore we included the additional delimbing in our calculation (1, 2 second term).

roughly delimbed energy round wood

$$m_{fm} = m_{mm} * (1-m_u) - (m_{fm} * m_{tad} * m_u) \quad (1)$$

$$m_{mm} = m_{fm} * (1+m_u) + (m_{fm} * m_{tad} * m_u) \quad (2)$$

whole crowns (forest residues)

$$m_{fm} = m_{mm} * (1-m_{tad}) \quad (3)$$

$$m_{mm} = m_{fm} * (1+m_{tad}) \quad (4)$$

where m_{mm} is biomass (atro) of wood chips harvested motor-manual, m_{fm} is biomass (atro) of wood chips harvested full mechanized, m_u is remaining branch biomass at the bottom side of the stem (atro in pro rata m of crown biomass (atro)) and m_{tad} is technical additional delimbing (atro in pro rata of crown biomass (atro)).

The measured element concentrations were registered and listed separately for full mechanized and motor-manual harvesting. In a second step the element concentrations were multiplied with the dry weight of the harvested biomass (atro) obtained from wood chip production per ha. That way information of the element content per ha could be received. The combination of harvesting whole crowns (forest residues) using full mechanized harvesting methods achieves the highest export of biomass and nutrients. Thus in a third step all exports and savings were expressed as a percentage of this combination. The original element content of the different tree parts used for production of wood chips from energy round wood (stem and bark from the spindle) and forest residues (stem and bark from the spindle, branches, twigs and needles) were considered as different (motor-manual and full mechanized) harvesting methods were converted to each other. At Silberbach a drum chipper “MusMax Wood Terminator WT 10 Z”, at Lauenstein a “Heizomat HM 14-800 K” and at Zusmarshausen “Eschlblöck Biber 92” were used.

2.2 Quantification of nutrient and biomass export and saving on tree based mass sum curves of tree compartments

2.1.1 Identifying reference Trees

Inventory random sampling was carried out at predefined grid resolution. The survey of the harvesting skid trail was performed using GPS and compass. To estimate the basal area and other important silvicultural key facts the angle count sample (ACS) was used (Bitterlich, 1984). For each tree inside the sample circle dbh, the distance to the circle center was detected, even the “social status” (Kraft’sche

Klasse) of the tree was recorded. Besides from five trees of each tree species total height and the height of the first green branch were measured using a Haglöf Vertex IV. The reference trees had to be representative for the stand just as for the removing trees, frequency distribution of dbh and social status were determined. This way a selection of potential reference trees was created and then safety proved for tree climbing. The safest trees were selected to take samples.

2.1.2 Sampling

The whole crown, branches and brushwood, was removed whorl by whorl by tree climbers. The cut-off branches were thrown down on a cover below the tree to avoid contamination with soil material which might falsify the element content of the tree compartments. The branches were cut at diameter of 1 cm. Branch material below diameter of 1 cm was defined as "brushwood", material bigger than 1 cm diameter was defined as "branch material". The material was separated and weighed once directly at the site (Dini Argeo STG100; 50 kg ± 0.01 g) and for a second time at the laboratory. To calculate the dry weight of the tree compartments (branches, twigs, needles, bark and wood) the water content was determined (DIN EN ISO 18134-2, König 2014). Sample-branches for chemical analyses were taken circumferential the stem, starting with the first green branch of the crown. Every second or third whorl, a sample-branch was taken. The sample-branch was separated into branch material and brushwood as well. To gather information about the element content and the chemical composition of stem wood and bark, six stem discs were taken at three different heights (above the felling cut, at about 10 m height and at height of the bucking limit) after cutting. Three of them were used for chemical analyses and the others to detect density of wood and bark. Furthermore, the stem diameter was determined every two meters up to bucking limit. Above that between every whorl, the measured height was noted. At all sites the height of each whorl was measured. At Silberbach and Lauenstein the cut stem was used, at Roding und Zusmarshausen the measurement was carried out at the standing trees.

2.1.3 Sample Preparation

After drying at 60 °C the separation of twigs and needles took place. Branch length and diameter at each ending of the branch were measured. Of each branch part proportional branch volumes were taken as subsample for chemical analyses. The wooden material, bark and twigs had to be shredded before milling. Just like as with the wood chips a microwave digestion was carried out (König 2014). To calculate bark and wood density the volume of fresh stem disc samples were determined using diameter gauge and and referred to their dry weights.

2.1.4 Evaluation und calculation

For each reference tree biomass (atro) was calculated for each sample branch separately for branches, twigs and needles. In the same manner each whorl and the whole crown were treated. Then the biomass of each compartment was expressed as percentage of the biomass of the particular compartment of the whole crown. Moreover the whorl height also was calculated as percentage of the total height of the tree. Graphs of mass sum curves for each compartment were created presenting the percentage of mass sum to percentage of height sum at whorl height (Figure 4). For biomass export or the remaining biomass during harvesting the bucking limit is relevant, assuming that the crown mass above is extracted for terms of biomass production. Using dbh and tree height the decrease of the diameter by increasing height can be calculated. Thus, tree height and relative tree height of the bucking limit was determined. Using the relative height of bucking diameter, the mass curve diagram can be applied to get the relative mass sum of the branches or brushwood above and below the bucking limit. This method has an inaccuracy, for whorls which are not allocated continuously around the stem. There is a gap between the whorls at the stem. When harvesting crown biomass the cutting of the crown is located in that gap. That means in fact, that it would be necessary to know which whorl exactly is above or below the gap. In practice for estimating the export or remaining biomass of the removed trees the mean mass curve or the mean curve of tree groups can be used. In this case there are so many different whorl heights that the mean mass curve could be considered as continuous. To calculate the mass sum curves the reference trees were exactly sized. During the regular harvesting process this effort could not be made. Minimum data for calculation were defined. While harvesting tree height (standing tree or cut down tree), height of the bucking limit, height of the crown starting point and dbh could be measured. If mass sum curves are available for the stand or a comparable stand they can be used to estimate relative biomass export or biomass residues. Moreover nutrient saving per kg dry weight could be calculated as well for compartments like branches and brushwood (see K-use case below).

3. Results

3.1 Quantification of nutrient and biomass export and saving on wood chip samples

The technical additional delimbing by the harvesting head, depending on the site and bucking diameter ranged between 27 and 31 m% of the crown biomass. 5 to 10 % of the stem roundness is not delimbed at the bottom site of the stem using motor-manual harvesting. A comparison of the wood chip yield and their element content takes all compartments usually utilized for wood chip production even spindle of the top and stem parts with wood decay into account in contrast to the estimation based on mass sum curve. But chemical analysis of the wood chips had to be made. This can only be carried out after harvesting and chipping. Forecasts could only be made for comparable stands with similar growing conditions. Setting wood chip production of whole spruce crowns as our reference value straight compared to the biomass supply of roughly delimbed energy roundwood, we determined 40 to 53 % less biomass (kg dry matter/ha) using fully mechanized harvesting methods and 52 to 66 % for motor-manual harvesting (Figure 1). Silberbach (Silb) differs from the others because of the lager bucking diameter of 18 cm (minimum diameter of saw logs) compared to the others with 14 cm.

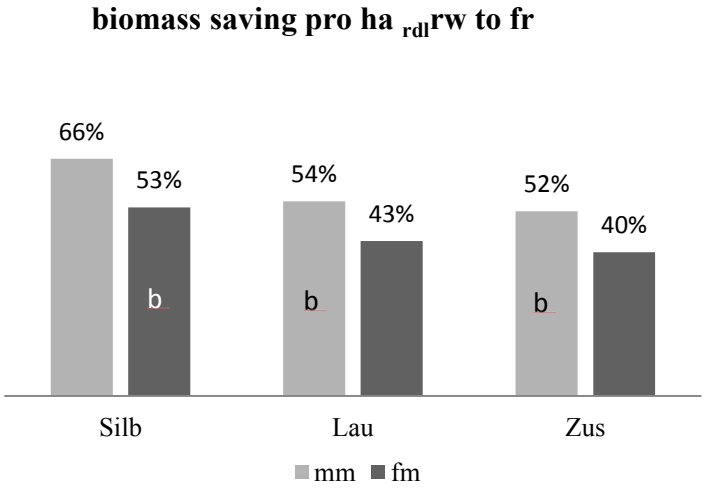


Figure 1: Export reduction (saving) of biomass by „roughly delimbed round wood“ ($_{rdl}$rw) and „forest residues (fr, whole crowns)“using motor-manual (mm) and full mechanized harvesting (fm) at the sites Silberbach (Silb), Lauenstein (Lau) and Zusmarshausen (Zus). “b”marks the calculated cases, not-marked bars show the field data.

Focused on nutrient export per kilogram dry biomass per ha, the higher nutrient-content of branches and needles shows an outstanding nutrient saving opportunity. In general the export of nutrients was lowered between 63 % and 95 % (kg dry matter/ha). Nutrient saving is lower using full mechanized harvesting methods than motor-manual harvesting. Nutrient saving is lowest for micro nutrients as Zn (63 %), Cu (66 %) and the trace element As (66 %) using full mechanized harvesting methods. For K as an emission-building element the export could be reduced up to 73 %. For other important nutrients as P, Mg and Ca the export can be reduced at least by 82 % (P), 76% (Mg) and 70% (Ca) (Dietz et al. 2018 unpublished). Best but not important for plant nutrition is the reduction for Al, Fe and Na. Under certain aspects as emission building element the reduction of Na up to 95 % could be important (Figure 2).

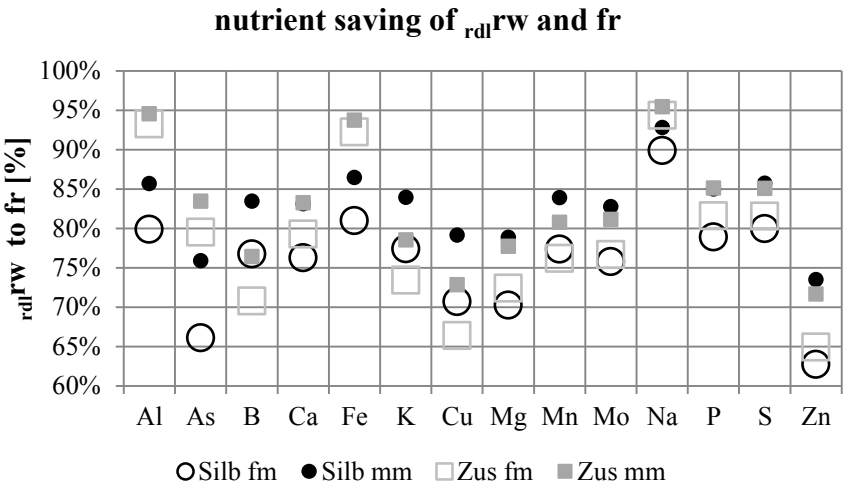
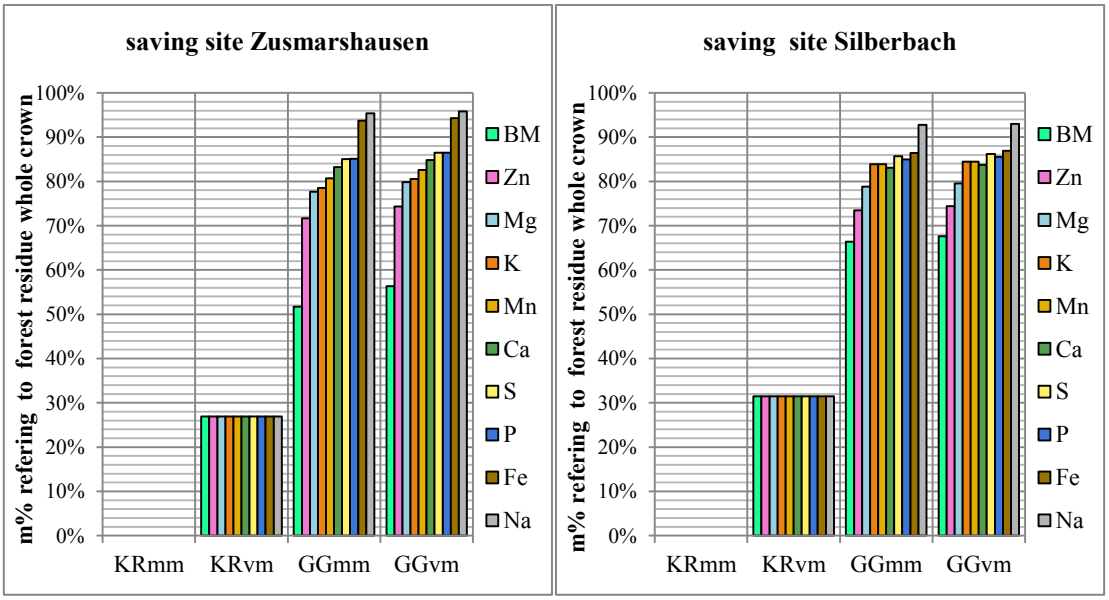


Figure 2: Pro rata export for „roughly delimbed round wood“ including spindle referring to forest residues (whole crowns) at the site Zusmarshausen. Full mechanized (large symbols) and motor-manual harvesting (little symbols) are compared. Data refer to washed wood chips (dry weight per ha). Elements aluminum (Al), arsenic (As), boron (B), calcium (Ca), iron (Fe), potassium (K), copper (Cu), magnesium (Mg), manganese (Mn), molybdenum (Mo), natrium (Na), phosphor (P), sulfur (S) and zinc (Zn).

The assortment forest residues (whole crowns) gives the worst balance between biomass saving and nutrient export, because the biomass export is the highest of all investigated harvesting methods as well as the nutrient export. Therefore this combination of assortment and harvesting method was used as reference for the others. Forest residues harvested full mechanized save from 31 m% (b. bld = 14 cm) to 27 m% (b. bld =18 cm) more of the crow biomass (Figure 3.) compared to forest residues harvested motor-manually (KRmm). Hence nutrient export is reduced as well. Depending on the kind of element, saving it is always higher than biomass saving. Seen from the opposite perspective, biomass export release is always less than nutrient saving.



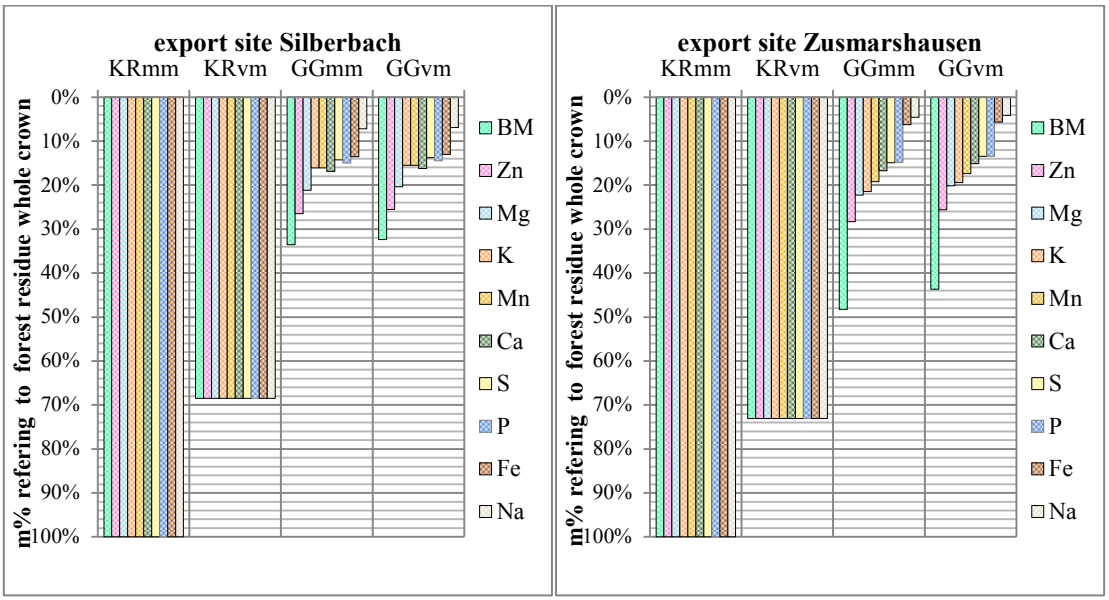


Figure 3: Comparison of pro rata biomass and nutrient saving (figures on top) and nutrient export (figures below) of different harvesting methods as full mechanized forest residues (KRvm), motor-manual roughly delimbed round wood (GGmm) and full mechanized roughly delimbed roundwood (GGvm). Forest residues (fr) motor-manual harvesting (mmKR).

Roughly delimbed energy round wood harvested full mechanized (GGvm) has the highest saving effect. The saving effects increase with increasing bucking limit. In Silberbach the bucking limit diameter (bld) is 18 cm, in Lauenstein 14 cm (Figure 3). The effect of biomass- and nutrient saving was expected because wooden biomass from the stem - spindle in contrast to biomass from other crown compartments as branches and brushwood is more relevant with increasing bucking limit. The nutrient content of biomass from the stem normally is lower than those from branches and brushwood. The efficiency of nutrient and biomass saving only increased marginally for roughly delimbed energy round wood using full mechanized instead of motor-manual harvesting (Figure 3).

3.2 Quantification of nutrient and biomass export and saving applying mass sum curves of tree compartments

3.2.1 Mass sum curves of branches and brushwood

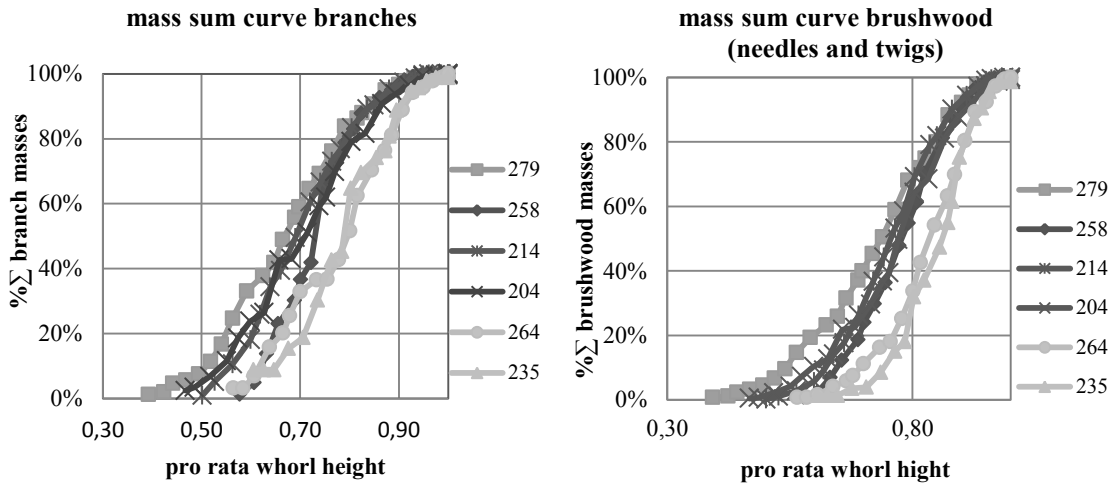


Figure 4: Mass sum curve for branches (left) and brushwood (right) for the site of Zusmarshausen.

The method used estimates the biomass and nutrient export respectively the biomass and nutrient saving for different assortments like roughly delimbed energy round wood and whole crowns (forest residues). Mass sum curves of brushwood and branches were calculated for the site of Zusmarshausen.

Table 2: Sum of pro rata tree height of the reference trees at Zusmarshausen at bld (cm).

tree number	bucking limit (bld) in cm					group
	18	14	11	7	5-4	number
279	0,76	0,83	0,87	0,93	0,96	1
258	0,69	0,74	0,81	0,89	0,95	2
214	0,69	0,76	0,84	0,91	0,95	2
204	0,47	0,63	0,74	0,87	0,95	2-3
264		0,67	0,75	0,91	0,97	3
235		0,65	0,74	0,87	0,94	3
mean	**0,65**	**0,71**	**0,79**	**0,90**	**0,95**	

Table 3: Pro rata mass sum of branch material referring to the whole crown of the reference trees at Zusmarshausen at bucking limit (cm).

tree number	bucking limit (bld) in cm					group
	18	14	11	7	5-4	number
279	0,76	0,88	0,95	0,99	1,00	1
258	0,30	0,64	0,83	0,95	0,98	2
214	0,50	0,73	0,79	0,97	1,00	2
204	0,02	0,26	0,59	0,91	0,99	2-3
264		0,20	0,37	0,89	0,98	3
235		0,09	0,30	0,76	0,96	3
mean	**0,40**	**0,47**	**0,64**	**0,91**	**0,98**	

Table 4: Pro rata mass sum of brushwood material referring to the whole crown of the reference trees at Zusmarshausen at bucking limit (cm).

tree number	bucking limit (bld) in cm					group
	18	14	11	7	5-4	number
279	0,59	0,75	0,88	0,97	0,99	1
258	0,19	0,36	0,54	0,63	0,98	1-2
214	0,26	0,53	0,76	0,94	0,99	2
204	0,00	0,26	0,37	0,81	0,97	2 -3
264		0,06	0,18	0,80	0,97	3
235		0,01	0,28	0,55	0,91	3
mean	**0,26**	**0,33**	**0,50**	**0,78**	**0,97**	

The sum curves cluster so that groups (1 to 3) could be detected (Figure 4). Some trees shift between the groups e.g. tree number 204 for tree height, branch and brushwood pro rata biomass (Table 2-4) and tree number 258 only for brushwood pro rata biomass (Table 4). For each group a single mean curve could be drawn. Analyses and investigations how the groups can be characterized by tree properties are still ongoing. At the moment the mean curve is used for further analysis concerning the removing trees.

3.2.2 Use case K-export of different harvesting methods

Chemical analyses of biomass at the site Zusmarshausen are not available yet. A use case was created using the K-content of Silberbach. There, the average K-content of branches for the reference trees is 800 mg/kg and for brushwood 3000 mg/kg (dry weight). If bucking limit diameter is 14 cm, above that roughly delimbed energy round wood is produced up to stem diameter of 7 cm. The tree top above 7 cm can be left at the site or used to produce wood chips as well. The use case was applied for tree number 258. For properties and mass sum of branches and brushwood see Table 2-4.

Table 5: Use case K-export of different harvesting methods; spindle and branches. Branch stumps are not jet considered in this use case. (export by harvesting (white), remaining at the site (grey)

use case crown without spindle		no harvesting		roughly delimbed round wood without tops		roughly delimbed round wood with tops		forest residues (whole corwn)	
bucking limit diameter		14							
diameter tree top		7							
material		biomass [m%]	K [mg]	biomass [m%]	K [mg]	biomass [m%]	K [mg]	biomass [m%]	K [mg]
below bucking limit	branches (br)	64	512	100 (br)	3000	95 (br)	2650	64 (br)	1592
	brush wood (bw)	36	1080					36 (bw)	
between bucking limit and top	branches (br)	31	248					36 (br)	2208
	brush wood (bw)	27	810			63 (bw)			
top	branches (br)	5	40			5 (br)	1150		
	brush wood (bw)	37	1110	100 (bw)		27 (bw)		64 (bw)	

Harvesting roughly delimbed energy round wood, almost the whole crown biomass (without spindle) and nutrient content are left at the site (Table 5). The harvesting of wood chips produced of roughly delimbed energy round wood including the tree top above diameter of 7 cm, exports 5 % of branch biomass and 27 % of brushwood; 95 % and 63 % are left at the site. If forest residues above top diameter including tree top are harvested for wood chip production 36 % of branch biomass and 64 % of brushwood is withdrawn from the stand. Normally braches from the stem are used for building a brush mat in case of fully mechanized harvesting. The calculation of the export of K per kg biomass dry weight for forest residues results in 2208 mg, for roughly delimbed energy round wood, including tree top in1150 mg. With regard to 1 t (dry weight) wood chips produced from forest residues 2.2 kg K were exported and in case of roughly delimbed round wood only 1.1 kg. Not included are spindles with diameter thicker than 7 cm and stem parts with wood decay.

4. Conclusions and Outlook

Quantification of nutrient and biomass export and saving, applying mass sum curves of tree compartments can be used if element concentrations of tree compartments, like branches and brushwood, are available for the particular stand or the region of interest. Frist results and the use case indicate that this method is a promising approach. Further investigation and calculations have to prove this. During the harvesting process data as tree height, cutting diameter and cutting height as well as the base diameter of the tree top, the height of the first green branch are necessary to collect. The development should be focused on collective properties of the tree groups and the investigation of further sites. If there are comparable results for the mass sum curve and the classification of tree groups, the use of this method could be extended. Ongoing analyses and evaluations have to be completed to receive more information. Comparing harvesting methods concerning nutrient saving, it is important to find the best balance between biomass yields and nutrient saving. The quantification of nutrient and biomass export and saving on wood chip samples allow a relative comparison of harvesting methods and/or bucking. The disadvantage is, that chemical analyses of the wood chips have to be available. This can only be carried out after harvesting and chipping. Forecasts can only be sufficient for comparable stands with similar growing conditions, soil and climatic conditions. In this case nutrient saving and biomass yield in dependence of the harvesting method and sorting can be considered already in the planning stage of the harvesting process. Whenever we produced wood chips of roughly delimbed energy roundwood instead of supplying wood chips of whole coniferous crowns, we observed a reasonable nutrient saving effect. Our data make us conclude, that the choice of harvesting method leads to a considerable nutrient savings potential.

5. Acknowledgements

This study was funded by the Bavarian State Ministry of Food, Agriculture and Forestry and was conducted by the department of Forest Technology, Economics and Timber of the Bavarian State Institute of Forestry from 2015 to 2018. Special thanks to Fabian Schulmeyer, Martin Högl, Birgit Reger, Marianne Schütt, Stefan Schuster and Karl Hüttl for their support and input. We also want to thank the Bavarian State Forest Enterprise for providing investigation stands and practitioner's expertise.

6. References

Bitterlich, W. (1984) The Relascope Idea. Relative Measurements in Forestry. Commenwealth Agricultural Bureaux. Farnham, England.

Deutsches Institut für Normung e. V. (DIN) (2010) DIN EN 14780. Feste Biobrennstoffe – Verfahren zur Probenherstellung. Berlin: Beuth-Verlag, 22 Seiten.

Deutsches Institut für Normung e. V.. (DIN) (2016) DIN EN ISO 18134-2. Biogene Festbrennstoffe – Bestimmung des Wassergehaltes - Ofentrocknung - Teil 2: Gesamtgehalt an Wasser – Vereinfachtes Verfahren. Berlin: Beuth-Verlag, 12 Seiten.

Daugbjerg-Jensen, P.; Bech, K. S.; Hartmann, H., Hinterreiter, S., Lazdins, A. and Bardule, A. (2010) „Methods for determining impurities in solid particulate biofuels". In: Wirkner, R.; Witt, J.; Seyfert U. (Hrsg.): BioNorm II - Pre-normative research on solid biofuels for improved European standards, Specific Targeted Research or Innovation Projekt, no. 038644, 01.01.2007-31.12.2009, Final Report, 11th Januar 2010. Leipzig: German Biomass Research Centre (DBFZ), European Commission (EC), S. 27–36.

Dietz, E., Kuptz, D., Blum, U., Schulmeyer, F., Borchert, H. and Hartmann, H. (2016) Qualität von Holzhackschnitzeln in Bayern. Gehalte ausgewählter Elemente, Heizwert und Aschegehalt . Berichte aus dem TFZ, Nr. 46. Straubing, Freising-Weihenstephan: Technologie- und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe (TFZ); Bayerische Landesanstalt für Wald und Forstwirtschaft (LWF), 141 Seiten, ISBN 1614-1008.

Dietz, E., Riebler, M., Schulmeyer, F., Schütt, M., Reger, B., Hüttl, K., and Schuster, S. (2018 unveröff.): Ressourcenschonung durch „Grob entastetes Energierundholz". Forschungsbericht LWF Projekt EW/13/47. 240 S

König, N. (2014) Handbuch Forstliche Analytik. 5. ergänzte Auflage. Herausgeber: Nordwestdeutsche Forstliche Versuchsanstalt. Göttingen.

Kuptz, D., Dietz, E., Schreiber K., Schön, C., Mack, R., Wiesbeck, M., Blum, U., Borchert, H. and Hartmann, H. (2018) Hackschnitzel aus dem Kurzumtrieb Brennstoffqualität und Verbrennungsverhalten. Berichte aus dem TFZ, Nr. 56. Straubing, Freising-Weihenstephan: Technologie- und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe (TFZ); Bayerische Landesanstalt für Wald und Forstwirtschaft (LWF), 190 Seiten.

Riebler, M., Dietz, E., Schulmeyer, F., Reger, B., Schütt, M., Schuster, S., Hüttl, K., Borchert, H. (2019) Quantification of logging losses related to biomass supply of forest residues caused by additional delimbing of harvesting heads.

Schulmeyer, F., Dietz, E., Reger, B., Hüttl, K. and Borchert, H. (2016): Effects of Roughly delimbing of coniferous crowns on biomass and nutrient exports and the productivity of teh forest wood chip production chain. Proceedings FORMEC 4th -7th of September, Warsaw, Poland.

FORMEC 2019 – Exceeding the Vision: Forest Mechanization of the Future
6-9 October 2019 – Sopron, Hungary

Soil Failures Under Rigid-Tracked Forestry Machines as a Function of Slope and Soil Wetness

D. H. McNabb
ForestSoil Science Ltd
Edmonton, Alberta Canada
dhmcnabb@telus.net

Abstract: *Forestry machines are at greatest risk of sliding on steep slopes when soils are essentially saturated. In soil mechanics, this situation is defined as the ϕ=0 condition. Values of c(ϕ=0) were calculated for a western Oregon forest soil from previously published data and soil water potentials wetter than -10 kPa. The distribution of pressure and soil contact for a rigid-track were calculated and combined with values of c(ϕ=0) to determine the net soil resistance. The value of c(ϕ=0) at saturation ratios of 0.8, 0.7, and 0.6, were 87, 155, and 287 kPa, respectively. As the value of c(ϕ=0) decreased, an uncontrolled, sliding failure was estimated to occur at slopes between -39 and -67 percent. When average track pressure and c(ϕ=0) were equal, a sliding failure was expected at a slope of -29 percent. Terramechanics models and coefficient of friction do not apply to track-soil interactions in the ϕ=0 condition.*

Keywords: ϕ=0 condition, terramechanics, coefficient of friction, unsaturated soil mechanics

1. Introduction

Using ground-based harvesting equipment on steep slopes is becoming more common because it is safer for workers and generally less expensive than cable systems (Visser and Stampfer 2015). Hence, operating large, rigid-tracked harvesting machines on steep slopes, with or without tethering, are becoming the preferred method of harvesting in mountainous terrain, especially in western North America and New Zealand (Sessions et al. 2017; Visser and Berkett 2015). Loss of traction on steep slopes is a major issue because of the risk of machines sliding downslope and turning over (Visser and Stampfer 2015). Turning, high slip, and repeated passes of ridge-tracked machines on steep slopes often destroys the tractive support of the slash mat and forest floor, as well as the underlying root mat, which results in a machine becoming dependent on the shear strength of the soil at the track-soil interface.

Soil wetness and slope are the two factors dominating soil shear strength at the track-soil interface. It is this complex interaction that determines the risk of a machine sliding downslope. There are currently two approaches to estimating the impact of soil wetness on a soil's resistance: 1) reducing the coefficient of friction, CoF, for wet soils (Hittenbeck, J. 2013; Visser and Stampfer 2015); and 2) using Bekker's (1962) terramechanics models of machine, soil, and slip-sinkage relationships (Sessions et a. 2017; Belart et al. 2019). These approaches are not valid when the soil at the track-soil interface is saturated, or becomes essentially saturated when the soil at the track-soil interface is compacted. Essentially saturated soils are common because some air is trapped in the pores of compacted soil. Two examples are: the separation between a soil compaction curve and the zero air voids line in soil compaction test; and the low air-filled porosity of soil after forestry machines traffic wet soils (McNabb et al. 2001).

1.1 Objective

The objective is to describe the soil mechanics of machine-soil failure for a rigid-tracked feller-buncher operating on wet soil that is compacted until the soil is essentially saturated. An example of soil failures will be given using the machine specifications recently published by Sessions et al. (2017), and adapta-

tion of surface forest soil shear strength and a consolidation/compressibility model for different soil densities and wetness for an interior Coast Range forest soil in western Oregon (McNabb and Boersma 1993, 1996).

1.2 Background

Bekker's (1962) terramechanics models were primarily developed using lateral earth pressure theory from foundation engineering, but applied it to top soils (Reece 1964). Bekker also developed his own instruments and protocols for measuring soil strength, which could also be used in the field. He reported soil strength as having two components: cohesion, c, and a frictional component, ϕ. The simple equation to described soil strength is

$$\tau = c + \sigma * \tan \phi, \qquad (1)$$

where τ is soil strength and σ is the normal force. The equation is the same as used in soil engineering; hence, Bekker also used soil engineering concepts to describe the soil failure process. In Equation 1, the normal force acts perpendicular to the slope while shear force acts perpendicular to the normal force. Hence, soil strength becomes a soil resistance force acting parallel to the slope.

In soil engineering, the values of c and ϕ are obtained by conducting soil engineering tests on several samples of the same soil at increasing initial values of σ. These tests are only done on drained undisturbed soil cores or when the values of σ have been corrected for changes pore water pressure (Das 2013). In a triaxial test, the test of each sample is defined by a Mohrs circle (dashed lines, Fig 1). The dashed line tangent to a series of increasing Mohrs circles defines the shear strength of the soil at failure. The cohesive value of soil strength, c, is defined as the intercept of the failure line when σ is zero. The slope of the dashed line is the angle of internal friction, ϕ. To clarify the ambiguity between the different values of c and ϕ obtained in soil engineering tests and his terramechanics measures of soil strength, Bekker (1969) later stated unequivocally that it was unwarranted to assume that values of soil strength obtained with a bevameter were the same as those obtained using soil engineering tests. Clay soil mixtures, and particularly natural clay soils, were also poorly represented in the development of terramechanics models. Consequently, soil wetness was also poorly integrated into his models. Hence, it soon became a common practice to reduce the value of ϕ to represent the shear strength of wet clay soils in terramechanics models (Reece 1964). This practice continues to be done (Sessions et al. 2017; Belart et al. 2019). Values of ϕ as low as 6 degrees have been used for forest soils when the values of ϕ for saturated forest soils in the Pacific Northwest obtained using soil engineering tests are greater than 30 degrees (Schroeder and Alto 1983; McNabb and Boersma 1993).

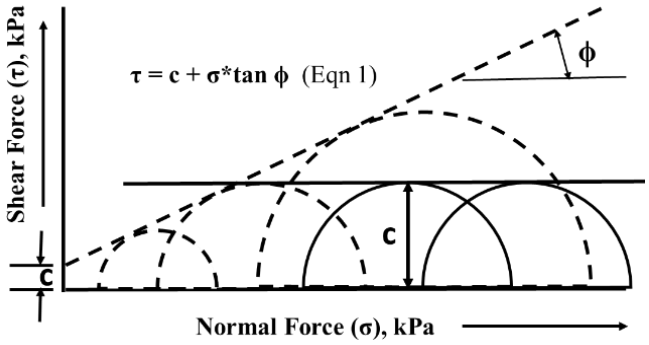


Fig 1. Mohrs circles and soil failure line (dashed lines) for drained soil strength, Eqn 1, and for unconsolidated-undrained tests of saturated soil (solid lines, Eqn 2)

Bekker (1962) focused exclusively on drained soils because his models included a sinkage component, but it is not clear how much was due to compressibility, compaction, of the soil versus soil displacement. Only twice was ϕ mentioned as having a value of zero and it was with regards to ideally plastic clays and snow. At which time, the shear strength was defined as being equal to c

$$\tau = c. \qquad (2)$$

Wong (2008) later reinforced the point that Eqn 1 did not apply to saturated clay soils. For the latter soils, Eqn 2 applied but with minimal elaboration. His explanation for focussing on Eqn 1 was that "…most of the trafficable earth surface generally have both cohesive and frictional properties…".

The values of c in Eqn 1 cannot be used in Eqn 2; however, only Reece (1964) explicitly state that a quick-test (an unconsolidated-undrained triaxial test) was the appropriate method for defining c when clay soils are saturated. This test is also referred to as the ϕ=0 condition. In an unconsolidated-undrained triaxial tests, the soil density remains constant in the absence of drainage and the grain-to-grain soil contacts responsible for soil strength remains unaffected (Mitchell 1976). Hence, the value of soil strength I the ϕ=0 condition is also constant.

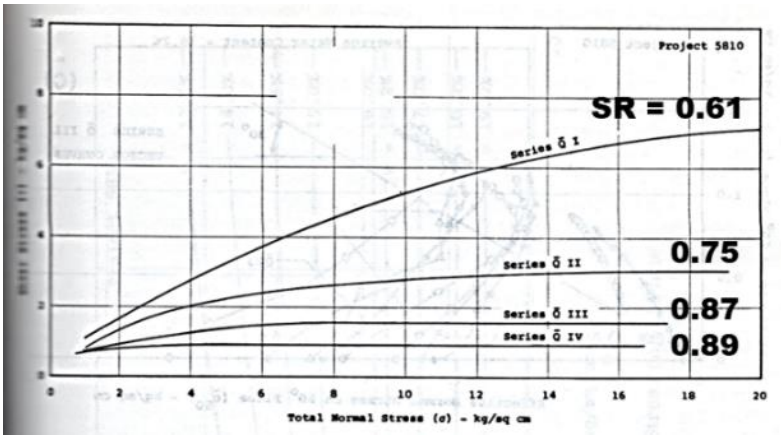


Fig 2. Failure curves as a function of τ (y axis) and σ (horizontal axis) for wet, partly saturated soils at four saturation ratios (Casagrande and Hirschfeld 1960)

Casagrande and Hirschfeld (1960) confirmed that compression of a soil at high saturation ratios can produce the ϕ=0 condition (Fig 2). In their example, curves were fit to several Mohrs circles, which showed τ as a function of σ (Fig 2). The value of τ initially increased with the increase in σ until the air in the soil had been compressed to a saturation ratio, SR, approaching 1. SR is a measure of relative amount of air-filled-pore space in a soil, and the total volume of soil voids. At such time, the curve became asymptotic; this is indicative of the ϕ=0 condition. The ϕ=0 condition is also illustrated in Figure 1 as a series of Mohrs circle of the same diameters (solid lines). Hence, soil strength in the ϕ=0 condition is the radius of the Mohrs circles, which is the value of cohesion, c(ϕ=0) that must be used in Eqn 2. Furthermore, Eqn 2 is only used when a soil is saturated, or is essentially saturated. The latter same condition also applies to wheels or tracks compacting a wet soil until only trapped air remains (McNabb et al. 2001).

Based on the example of Casagrande and Hirschfeld (1960), as the saturation ratio, SR, decreases, the inherent soil strength of the initially drier soil requires a larger value of σ to compress the soil until the curve become asymptotic (Fig 2). As a result, soils of a lower SR will have higher values of c(ϕ=0) as long as the soil remains essentially saturated. An example of how a series of Mohrs circles at different SRs, which had been compressed until essentially saturated, would appear relative to the drained shear strength at failure line is shown in Figure 3.

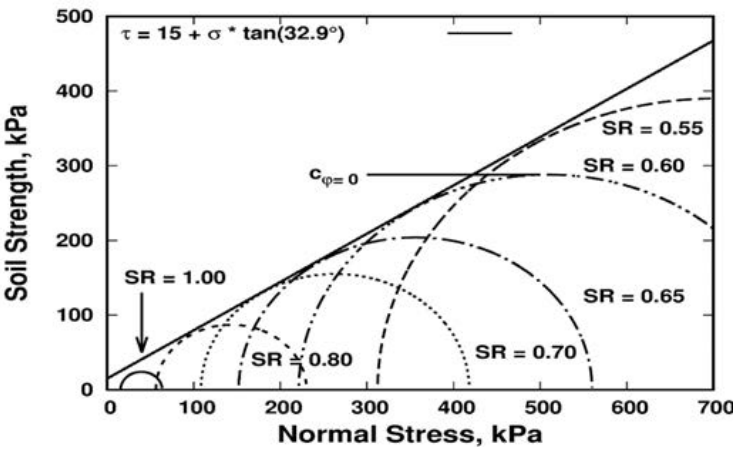


Fig 3. The c(ϕ=0) values of soil strength for an essentially saturated soil compressed at a initial SR between 0.55 and 1

2. Materials and Methods

The values of c(ϕ=0) for a range of saturation ratios was estimated for a soil similar to the soil for which Belart et al. (2019) reported a rigid-track harvester had slid down a 38 percent slope in western Oregon. Five values of c(ϕ=0) were estimated for the Jory soil based on a nonlinear model of soil density as a function of normal stress and saturation ratio, the drained shear strength of saturated soil, and the volume-weight relationships among soil density, specific gravity, soil water content, and air-filled porosity of the Jory (McNabb and Boersma 1993, 1996; Das 2013). The Jory soil is a clayey, mixed, mesic Xeric Haplohumult; it is a mature soil found in the lower foothills along the east side of the Coast Range Mountains in western Oregon. The soil is a clay loam and classified as an MH. The undisturbed soil density was 0.992 Mg/m^3, and had a specific gravity of 2.44 Mg/m^3. At a soil water potential of -10kPa, soil water content was 0.30 Mg/Mg, and had a saturation ratio of 0.58.

Undisturbed soil cores had been collected from the 7-12 cm depth, which was near the middle of the topsoil horizons; soil water content ranged from nearly saturated to dry when collected. A nonlinear model of soil density as a function on σ and SR was developed from one-dimensional consolidation tests (n=140, McNabb and Boersma 1996). Twenty-three of the samples were saturated and subsequently used in a direct shear test to measure the drained shear strength: c was 15 kPa, and ϕ was 32.9° (McNabb and Boersma 1993), For the five values of SR, in Fig 3, σ was estimated by calculating the soil density at which the soil would be essentially saturated soil for the respective SR. The value of τ for each value of σ was estimated from the drained soil shear strength, and the c(ϕ=0) of soil strength estimated from the Mohrs circle and soil strength relationships in Fig 1.

The maximum force exerted pm the leading and trailing edge of the rigid-track, and length of track in contact with the soil were recalculated for these analyses using the same machine dimensions and weight of a feller-buncher as Sessions et al. (2017). For a rigid track, the change in force along the length of the track in contact with the soil was assumed to be linear (Reece 1964).

When the track pressures were all less than the c(ϕ=0) value of soil strength, a stationary machine had not fully engaged the available soil strength and was not in the ϕ=0 condition. Whenever the track pressure was greater than the c(ϕ=0) value of soil strength, the track-soil interface along that length of track was assumed to be in failure. For all track force less than the c(ϕ=0) value of soil strength, the machine was not fully engaging the available soil strength, and when values of all track force were greater than c(ϕ=0). All three factors decrease the stability of the machine.

3. Results

A rigid-track feller-buncher exerts an eccentric force on the soil when the boom, stick, and felling head without out a tree is fully extended (Sessions et al. 2917). In this configuration and on level terrain, the rear edge of the track is not applying force to the soil (Fig 4). When oriented down-slope, the maximum force exerted by the front edge of the track increases several-fold. During uphill travel, the distribution of force on the soil is nearly constant as a slope of +50 percent. These are all static forces on the soil, which changes when the machine is working to fell trees or thrust is required to move on the slope (Lysne and Burditt 1983).

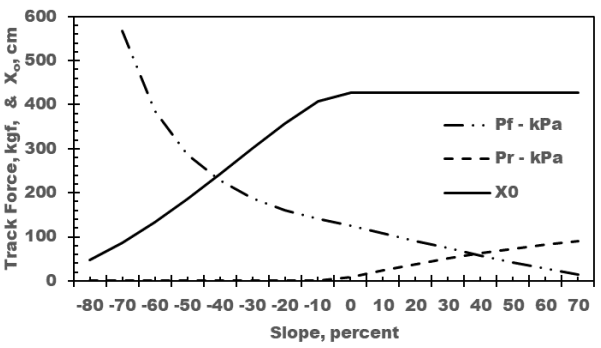


Fig 4. Maximum track force at front, P_f, and rear, P_r, edge of track, and length of track, X_0, in contact with soil as a function of slope for an untethered machine

The increase in soil density as a result of compression of unsaturated soil is seldom a consideration when the shear strength of soil is calculated (Fig 1). However, an increase in soil density is required for increasing grain-to-grain contact required to increase soil

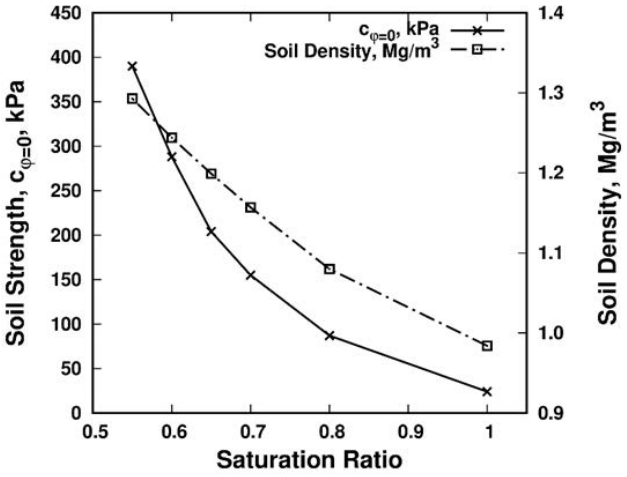


Fig 5. Soil strength, cϕ=0, and soil density as a function of the saturation ratio

strength (Mitchell 1976; McNabb and Boersma 1993). For unsaturated soil, compaction to increase soil strength and how soil density is limited by a lack of air-filled-porosity in wet soil is well understood. For the Jory soil, the soil density increased approximately in proportion to the decrease in saturation ratio (Fig 5). More importantly, the increase in the c(ϕ=0) value of soil strength increased exponentially as SR decreased. This increase occurred for a small range of soil water potentials (-10 to 0 kPa). A free-to-drain soil would be expected to drain to about -10 kPa in two days (McNabb et al. 2001). This range of soil water potential coupled with the range of saturation ratio would have had a minimal impacted on the soil strength un saturated soil (Bishop and Blight 1963). Hence, the increased in soil density is the dominant factor responsible for the increase in soil strength, but the increase is always limited by the air-filled porosity of the soil at the time of trafficking.

Bekker (1962) and Wong (2008) recognized the following equation as quantifying the maximum thrust, or total soil resistance, that wet soil could provide

$$TSR = c(\phi=0) * 2 * W * L \quad (3)$$

where L is track length and W is the width of one track; the value of soil strength has to be c(ϕ=0), and not c used in Eqn 1. TSR is also the maximum soil resistance preventing a machine from sliding downslope. TSR will frequently have to be reduced for the wide range of forces that exist at the track-soil interface because of machine geometry and slope (Fig 4), and for the effect that differences in soil wetness has on c(ϕ=0) (Fig 5). As a result, three scenarios are required to calculate the amount of the c(ϕ=0) soil strength that the area of track in contact with the soil engages (Fig 6). The direction of travel and slope were the two additional site-specific factors determining the value of the engaged soil resistance, ESR_i, for each value of c(ϕ=0). The three scenarios are: a) track pressures less than c(ϕ=0); b) track in full contact with the soil but the pressure under one section of the track exceeded c(ϕ=0); and c) only part of the track was in contact with the soil and consequently, the track force exceeded c(ϕ=0) (Fig 6).The correct scenario ultimately depends on the direction of travel, felling head extension, slope steepness, and how the track force interacts with the value of c(ϕ=0). When the track is not fully in contact with the soil, L is preplaced with the length, X_0 (Fig 6c).

The engaged soil resistance, ESRi, is the amount of the total soil resistance that the track can engage. The unengaged soil resistance, USR, is the amount of the TSR that the machine does not engage when the track force is less than the value of c(ϕ=0) (Fig 6a). In this situation, the USR can be used for the work and movement of the machine. USR also occurs when the track force are eccentrically distributed and some values of force is less than the value of c(ϕ=0) (Fig 6b,c). This USR may only be engaged if some minor sinkage of the track occurs in a stationary position.

The line defined by 'be' in Figures 6b,c is the length of track where the track-soil interface is in a state of failure. This failure plane is at the bottom edge of the grousers. Another way of thinking of the track-soil failure plane is conceptually similar to a shallow translational landside where the machine acts as a surcharge on the shallow failure plane. However, as a surcharge on the failure plane, the track force greater than c(ϕ=0) is an unengaged machine force, $UMF_{b,c}$. The original machine downslope force, M_τ, assumes that the machine normal force M_σ, is fully engaging the total soil resistance. This does not occur in the ϕ=0 condition because the value of c(ϕ=0) is constant and excess M_σ produces an additional downslope force. The excess M_σ is the $UMF_{b,c}$ in Figure 6b,c.

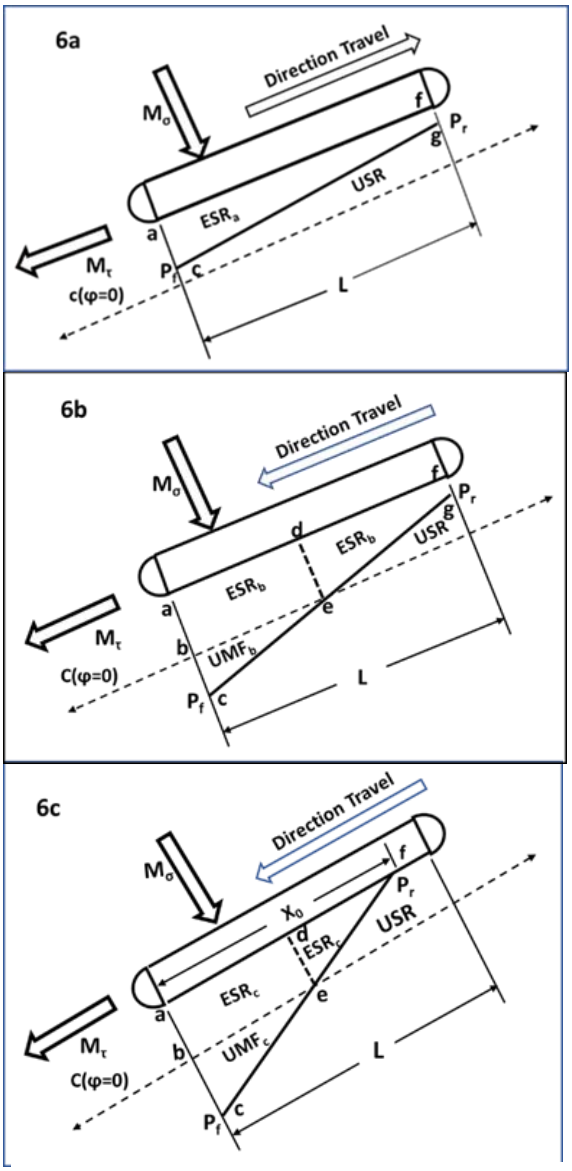


Fig 6. Diagrams illustrating the three scenarios for the track pressure-soil resistance c(ϕ=0) interface

The average track pressure of this machine is approximately 67 kPa. For an initially saturated soil, no increase in soil density is possible; hence, a c(ϕ=0) value of 67 kPa results in the minimum slope angle for this machine to slide of -29 percent. However, at a c(ϕ=o) of 67 kPa, the machine would be immobile regardless of slope because of the eccentric distribution of track pressures (Fig 4). This machine will not be stable on slopes over -65 degrees regardless of whether c(ϕ=0) is higher because of the small area of track in contract with the soil (Fig 4). Belart et al. (2019) recently reported that a feller-buncher of this size slid downslope on a soil similar to this soil at a slope of -38 percent.

Whenever the sum Mτ and the downslope component of UMF are greater than the engaged soil resistance, ESR, the machine is assumed to be in a state of a sliding, bare earth failure. The sliding of a machine also assumes that the forest floor and root system is no longer able to provide additional soil resistance because it has been removed or damage by previous track slip. Therefore, a machine sliding on bare earth is the worst-case scenario, which results following high wheel or track slip.

The difference between ESRi and the sum of the downslope forces is the net soil resistance, NSR. When the value of NSR is negative, the machine is assumed to be in a state of a machine sliding failure at the track-soil interface. For values of c(ϕ=0) of 87, 155, and 287 kPa, the corresponding slope angles at which the ESR is equal to the downslope forces are -39, -56, and -67 percent, respectively (Fig 7). A machine can be quasi-stable at slightly lower angles if sinkage of the machine is able to engage some of the USR, but any movement or rocking of the machine could readily disengage the USR thereby causing a machine to slide. Whenever a machine starts to slip, the machine is assumed to disengage from the USR, regardless. This disengagement process for an untethered machine is probably responsible for a machine accelerating downslope once a stationary machine starts to slip. Such acceleration contributes to the momentum that a sliding machine needs to plow through slash, forest floor and tree roots further down the slope.

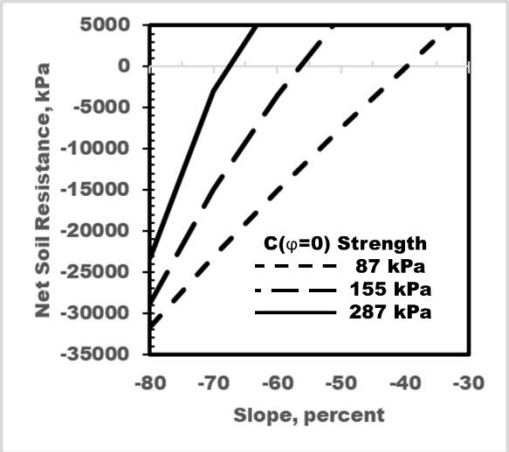


Fig 7. Net soil resistance is dependent on the c(ϕ=0) value of soil strength and slope when traveling downslope. Negatives values are indicative of a sliding failure.

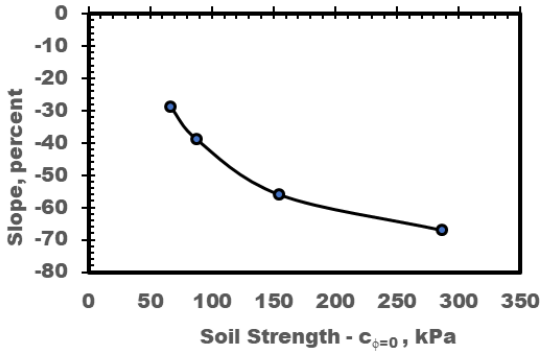


Fig 8. Downslope travel as a function of c(ϕ=0) when a sliding failure is anticipated

The NSR for an untethered feller-buncher operating on a wet soil at a SR of 0.80 is approximately -19 Mgf at a slope of -65 percent (Fig 7). On uneven terrain or when going over a stump or windfall, the slope may temporarily increase to -75 percent or more. At a slope of -75 percent, the NSR is approximately -28 Mgf. The values of NSR tend to converge for downslope operations on the steepest slopes, because the length at track able to engage the soil resistance is small (Fig 4). The value of NSR in the ϕ=0 condition also is the magnitude of the restraining force that tethering machines and associated cable systems must provide to stabilize a machine on a steep, wet soil. Additional force is required to allow the machine to effectively move and work.

4. Discussion

The $c_{\phi=0}$ values of soil strength have not been measured in surface soils because the engineering design requirements for this specific measure of soil strength is generally only measured when positive pore water pressures are anticipated on construction projects at depths of 2 to 20 m (Vardanega and Bolton 2011). Unfortunately, Reece (1964) was the only person that recognized saturated cohesive soils required a different method for measuring the cohesive strength of soil. These results confirm that the value of c(ϕ=0) increases exponentially with decreasing saturation ratio (Fig 5). While soil density is responsible for the increase in soil strength, soil density is not a particularly reliable method for quantifying the increases in the value of c(ϕ=0). For a SR of 0.80, soil density only increased about 10 percent; hence, small increases in soil density could be indicative of a soil at high risk of failure, but only if the ϕ=0 condition can be assumed. Furthermore, the feasibility of collecting a sufficient number of samples to reliably analyze soil density in this situation is very low (McNabb et al. 2001).

The ability to engage the USR is uncertain on steeper slopes. The engagement and effectiveness of the USR is most likely associated with maintaining an intact forest floor, and its relationship in maintaining an intact root system. Hence, maintaining the forest floor has many ecological and operational values. Deep slash mats and forest floors effectively spread track forces over a larger area of mineral soil, which significantly reduces the peak values of track pressures transferred to the underlying soil surface (Labelle et. al. 2015). Reducing the maximum values of track pressure on soil reduces the unengaged machine force on soil, which is an important factor reducing machine stability (Fig 6b,c). Soil strength is also increased by the root network (Wu 2013). Hence, terramechanics models that assume high slip is of value in increasing soil traction (Bekker (1962; 1969) can readily destroy the added value that the forest floor and root system have for increasing the effective soil resistance. Finally, sinkage of a track is highest at the point where the track force on the soil is highest (Reece 1964). For the feller-buncher, this is the leading edge of the track when operating downslope (Fig 4). If the machine starts to slide, the rear section of the track is expected to disengage from the USR because the leading edge of the track as already compacted the soil. Hence, c(ϕ=0) values of soil strength without consideration of the USR have been used for estimating the risk of soil failures because a bare earth failure is assumed to be the worst-case situation.

In the ϕ=0 condition, the failure plane is assumed to occur at the grouser edge of the track-soil interface, because grousers will sink quickly and fill with the soft soil. After working with a model tracked machine, Reece (1964) questioned the use of the Rankine geometry of soil strength and displacement in terramechanics models. Field experience concurs with his observations as well. The increases in soil density with increasing soil depth (McNabb et al. 2001) would also increase soil strength, which should also focus the location of the failure plane to a thin layer of soil below the grouser edge. Hence, the failure plane when a machine is sliding could be as thin as 1 cm.

Negative soil water potentials have long been an important parameter added to Eqn 1 when calculating the effect that changes in soil water content have on unsaturated, soil strength (Bishop and Blight 1963). Unfortunately, the related theories have not been refined enough to be used to solve many practical problems (Lu et al. 2014), such as this problem. An important issue is the approach does not consider how soil water potential and soil compaction interact to affect unsaturated soil strength. The measurement of soil water potential in the field with a handheld tensiometer has confirmed when soils were drier than about -15 kPa, forest soils were not significantly compacted by wide-tire skidder (McNabb et al. 2001). However, tensiometers are less likely to be sensitive enough to measure the small differences in the range of -10 to 0 kPa that these data show are important. Furthermore, values of soil water potentials are not easily related to the air-filled-porosity of soils.

The angle of internal friction of 32.9° for the Jory soil is high compared to other cohesive soils (Mitchell 1976). Hence, values of c(ϕ=0) for the Jory increases at a faster rate as the saturation ratio decreases (Fig 3) than the value will when weaker soils are compacted across the same range of saturation ratio. Therefore, the inherent drained shear strength of soil is an important factor determining the c(ϕ=0) value of soil strength. An equally important factor according to these data is the effect that the decreasing saturation ratio has on the value of c(ϕ=0) (Fig 5). How saturation ratios of different soils vary at soil water potentials is wetter than -10 kPa is poorly understood, and several components are required to measure it.

The measurement of air-filled-porosity, units are m^3/m^3, is proposed at the most efficient and effective method of assessing the impact of changing soil wetness on the value of c(ϕ=0). However, air-filled-porosity of soil is rarely measured (McNabb et al. 2001). Higher the air-filled-porosities will allow the wet soil to be compacted to a higher soil density, and consequently, a higher value of c(ϕ=0). Most importantly, air-filled porosity can easily be measure in the field, the mean values of air-filled-porosity are much smaller than those for soil density, and their standard errors of measurement are lower than for soil density (McNabb et al. 2001).

The ϕ=0 condition is also responsible, or a major contributing factor, for machines causing deep ruts on level terrain, particularly those ruts that develop after as few as one pass of a machine. Deeper ruts will quickly form in soils with minimal differentiation among horizons when the value of c(ϕ=0) remains relatively constant with increasing depth, or drier soil is encountered. These types of ruts are a form of bearing capacity soil failure (McNabb 1993), and more precisely defined as a punching soil failure (Vesic 1963; Das 2013). In soil engineering, punching soil failures produce minimal lateral displacement of the soil. In forest operations, the soil displaced by skidder wheels rises upward along the sidewall of the tire, and a relatively intact forest floor can sometime be found in the bottom of the rut after one pass. These types of ruts are appropriated described as bearing capacity ruts in contrast to ruts developing from many cycles of wheel or track slip and sinkage. Managing operations to reduce the latter is probably more likely.

Changing terrain, soil, and weather become important issues affecting machine mobility, operability, and stability when air-filled-porosity of wet soil limits the compaction required to increase soil strength in the ϕ=0 condition. The interaction of precipitation amount and frequency with terrain and soil are the primary issue. Although overland flow seldom occurs on the surface of most undisturbed forest soils, the downslope, saturated flow of water in and over one or more mineral soil horizons is common. Anytime there is a temporary, saturated zone in a soil profile (perched watertable), there is also a phreatic zone of water extending upward at a decreasing saturation ratio. These two factors increase the risk of ϕ=0 conditions developing during and after precipitation or in areas where water will accumulate within a harvest block. Therefore, on-site tracking of rainfall is obviously an important management option to help assess the risk of when ϕ=0 conditions are most likely to occur. The dynamic impact of the frequency and duration of precipitation on the development and duration of ϕ=0 conditions in a soil, make developing a risk rating system for machine sliding on slopes based on a fixed set of slope classes unworkable. However, more complex rating systems to include terrain, soil, recent precipitation, and hillslope hydrology are possible but require testing (McNabb, unpublished).

The coefficient of friction also does not apply to the machine trafficking of soil when the ϕ=0 condition exists. During the ϕ=0 condition, soil strength at the track-soil interface is constant and total soil resistance is defined by Eqn 3 (Bekker 1969; Wong 2008). This is in contrast to CoF, which is based on Eqn 1. CoF is simply the ratio of τ/σ, or the tangent of ϕ. Therefore, CoF only applies to drained soil where soil resistance increases in direct proportion to the force applied to the soil. Most important, CoF applies regardless of the distribution of force under the track or wheel, and regardless of whether the track or wheel are in contact with the soil. In the ϕ=0 condition, track pressure at the track-soil interface is required to engage the TSR (Fig 6a). This seldom occurs when there is an eccentric distribution of pressure under a rigid track (Fig 4). As a result, the effective soil resistance is generally less than TSR because it is reduced for areas where track force is less than c(ϕ=0), and the downslope force increases when the force is greater than c(ϕ=0). Both factors reduce machine stability on steep slopes.

5. Conclusions

Trafficking of wet soil by forestry machines often compacts the soil until it is essentially saturated, and no further increase in soil density or strength is possible. In a soil mechanics context, this situation is defined as the ϕ=0 condition. The ϕ=0 condition is unique because it produces a single value of soil strength, c(ϕ=0), that is independent of the forces exerted on the soil. The value of c(ϕ=0) is dynamic for a specific soil because deceases in the initial air-filled-porosity with the drying of soil allows the soil to be compacted to a higher value of c(ϕ=0). The ϕ=0 condition only applies as long as the soil remains essentially saturated. Therefore, the value of c(ϕ=0) and area of track-soil contact determines the effective soil resistance to a machine sliding on steeper slopes. When any point at the track-soil interface is less than or greater than the c(ϕ=0) value of soil strength, the stability of a machine decreases. As a result, the slope at which a forestry machine is at risk of sliding on bare earth depends on the eccentric distribution of force along the bottom of the track as the slope angle changes and the value of c(ϕ=0). Hence, a specific slope angle can not be specified for when a machine is at risk of sliding because of the effects that weather, soil and terrain has on air-filled-porosity. Unfortunately, this introduces considerable uncertainty as to the stability of untethered rigid-track machine on wet soils, and risk of sliding can not be defined by a set range of slope classes. The downslope forces produced by a machine on steep slopes and soils with low values of c(ϕ=0) exerts a high force on tethering machines and cables, which increases the risk of these systems failing as well.

When a machine is operating on a soil in the ϕ=0 condition, terramechanics models and values of the coefficient of traction are invalid because they are based on soil strength parameters, c and ϕ (Eqn 1), for drained soil.

6. References

Bekker, M.G. 1962. Theory of Land Locomotion, 2nd Ed. Univ. of Michigan Press, Ann Arbor, MI. 522 p.

Bekker, M.G. 1969. Introduction to Terrain-Vehicle Systems.

Belart, F., B. Leshchinsky, J. Sessions, W. Chung. P. Green, J Wimer, and B. Morrissette. 2019. Sliding stability of cable-assisted tracked equipment on steep slopes. For. Sci. 65:304-311.

Bishop, A.W., and G.E. Blight. 1963. Some aspects of effective stress in saturated and partly saturated soils. Geotechnique 13:177-197.

Casagrande, A., and R.C. Hirschfeld. 1960. Stress-deformation and strength characteristics of a clay compacted to a constant dry unit weight, p. 359-417. In: Amer. Soc. Civil Engr, Research Conf. on Shear Strength of Cohesive Soils. Boulder, CO.

Das, B.M. 2013. Fundamentals of Geotechnical Engineering, 4th Ed. Cengage Learning. Stamford, CT. 636 p. ISBN-10: 1-111-57675-0

Hittenbeck, J. 2013. Estimation of trafficable grades from traction performance of a forwarder. Croat. J. For. Eng. 34(1):71-81.

Labelle, E.R., D. Jaeger, and B.J. Poltorak. 2015. Assessing the ability of hardwood and softwood brush mats to distribute applied loads. Croat. J. For. Engr. 36:227-242.

Lysne, D.H., and A.L. Burditt. 1983. Theoretical ground pressure distributions of log skidders (forest equipment). Trans. ASAE 26:1327-1132.

McNabb, D.H. 1993. Soil care: Plan now or pay later. Can. For. Industries (June):33-37.

McNabb, D.H., and L. Boersma. 1993. Evaluation of the relationship between compressibility and shear strength of Andisols. Soil Sci. Soc. Am. J. 57:923-929. doi:10.2136/sssaj1993.03615995005700040007x

McNabb, DH., and L. Boersma. 1996. Nonlinear model for the compressibility of partly saturated soils. Soil Sci. Soc. Am. J. 60:333-341. doi:10.2136/sssaj1996.03615995006000020003x

McNabb, D.H., A.D. Startsev, and H. Nguyen. 2001. Soil wetness and traffic level effects on bulk density and air-filled porosity of compacted boreal forest soils. Soil Sci. Soc. Am. J. 65:1238-1247. doi:10.2136/sssaj2001.6541238x

Mitchell, J.K. 1976. Fundamentals of soil behavior. John Wiley & Sons, Inc., New York. 422 p.

Lu, N., N. Khalili, E. Nikooee, and S. Hassanizadeh. 2014. Principle of effective stress in variably saturated porous media. Vadose Zone J. 13:vzj2014.04.0038. doi:10.2136/vzj2014.04.0038

Reece, A.R. 1964. Problems of soil vehicle mechanics. Land Locomotion Laboratory, U.S. Army Tank-Automotive Center, Warren, MI 228p.

Sessions, J., B. Leshchinsky, W. Chung, K. Boston, and J. Wimer. 2017. Theoretical stability and traction of steep slope tethered feller-bunchers. For. Sci. 63:192-200. dx.doi.org/10.5849/forsci.16-069

Schroeder, W.L., and J.V. Alto. 1983. Soil properties for slope stability analysis; Oregon and Washington coastal mountains. For. Sci. 29:823-833.

Vesic, A.S. 1963. Bearing capacity of deep foundations in sand. Highway Res. Record No 39:112-153. Nat'l Acad Sci.

Visser, R., and H. Berkett. 2015. Effect of terrain steepness on machine slope when harvesting. Int'l J. For. Engr. 26(1):1-9. doi.org/10.080/14942119.2015.1033211

Visser, R., and K. Stampfer. 2015. Expanding ground-based harvesting onto steep terrain: A review. Croat. J. For. Eng. 36:321331.

Wong, J.Y. 2008. Theory of Ground Vehicles, 4th Edition. John Wiley & Sons, Hoboken, NJ. 560 p.

Wu, T.H. 2013. Root reinforcement of soil: review of analytical models, tests, results, and applications to design. Can. Geotech. J. 50:259-274. doi.org/10.1139/cgi-2012-0160.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

MECHANIZED PRE-COMMERCIAL THINNING BY UPROOTING

Karri Uotila
Natural Resource Institute Finland
Neulaniementie 5, 70210 Kuopio
karri.uotila@luke.fi

Abstract:
Uprooting offers a novel and refreshing perspective for Mechanization of pre-commercial thinning (PCT), which has been challenging task to comply. PCT-process has been re-thought in uprooting to take advantage of mechanization with an innovative way, which would not be possible manually. Uprooting efficiently prevents sprouting, and there is no need for herbicides. The work is done with Naarva P25 – device attached to the harvester boom. The idea behind uprooting works, and it can offer serious competition to traditional motor-manual PCT.

Keywords: mechanized silviculture, productivity, quality, alternative forest vegetation management

1. Introduction

Conifer sapling stands are typically Pre-Commercially Thinned (PCT) by cutting competing trees, which reduce the growth of commercially valuable conifers. Removal in PCT consists mainly of broadleaves, which will re-sprout vigorously from stumps (e.g. *Betula* sp.). Sprouting causes the need for repeated cuttings, why typical management program consist of more than one PCT. In Finland, the first PCT is recommended in around 1 meter high conifer stands (4–6 years old) and the second in 3–4 meters high (Saksa et al. 2016). Sometimes even more PCTs are needed.

Preventing sprouting saves further expenses. Or, in other word, a method that prevents sprouting can be more expensive to comply on the first phase of the management program, and still be efficient. Sprout prevention also makes sooner PCT possible, as crop trees benefit and get more advantage after removal of competing trees.

Mechanized PCT by uprooting prevents sprouting of broadleaves efficiently, as uprooted trees do not sprout from stumps. Uprooting can also reduce the number of root suckers, which are generated by some tree species e.g. *Populus Tremula* and *Alnus incana*, even though it won't totally prevent them. However, trees regenerating from root suckers are typically in minor part of the removal in PCT.

Uprooting has been introduced in Finland, and it is yet to be almost exclusively used in there. The aim of this paper is to introduce the method and the most relevant information about productivity, expenses and quality of its work published about it. Moreover, based on the available information, expenses of the method are compared to motor-manual PCT.

2. Uprooting with Naarva P25 –device

Naarva P25 is a PCT-device made for harvesters (Fig 1). It is designed in Finland by Pentin Paja Ltd. The P25 weighs 590 kg and, according to Hallongren & Rantala (2013), the purchase price of it is about 15000 €.

The P25 has a frame able to PCT 2 m^2 per movement. The trees removed in PCT are squeezed in to the frame of the device, after which the driver raises the device, and the movement uproots the trees. Then the operator lets the trees loose and drops them on the ground. Hence, mechanized PCT with Naarva P25 is also described as uprooting.

The P25 is a suitable device for PCT on conifer stands on mineral soils during spring, summer and autumn, when the ground is not in frost (Kukkonen & Kukkonen 2013). Stands of average height of main stems of 0.8–1.5 m are the best fit for uprooting (Uotila 2016, Luukkonen 2018).

Uprooting is more effective release treatment than cutting the broadleaves, because uprooting decreases the competition in the root system for rather long-term. According to Hytönen (2013), four years after PCT spruce was as an average 7% longer and its' stem was 14% thicker on uprooted stands compared to motor-manually sawed stands.

3. Productivity & costs

3.1. Mechanized PCT with Naarva P25

In experimental conditions, Naarva uprooter attached to the harvester boom have typically done PCT about 0.15 hectares per productive work hour (pwh), or, in the other words, PCT has taken about 6.7 pwh/ha (Rantala & Kautto 2011, Hallongren & Rantala (2013). According to Rantala & Hallongren (2013) the current model, Naarva P25, consumed 6.3 pwh/ha in PCT and the time consumption varied between 3.5–9.9 pwh/ha. The time consumed in PCT depends on density and height of the removal (Fig 2).

According to Hallongren & Rantala (2013) the total costs of the harvester operating Naarva P25 is 63.46 €/pwh. The variable cost is 40.43 €/pwh and the fixed part of the P25-device is 2.10 €/pwh. The average uprooting cost per hectare based on productive work hours was 399 € on average, varying 223–628 €.



Fig 1. Naarva P25 –device for mechanized PCT by uprooting.

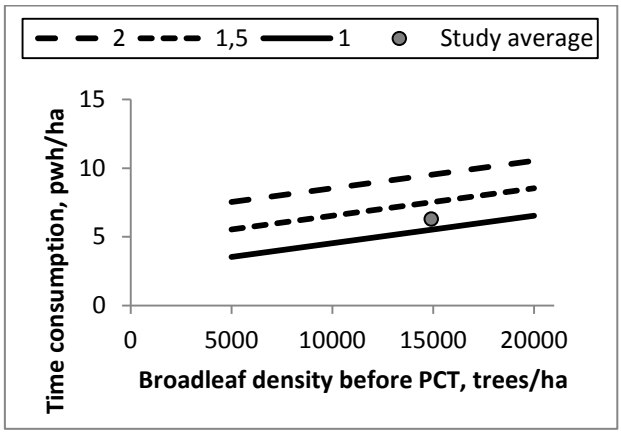


Fig 2. Time consumption in PCT done with Naarva P25 in productive hours per hectare (pwh/ha) according to Hallongren & Rantala (2013). The lines represent broadleaf height before PCT from 1 to 2 meters in different densities.

3.2. Comparison to motor-manual PCT

The average time consumption of uprooting is rather similar to motor-manual cleaning on typical first stage PCT of 4–6 years old stand. Thus, per hectare costs of uprooting are higher than that of motor-manual PCT. However, in early stage PCT, the ability of uprooting to prevent sprouting decreases need and costs for the forthcoming PCT(s).

In similar conditions and removal to Hallongren & Rantala (2013), the speed of motor-manual cleaning is 6.6 twh/ha (total working hours) (Hämäläinen & Kaila 1983, Metsäalan TES 2010). The twh-based cost of such motor-manual PCT is 168 €/ha, with the rate of 25.5 €/pwh including salary, equipments (4 €/pwh), and travelling (2.2 €/pwh). Salary equals the salary used for the operator in Hallongren & Rantala (2013). The twh-based cost was used for motor-manual work, because all of the fixed costs, and relocation time and preparatory work were included in the pwh-based costs of uprooting in Hallongren & Rantala (2013).

The total cost of uprooting was 399 €/ha (Hallongren & Rantala 2013). Thus, the second PCT in motor-manual program should cost less than 230 €/ha or take less than 9 twh/ha to be less expensive than uprooting. However, the expenses are likely higher than that. The cost of the second stage motor-manual PCT is typically somewhat higher than the first management (Uotila et al. 2010 & 2014). Assuming 1.5 time multiplier, the second management is 253 €/ha. Thus, the total costs of the motor-manual PCT-program is 421 €/ha. Mechanized PCT by uprooting can be cheaper than motor-manual PCT, if uprooting prevents the need for the second management. The result is in line with the cost comparisons of Strandström et al. (2011) and Kukkonen & Kukkonen (2013).

Moreover, only those machines that do not have primary, i.e. logging worksites available during summer are used in mechanized PCT. Such harvesters can be rational in PCT if the payment exceeds variable costs of the use added with the cost of the PCT-device. The pwh-based variable costs of uprooting with Naarva P25 is 267 €/ha (including the total cost of the device) on average site introduced in Hallongren & Rantala (2013). It is the minimum rational cost for mechanized PCT.

4. Quality of mechanized PCT by uprooting

Quality of mechanized PCT by uprooting can be quantified numerically according to the success of the spacing. Moreover, mechanized PCT indices more damage to main stems than motor-manual PCT, which should be also accounted in quality.

There is still some room to improve the thinning precision in uprooting. According to Hallongren & Rantala (2013), 10–25% of the trees that were supposed to be removed in PCT, were not removed. Because of retained disturbing trees, some main stems were still under broadleaf competition after uprooting. Typically 48–66% of the main stems have been perfectly released in uprooting (Hallongren & Rantala 2013, Korhonen 2013, Uotila 2016, Luukkonen 2018).

The success of release depends on worksite selection, especially on stand height. Success rates are often poor in stands under 80 cm of average height of main stems (Uotila 2016, Luukkonen 2018). On the other hand, the release is often highly successful in stands over 120 cm (Uotila 2016, Luukkonen 2018). The highest stands in the studies have been mainly under 200 cm long, which has not yet reduced the success rate in the studies. However, other problems may incur in longer stands, e.g. time consumption increases or incidence of damage for main stems in PCT. Also site factors affect the success rate, which is often poorer on highly fertile and moist sites (Luukkonen 2018). The results consider mostly mineral sites, as mechanized uprooting is not recommended on peatlands (Kukkonen & Kukkonen 2013).

The incidence of damage to main trees is higher in uprooting than in motor-manual PCT. The incidence of serious damage is typically 5–8% of the saplings in uprooting (Rantala & Kautto 2011, Hallongren & Rantala 2013, Uotila 2016). The main cause for the damage is the base machine driving over the main tree (Hallongren & Rantala 2013, Uotila 2016). Also movements of the uprooting device cause some damage.

Over time, the damage of uprooting seems to vanish, 3–5 years after uprooting there was visible damage only on less than 1% of the main trees and only in 42% of the stands (Luukkonen 2018). However, the density of competing trees increases over time because some new broadleaves still germinate and grow after uprooting. The average density 3–5 years after uprooting was 7000 trees/ha, including main stems, and all the trees retained in uprooting and the broadleaves germinated and grown after it (Luukkonen 2018). Even though the number is much higher than would be appropriate to grow during that stage, major part of them are small broadleaves, which might not survive long in competition caused by higher main stems.

5. Conclusions

Mechanized uprooting is a novel PCT method, which prevents sprouting efficiently. It decreases the need and costs of later PCT(s). However, at its present state, uprooting has not been able to totally prevent the need for later PCT. Mechanized PCT by uprooting can still be less expensive method than conventional motor-manual PCT. Though, when total costs of a new harvester and an uprooting device were accounted, it should prevent the second PCT to be more profitable than motor-manual method.

Those harvesters that do not have primary, i.e. logging worksites available during summer, can be used for PCT rather inexpensively. At the minimum, the cost should cover total costs of the uprooting device and the variable costs of the harvester. With such cost, mechanized PCT by uprooting can be very rational alternative for motor-manual PCT, even though it should still reduce forthcoming PCT costs.

Mechanized uprooting has been shown to prevent sprouting. However, it still remains unclear how often uprooted stands actually need later PCT. Anyhow, if needed, the later PCT can be done only partially and the removal is lesser than with the conventional method. Thus, the second PCT is less expensive than after motor-manual PCT.

Quality of uprooting still needs improvement, and it can be improved by better selection of worksites or by improving working techniques. Total stand densities after uprooting have been too high to reach the target of only one PCT in the PCT-program as a rule. On the other hand, the damage caused by uprooting for the main trees can be considered rather minor according to the longer term observations, especially if the initial spacing is appropriate.

Overall, mechanical uprooting of broadleaves has a great potential. It takes advantage from the power that mechanization has to offer, and the idea of uprooting actually works well in practice. However, improvements in productivity and quality of the work are still needed. Otherwise motor-manual option is likely to remain the primary method on major part of PCT worksites.

6. References

Hallongren, H. & Rantala, J. (2013) A search for better competitiveness in mechanized early cleaning through product development: evaluation of two Naarva uprooters, International Journal of Forest Engineering, 24:2, 91-100, DOI: 10.1080/14942119.2013.841930

Hämäläinen J., Kaila S. (1983). Taimikon perkauksen ja harvennuksen sekä uudistusalan raivauksen ajanmenekkisuhteet. [Relative time consumption of clearing-saw (brush-cutter) work in clearing, and in young stand cleaning and thinning]. Metsätehon katsaus. 4 p. (In Finnish)

Hytönen, Harri. (2013). Kitkentäperkauksen ja raivaussahatyön vaikutus kuusen pituuskasvuun ja kantoläpimittaan neljä vuotta varhaisperkauksen jälkeen. [The effect of Mechanized PCT by uprooting and motor-manual PCT on four year growth of spruce]. University of Eastern Finland, Faculty of Scienc and Forestry. Bachelor's thesis 25 p. (In Finnish)

Korhonen, N. (2013). Kitkentäperkauksen laatu metsähallituksen Lieksan ja Nurmeksen tiimeillä. Summary: Quality of Mechanical Cleaning in Lieksa and Nurmes teams of Metsähallitus. Karelia university of applied sciences. Thesis. 36 p. + 2 appendices.

Kukkonen, K. & Kukkonen, E. (2013). Koneellinen metsänhoito. [Mechanized silviculture]. Karelia ammattikorkeakoulu. Kopijyvä Oy, Kuopio. 131 p. ISBN 978-952-275-085-3 (In Finnish)

Luukkonen, O. (2018). Konekitkentä varhaisperkausmenetelmänä kuusen istutustaimikossa. Summary: Mechanical uprooting as early cleaning method in planted spruce stands. University of Helsinki, Forest Ecology and Management. Master's thesis. 39 p.

Metsäalan työehtosopimus 1.5.2008–31.5.2010. (2008). [Collective labor agreement on forestry 2008]. Maaseudun Työnantajaliitto, Metsähallitus, Metsäteollisuus ry, Yksityismetsätalouden Työnantajat, Puu- ja erityisalojen liitto. 87 p. (In Finnish.)

Rantala, J. & Kautto, K. 2011. Koneellinen kitkentä taimikon varhaisperkauksessa – työajanmenekki, kustannukset ja työjäljen laatu. [Mechanized uprooting in early PCT of a sapling stand – time consumption, expenses and quality]. Metsätieteen aikakauskirja 1/2011: 3–12. (In Finnish)

Saksa, T., Miina, J. & Uotila, K. (2016). Taimikonhoito. [Pre-commercial Thinning]. Metsäkustannus Oy ja Luonnonvarakeskus. Latvija, Jelgeva Printing House. ISBN 978-952-6612-82-9. (In Finnish)

Strandström, M., Saarinen, V-M., Hallongren, H., Hämäläinen, J., Poikela, A. & Rantala, J. (2011). Koneellisen istutuksen ja taimikonhoidon kilpailukyky. [Competitiveness of mechanized planting and PCT]. Metsätehon raportti 218. 29 p. (In Finnish)

Uotila, K., Rantala, J., Saksa, T. & Harstela, P. (2010). Effect of soil preparation method on economic result of Norway spruce regeneration chain. Silva Fennica 44(3): 511–524.

Uotila K., Saksa T., Rantala J., Kiljunen N. (2014). Labour consumption models applied to motor-manual pre-commercial thinning in Finland. Silva Fennica vol. 48 no. 2 article id 982. 14 p.

Uotila, K. (2016). Konekitkennän laatu yksityismetsissä – case Pohjois-Savo. [Quality of mechanized PCT by uprooting in non-industrialiazed private forests – case Northern Savonia]. Taimiuutiset 4/2016: 13–15. (In Finnish)

FORMEC 2019 – Exceeding the Vision: Forest Mechanization of the Future
6-9 October, 2019 - Sopron, Hungary

GROUND-BASED FOREST MACHINERY AND TACTICS: IMPROVING WILDLAND FIRE SUPPRESSION OPERATIONS IN WESTERN NORTH AMERICA

Chris Bielecki
Supervisory Civil Engineer
USDA Forest Service, Modoc National Forest
225 W 8th St, Alturas, California, United States of America
christopher.s.bielecki@usda.gov

Stephen "Obie" O'Brien
Logging Engineer, Forest Operations Engineering, LLC (US Forest Service, Retired)
Helena, Montana, United State of America
obie@foresterobie.com

Abstract: The 2018 wildland fire season was the deadliest and most destructive year on record in California. While proactive land management (e.g., forest thinning, fuels treatments, and prescribed burning) may be the most effective preventative measure to mitigate wildfire impacts, reactive fire suppression techniques can also benefit from emerging and available mechanical technologies.

Empirical evidence and fire behavior observations from the Stone Fire (2018) in Northeast California became another costly example of logging equipment underutilization. Logging equipment could have been deployed to construct indirect firelines to avoid evacuation and burn-over of the nearly completed, active timber sale area. Modernization within the traditional North America wildland fire suppression organization are increasing the use of mechanized equipment and improving required firefighter qualifications. This paper highlights helpful references that inform and assist wildland firefighting management teams, land managers and operations experts on selecting the correct forestry tools and tactics.

Keywords: *wildland fire suppression, forest operations, heavy equipment, tactics*

1. Introduction

Catastrophic wildfires have become common place in the western United States. In California during 2018, nearly 2 million acres burned, exceeding $12 billion in damages. Almost 23,000 homes were destroyed, and 103 people were killed. Wildland firefighting varied greatly across the State based on the different vegetation, topography, and available resources.

In northern California, use of logging equipment in the right conditions and situations presents a viable tool for direct and indirect suppression in timbered locations. Other areas of North America, including the Northern Rockies, have further embraced and used logging equipment for wildland fire suppression. This paper presents a brief summary of available tools and associated issues with the use of logging equipment to fight wildland fires in Western North America.

2. Machines: Types and Tasks

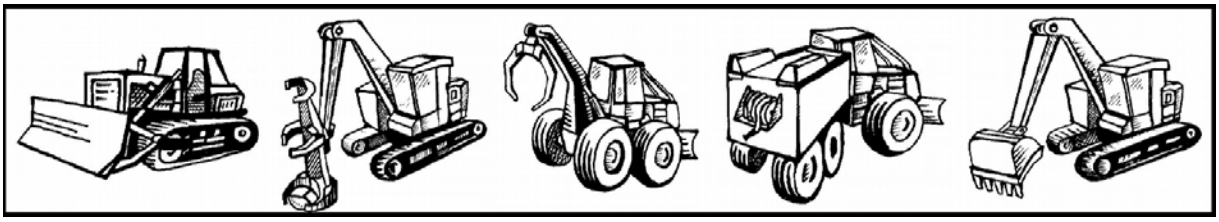


Figure 1 - Forestry machines are purpose-built for many tasks
Graphics credit: Ry Basko

Many individuals working in fire and fuels management are unfamiliar with the broad range of forestry equipment. This is particularly true when incident managers are brought in from out-of-state or region. Likewise, many agency land managers are not familiar with machine capabilities, costs, limitations and site impacts when heavy equipment is used to manage fire.

Fire and fuels personnel benefit from learning more about these machines and the values of a mechanized task force to order and use the best available machine to the task. Wildfire personnel need better access to heavy equipment training and information to correctly match their task objectives with forestry machine capabilities and limitations.

MACHINE TYPE / FIRE TASK	Feller Bunchers & Harvesters	Wheeled Skidder	Dozer & Tracked Skidders	SoftTrack Skidgines	Excavators, Shovels and Loaders	Forwarders & SuperSkidgines	Skidgines (Tracked, Wheeled)	Mulchers	Road Grader
Fireline and Fuelbreak Construction	X	X	X	X	X	X	X	X	X
Night Operation	X	X	X	X	X	X	X	X	X
Site Rehab	X	X	X	X	X	X	X	X	X
Vehicle Assistance	X	X	X	X	X	X	X	X	X
Tree Felling or Snagging	X	X	X	X	X		X	X	
Tree or Log Skidding		X	X	X	X	X	X		
Tree or Log Decking		X	X	X	X	X	X		
Tree or Log Bunching	X	X	X		X				
Brush Piling		X	X		X		X		
Brush Trampling			X		X		X		
Brush Cutting	X				X			X	
Pruning	X				X			X	
Water Hauling				X		X	X		
Water Application				X		X	X		
Road Work			X		X				X

Figure 2 - Machines and task capabilities

Tools and Tactics

Modern forestry machines expand operational capabilities for wildfire Incident Management Teams and land managers. Forestry machines are purpose-built to increase safety, speed, efficiency and operation periods.



Image 1 - Cutting indirect fireline with feller-buncher, while track and wheel skidders swing logs to decking area

Heavy forestry equipment offers firefighters increased capabilities:

- Safer, night-time fireline construction, when most fire activity decreases;
- Faster, safer indirect and contingency fireline construction;
- More opportunities for direct line on fires too dangerous for hand crews (>4 ft. flame length);
- Safer methods of hazardous tree removal and brush clearing;
- A force multiplier to increase crew capabilities, efficiency and safety;
- Contracted equipment is an economic option as call-when-needed resources.



Image 2 - Left to Right: Dozer, pumpercat, wheel skidder, wheel skidder with drop-tank, feller-buncher, excavator, softtrack skidgines

3. Safety

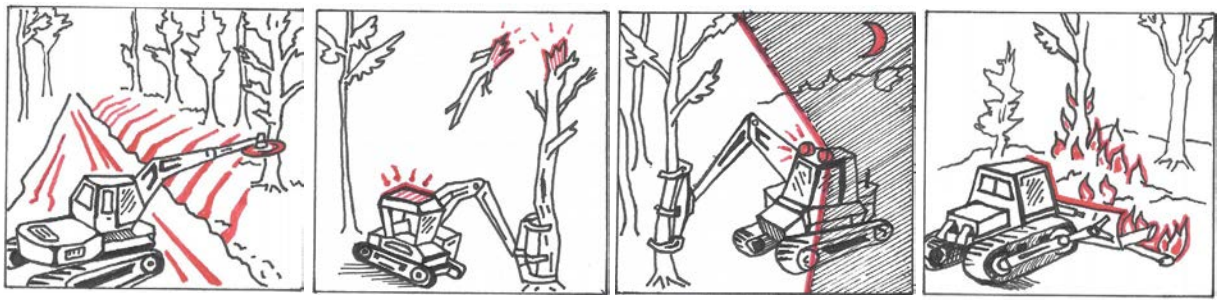


Figure 3 - Safety advantages using mechanized wildfire operations: cut, position, night operations, clear hotspots
Graphics credit: Ry Basko

Hazard trees are present before, during, and especially after a wildfire. The longer a wildfire burns, the greater the increased risk to personnel and the public from overhead hazards. A special concern on wildland fires is the increased presence of dead and burned-out trees that result in falling snags. These overhead hazards are of critical concern for personnel outside of machine cabs and under poor visibility conditions.

The three primary hazards for in-woods heavy equipment operators are addressed by the machine cab structure: machine rollover, falling objects and cab penetration by limbs or trees. Forest equipment manufacturers design and build forest machine cabs that meet Occupational Safety and Health Administration (OSHA) specifications to protect the operator: Operator Protection System (OPS), Falling Object Protection System (FOPS) and Rollover Operator Protection System (ROPS).

Safe operating slope limits and site conditions are key factors for using machinery in the wildland fire environment. Machine design and the operator's experience must also be evaluated to determine where and when to allow mechanized operations.

Operational slope limits vary by what the machine is expected to do, the machine design (e.g., woods safety package, leveling cab, longer tracks with deeper grousers) and site conditions (e.g., amount of rock, jack-strawed deadfall, bogs). Machine and ground factors must be understood to select the right equipment for the location and assigned task: tracks or wheels (with chains or track bands), traction (i.e., slope limits, soil conditions) and float (i.e., soil strength, machine ground pressure).

4. Dispatch, Transport, and Access

Wildland fire dispatch requires agency ordering, machine preparation and vehicle access. This often requires use of road maintenance equipment to ensure access and escape routes, e.g., brushing out roads for increased sight distance, dust abatement, verification of bridge weight limits and traffic controls. Dozers were used to clear some escape routes in Paradise, California, when burnt power-poles and trees fell across public escape routes.



Image 3 – Mobilizing dozer strike team

Lowboy transport is critical, and is often a problem for highway lowboys transporting heavy equipment. Tight road alignment in mountainous terrain and poor maintenance of forest road systems often present major challenges for machine transport attempting to deliver heavy equipment close to the fire. In steep and rough terrain, poor road alignment with steep vertical curves or tight horizontal curves (<60' ft. radius) may require route access improvements prior to lowboy entry or a long machine walk-in.

5. Remote Delivery of Water

Large super-skidgines (>1200 gal tank) and smaller more agile skidgines (tracked, wheeled) extend water availability to remote areas beyond the reach of fire engines and water tenders. Large skidgines are used to transfer water from roadside tenders to porta-tanks, and as trailside water tenders for smaller mobile skidgines, softtracks and pumpercats. Skidgines also ensure water delivery when aerial methods are grounded due to darkness, smoke or fog.

Skidgines are popular with crews for mop-up. The log grapple and blade help reposition logs and pull apart brush piles while providing water for crews. Water cannon equipped, a skidgine can knock down torching and fire in treetops. The light-duty blade can also be used for a safety brake, can dig out hotspots, and push over small hazard trees, reducing risks to hand crews and chainsaw fallers.

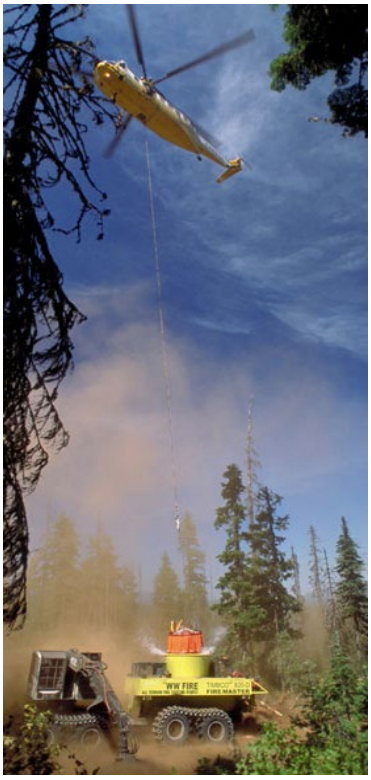


Image 4 - A helicopter transfers water to a super-skidgine for night shift work

6. Stone Fire, Northeast California, 2018

The Stone Fire began with a summer lightning strike in a remote area of northeastern California on the Modoc National Forest. The smoke was first detected on the morning of August 15, 2018. The fire initially smoldered in the morning. The same afternoon sun, heat and wind led to increased fire behavior. A Type II Fire Management Team was ordered the same afternoon due to the fire growth and complexity.

As the wildfire spread over the next few days, daytime suppression operations included direct aerial suppression and retardant drops, combined with indirect bulldozer line construction. Nighttime operations applied backfiring and burning out to blacken and solidify indirect fireline while anchoring to existing roads and bulldozer lines. For the first several days, the fire spotted and jumped containment lines, before it entered treated areas of the Turner and Craig timber sales.

On August 21, the fire was observed burning through the Turner Timber Sale by firefighter John Toomey, Fire Battalion Chief on the Modoc National Forest. Due to the terrain, residual vegetation and tree spacing in the recently treated timber stand, the fire behavior was moderate and dropped below the canopy to move through the treated area as a surface fire. The reduced flame lengths and spread in this situation allowed for safe direct fire suppression, presenting a reasonable opportunity for control and containment.



Image 5 - Observed fire behavior in the Turner Timber Sale
Photo courtesy of John Toomey, USDA Forest Service



Image 6 - Condition of the Turner Timber Sale immediately after the fire passed through
Photo courtesy of John Toomey, USDA Forest Service

During this time, another adjacent timber sale was also burning with similar results. The Craig Timber Sale was still actively being harvested at the start of the Stone Fire. The logging crew was subsequently evacuated, and forced to demobilize a side of equipment several miles to a safety zone. The crew was safely evacuated, though the loggers and equipment were not use for further work to suppress the wildfire in adjacent timber stands.

Fire behavior in the Craig Timber Sale area was even more telling, demonstrating how forest stand treatments can effectively change fire behavior to reduce damaging fire impacts. Here Toomey observed the flames transition from a crown fire to a ground fire after progressing approximately two tree lengths into the treated sale area.



Image 7 - Craig Timber Sale after the fire front moved through; on the left of the road is the freshly-treated stand, on the right of the road is an untreated stand
Photo courtesy of John Toomey, USDA Forest Service

7. Northern California Fire Operations

This section is based on a conversation with Gwen Sanchez, who leads Northern California Firefighting Operations for the USDA Forest Service. Sanchez noted that there is good potential yet limited use of logging equipment on federally managed fires in California. Feller bunchers were used in 2018 on the Ranch and Carr Fires, though most of the work involved repair and rehabilitation that occurred late during the tail end of fire suppression.

Construction of safety zones and escape routes in timber are recognizable tasks that would benefit from machines built to cut and maneuver tall trees while protecting the operator in an enclosed and protected cab,

especially in dead or dying timber and where snags subject manual sawyers to risk from tops and limbs falling and striking firefighters on the ground.

Use and choice of equipment is based on a number of factors, including probability of success. Some areas have high potential for effective fuels treatments in preparation for a fire front moving through, while others may have too much risk associated with felling and decking timber that flames can reach. If unremoved or still-awaiting yarding when a fire front passes over, decked timber can create a situation where too much fuel creates hazardous conditions for firefighters and ineffectively changes fire behavior.

Experience and assurance with fire managers is another factor. California-based incident management teams typically are assigned to fight fire within California, resulting in less mixing of experience and knowledge regarding tools and tactics that may be used in other locations – such as the Northern Rockies. Furthermore, political and environmental challenges exist with cutting, yarding, and decking timber during an emergency. Though the fuels treatments and changes in fire behavior may be successful and allow for more efficient and safe fire suppression, others may view this as circumventing the National Environmental Policy Act process, including the required public involvement.

8. Tools and Tactical Innovations

Tethered Logging Equipment Use of logging machines that are assisted by winch and cables on steep slopes is increasing in the Pacific Northwest (PNW) USA and western Canada. Ponsse estimates that there are twenty tethered cable-equipped Ponsse machines operating in the PNW. There are four different makes and models of tethering systems marketed in the western US. Tethered machinery use is increasing in the mountainous regions of the western US for logging. It is just starting to be used for forest fireline construction.



Image 8 - Dual cable tethering system with leveling feller-buncher and remote-controlled drum set mounted on an excavator

In the summer of 2017 the Whitewater Fire threatened to burn from federal land onto private timberlands near Detroit, Oregon. The lumber company contacted a local logging contractor with a tethered side for operating on steep slopes. The 2-machine tethering system allowed the company's swing boom feller-buncher with a 28-inch felling sawhead to operate on steep slopes (55-80 % slopes). The remote-controlled winch cable drum set was attached to a track excavator anchored upslope.

Due to the short time predicted before the fire would reach the private property boundary, the lumber company needed to quickly clear an indirect fireline and create a backfiring opportunity. The agency incident team did not have adequate fire suppression resources (e.g., hand crews) to do the work on the steep terrain (up to 80% ground slope) before the fire might reach the private ground.

The 2-machine EMS Tractionline tethered equipped logging side constructed a 1,500-ft long x 80 ft.-wide swath of felled timber as a fireline in less than 3 days. The agency incident team later contracted the logging side to construct fireline on federal portions of the fire.

The wildfire did not reach the indirect line, and backfiring from that line was not done. After the fire the felled timber was skidded from the gentle ground, and skyline yarded from the steep slope sections for use by the mill.

Heavy Equipment Task Force (HETF) Logging equipment for fire suppression has been in use in the Northern Rockies (ID, MT, ND, SD, WY) since the mid-1980s. Currently, the Northern Rockies Wildfire Contracting Group (NWCG) is the only fire coordinating group contracting up to six machines for one resource order as a Heavy Equipment Task Force (HETF). The HETF resource is primarily contracted to contain the fire by building fireline, constructing safety zones, clearing access and escape routes. When the fireline is constructed other resources, primarily agency resources (e.g., hand crews, engines and aviation) will hold the line and suppress the fire.

The HETF is fashioned after the local equipment configurations of a mechanized logging side. These are typically a whole-tree logging side consisting of tree felling machines (i.e., feller-buncher/harvester), tree and log skidding machines (e.g., wheel or track skidder), earth moving machines (e.g., dozer with 6-way blade or excavator with bucket and thumb), and water carrying machines capable of off-road travel (e.g., skidgines or pumpercats).

Water is delivered most often by a skidgine, which is a skidder, dozer or soft-track machine with a water tank, pump and live-hose reel. Another option is a grapple skidding machine with a water drop tank, a pump and live hose reel. These machines can do the work of a grapple skidder, and serve as a skidgine to deliver water as needed. The pumpercat is a fully-functional dozer, and has an attached water tank, pump and live-hose reel to function as an off-road engine. The softtrack skidgine is an agile machine with a steep-slope climbing flexible track and large tank capacity (>1200 gal.), often equipped with a water canyon.

Another popular alternative machine in a HETF may be a tracked swing-boom excavator or shovel with a mulcher head. The mulcher (i.e., masticator) can fell small trees, brush and prune lower branches from larger trees. Each HETF is made up of the same machines designed to harvest timber and construct roads, landings and trails as part of timber sales, road construction or forestland clearing operations.

The HETF also includes its own siderod or foreman. This person provides the additional benefit of local knowledge of the operators, and familiarity with the logistical needs of the equipment. This supervisory position is coupled with an agency fire team Heavy Equipment Boss (HEQB). The HEQB is the tactical partner to help achieve the fire team's objectives. The HETF includes machine operators who are familiar with working together. The operators have the skills to perform equipment maintenance and servicing on their specific machine makes and models.

The HETF equipment is contracted on a call-when-needed basis, minimizing incident costs. When the fire and site rehabilitation are complete, the job is done, and the HETF is released. Its crew members return to work at their regular forestry jobs.

Ground Slope Maps Topographic maps with ground slope classes based on machine operation capabilities and slope limitations are helpful in wildland fire incident operations planning. Additional data, particularly LIDAR (Light Imaging Detection and Ranging), is invaluable in planning fire incident operations and heavy equipment deployment. This is especially important when the fire team or contracted resources are not local.

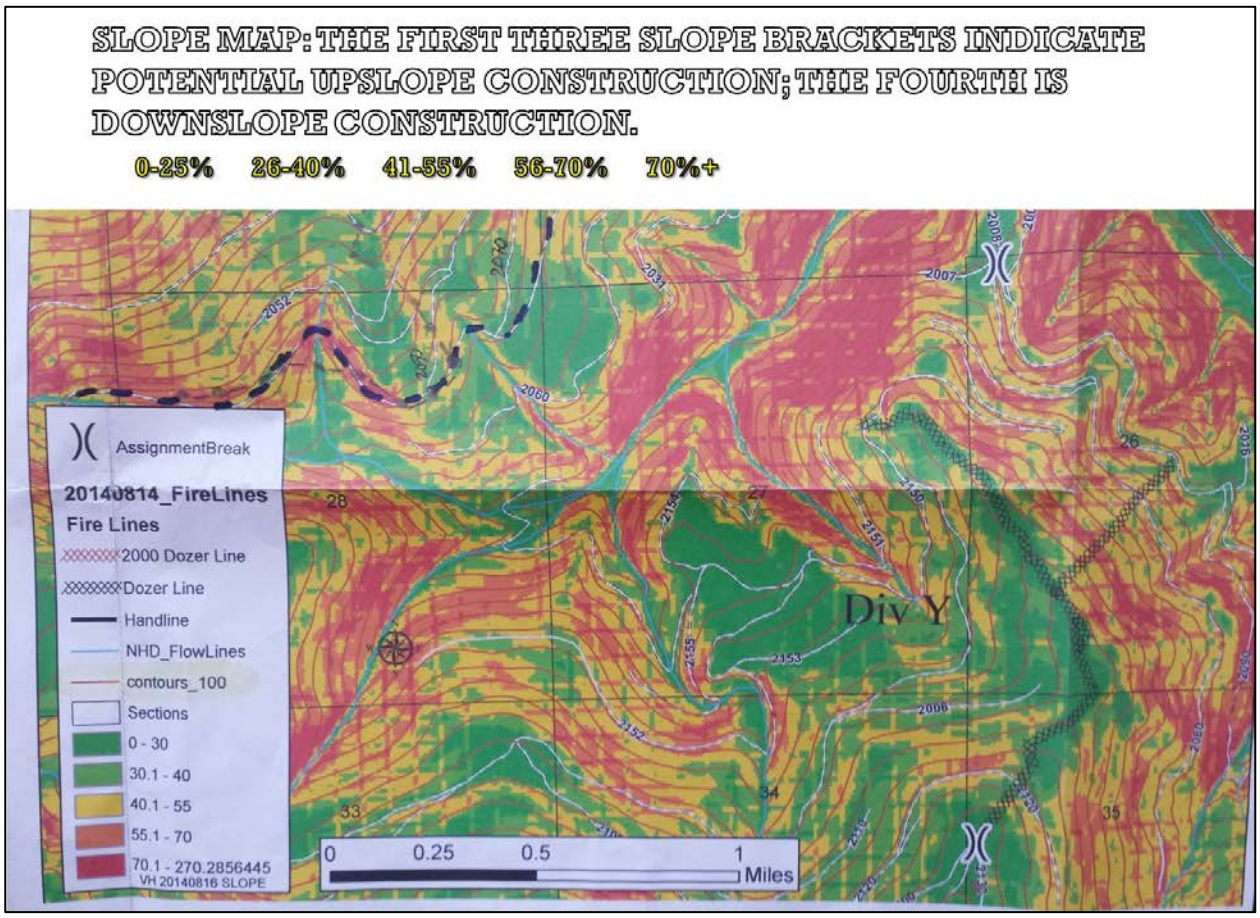


Figure 4 - Contour map with machine operability slope classes commonly found in the Northern Rockies region

9. References

Bielecki, Christopher S. (2004) Using loggers and logging equipment to fight wildland fires. Master of Forestry Paper, Forest Engineering Department, Oregon State University. Accessed online Aug 31, 2019 @ https://ir.library.oregonstate.edu/concern/defaults/1j92gd121

Jaffe, Valerie and O'Brien, Stephen. (2009) Mechanized Equipment for Fire and Fuels Operations. Accessed online Aug 31, 2019 @ https://www.fs.fed.us/r1/fire/nrcg/Committees/Equipment/Mechanized%20Equipment.pdf

Wikipedia: 2018 California wildfires. (2019). Accessed online Aug 31, 2019 @ https://en.wikipedia.org/wiki/2018_California_wildfires

S17 Decision Support & Virtual Reality
Simplify your decisions

ANALYSIS OF RUT FORMATION USING PARTICLE-BASED TERRAIN SIMULATION

Viktor Wiberg [1], Martin Servin [1], Tomas Nordfjell [2]
[1] Umeå University, Umeå, Sweden; [2] Swedish University of Agricultural Sciences

MULTICRITERIA DECISION ANALYSIS FOR SELECTING THE SUSTAINABLE LOGGING SYSTEM IN TEAK PLANTATION

Nichmon Plodchum, Nopparat Kaakkurivaara, Wanchai Arunpraparut
Department of Forest Engineering, Faculty of Forestry, Kasetsart University, Bangkok, Thailand

USING VIRTUAL REALITY TO IMPROVE OPERATIONAL PLANNING AND TEACHING

Dominik Roeser [1], Tim Caldecott [2], Holger Griess [1]
[1] University of British Columbia, Vancouver, Canada; [2] FPInnovations, Vancouver, Canada

MANIPULATING CHAIN TYPE AND FLAIL DRUM SPEED FOR INCREASED PRODUCTIVITY AND VALUE RECOVERY IN CFDDC OPERATIONS

Raffaele Spinelli [1,2], Rick Mitchell [2], Mark Brown [2], Natascia Magagnotti [1,2], Andrew McEwan [3]
[1] CNR IVALSA, Firenze, Italy; [2] University of the Sunshine Coast, Marochydoore, QLD, Australia; [3] Nelson Mandela University, George, Republic of South Africa

AVATAR: ADVANCED VIRTUAL APTITUDE AND TRAINING APPLICATION IN REAL TIME

Dirk Jaeger [1], Marian Schönauer [1], Bruce Talbot [2], Rolf Björheden [3], Eva Skagestad [4], Michael Corsano [5], Gerhard Rinkenauer [6], Thilo Wagner [7]
[1] Department of Forest Work Science and Engineering, Georg-August-Universität, Göttingen, Germany; [2] Norwegian Institute of Bioeconomy Research, Ås, Norway; [3] Skogforsk, Uppsala, Sveden; [4] Skogbrukets Kursinstitutt, Biri, Norway; [5] Optea, Oslo, Norway; [6] Leibniz Research Centre for Working Environment and Human Factors, Dortmund, Germany; [7] Wald und Holz NRW, Arnsberg, Germany

Analysis of rut formation using particle-based terrain simulation

Viktor Wiberg*, Martin Servin* and Tomas Nordfjell†

* Department of Physics
Umeå University
SE-90187 Umeå, Sweden
e-mail: viktor.wiberg@umu.se, martin.servin@umu.se, web page: http://www.umu.se/

† Department of Forest Biomaterials and Technology
Swedish University of Agricultural Sciences
SE-901 83 Umeå, Sweden
e-mail: tomas.nordfjell@slu.se, web page: https://www.slu.se

ABSTRACT

The possibility of simulating realistic rut formation from heavy terrain vehicles with 3D dynamics simulation is investigated [1]. The used simulation technology combines rigid multibody dynamics for the machine and the discrete element method for the terrain. A number of virtual soil beds are created with different microscopic model parameters, which control the interaction between the pseudo-particles of the soil. Simulated cone penetrometer and triaxial test are performed to determine macroscopic mechanical properties, i.e., the soil's cone index, internal friction, and cohesion, for each soil bed. Next, a quarter-vehicle with a two-wheeled bogie is driven repeatedly over the different terrains and the rut depth is measured after each passage.

A soil with cone index 400 kPa, internal friction angle of 25° and cohesion 8 kPa was studied in particular. The simulated rut depths and rut depth evolutions were studied for three different quarter vehicle masses, 3.6, 4.4, and 5.2 tons. The 4.4 ton vehicle was also tested on a stronger soil with cone index 840 kPa, internal friction angle 35° and cohesion 6 kPa. The results are in good agreement with WES-based models for rutting, expressed as functions of the vehicle's geometry, weight, and the soil's cone index.

In the present form, the model is limited to sedimentary soils where moisture content can be viewed as implicitly included. The computational time and memory usage depend on the number of pseudo-particles in the soil model. Therefore, the spatial resolution of the terrain is limited by practical restrictions. In the study carried out, the particle size ranged between 20 to 40 mm.

The conclusion is that the examined simulation technique is valid for studying the rut formation from forest machines and how the rut depends on the geometric design, weight and control of the machine.

REFERENCES

[1] V. Wiberg, M. Servin, and T. Nordfjell. Particle-based terrain - a validation study. Technical Report Technical Report, Umeà University, Mar. 2019.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

Multicriteria Decision Analysis for Selecting the Sustainable Logging System in Teak Plantation

Nichmon Plodchum, Nopparat Kaakkurivaara, Wanchai Arunpraparut
Department of Forest Engineering
Faculty of Forestry, Kasetsart University, Bangkok, Thailand
50 Ngamwongwan Rd., Chatuchak, Bangkok, 10900
Nichmon.pl@ku.th

Abstract: *Currently Thailand's export of wood products is in a crucial period since both domestic and foreign consumers become more aware of the environment and society. Many consumers prefer toward legally, socially, and environmentally product, in other words, wood products must be certified. This is relatively new for Thailand's logging industry. Forest certification requires a reform of logging and forest plantation management to compliance with international standard. Selection of logging is an important measure in plantation forestry and each work task requires different equipments, machineries and methods, resulting in differences in operating cost and environmental impacts. In order to maintain the forest certification, logging planning is required to select proper tools and machinery for the specific area, in all consideration of economic, social and environmental factors. This study uses a preliminary survey of forest plantation experts in accordance with Delphi method to determine the factor weight in logging system. The Physical characteristics such as slope, transportation route and water body are also taken in consideration. The expected results of this study is to determine a suitable logging system for the specific area and meet requirements of forest certification standard.*

Keywords: Multicriteria decision analysis, Technical feasibility, Logging system, SFM

1. Introduction

Nowadays overuse of natural resources effect to degradation of natural resources and environment as consumption soars in accordance with population and economic growth. Thus, existing resources are inadequate to the increasing needs, leading to conflict between the state, private and community (both rural and urban) sectors as they compete for the limited resources. The state's resource allocation efficiency is also lacking. For this reason, development of knowledge for sustainable resource management is necessary to promote long-term resource abundance, reduce tension between sectors and maximize public interests such as the economy, society and environment. Sustainable resource management can improve logging efficiency and promote sustainable timber supply and thus resource consumption should be based on sustainability.

Sustainable forestry management involves economic, social and environment factors with the goal to ensure that products and services can meet the needs while the forest area is preserved in the long run. Nevertheless, export of wood product in Thailand have both good and bad times simultaneously (Tosatjawong, 2011) because the standard put forth by the forest certification is more conducive to transparency and good management. In order to satisfy forest certification standard, systematic and sustainable management is necessary.

Logging operation is crucial to achieve adequate level of productivity in plantation forestry and each phase requires different tools, machinery and procedure. In Thailand, the common method is tree-length method: the felled tree will be delimbed, then skidded to the roadside for grading and cross cutting, after that the logs are moved to stacks for timber auction or delivery to factory. Each step requires different

tools, machinery and procedure, which causing different amount of cost and impact to the environment. To create an effective logging that complies with the forest certification standard, many social, economic and environment factors must be put into consideration, also multi-criteria decision analysis must be integrated with geographical information system (Boroushaki and Malczewski, 2008; Liu *et al*., 2007; Malczewski, 2006).

This study aims to find a suitable logging method using by multiple-criteria decision technique to compere results three interconnected performance areas to ensure the sustainability of forest operations include: environment, economics (quality optimization of products and production) and society (Marchi *et al*., 2018). Practical field examples are presented to demonstrate how these three interconnected principles are relevant to achieving sustainability, namely profit and wood quality maximization, ecological benefits and forest worker's health and safety. However, as the analysis is still in-progress, technologically-suitable solution is presented first.

2. Materials and methods

2.1 Study Area

This research is planned to be conducted in the area of Khao Kra Yang Teak Plantation, Phitsanulok Province. Khao Kra Yang Forest Plantation is under Phitsanulok Area Forest Industry Organization. Khao Kra Yang Forest Plantation is located at UTM satellite coordinates (WGS1984) 47Q E 0686239 N 1863226. The geography is Hanginal plain with elevation between 200 and 700 meters above mean sea level. The area generally consists of dry deciduous forests and deciduous dipterocarp forests. Notable natural flora is Teak, Xylia xylocarpa, and Burmese Padauk. Silvicultural system is selection thinning and rotation period are 30 years, This planation was established between 1968 to 1984 with the area of 2,420 hectares.

2.2 Overall research project information

This study aims to analyze information using physical characteristics and logging system to get a technologically suitable solution. Inclination, stand data, skid trail and technological specification are used as factors in identifying the suitable logging system for the area. Three other factors (economical, social and environmental) are also analyzed. Economical factor includes hourly cost and productivity system (Greulich *et al*., 1996). Environmental factor is ground pressure of the machine, which depends mainly on weight of the machine and contact surface area. Impact of the machine consists of empty weight, maximum load weight, width and height of tires (Kuhmaier and Stampfer, 2010). Tracked vehicles have less load pressure compared to wheeled vehicles. Calculation is done by using vehicle cone index (Maclaurin, 2007). Lastly, social factor is worker injury rate. Then, all three factors are calculated by using Delphi weight and analyzed together with the technologically suitable logging system (Figure 1).

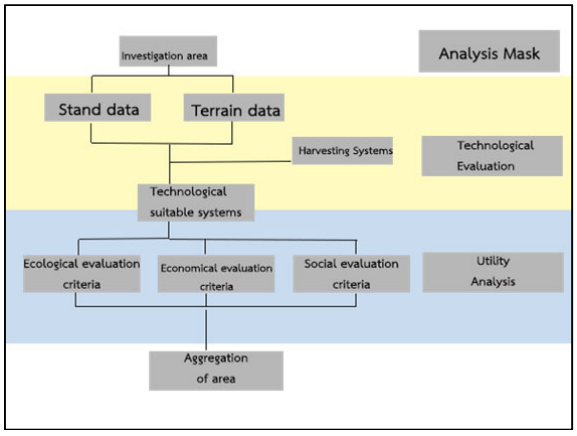


Figure 1 Overall research framework

2.3 Machine limitations analysis

The study aims trying to examine a suitable logging system for teak plantaion based on sustainable management, which requires awareness of economic, social and environmental factors, along with analysis of logging technology in order to find the best machine for each harvesting site, Where have different degree of accessibility of harvesting machines. Used factors are slope (shown as %) that is a limitation for both tracked and wheeled vehicles (Kuhmaier and Stampfer, 2010), and skid trail is a limitation for machines such as towers yarders and skidders (Pentek *et al*., 2008). Another factor is the limiting DBH for fellers bunchers, harvesters and processors depends on the type of harvesting head (Table 1).

Table 1 Definitions of logging systems and technological specifications to stand and terrain data

Systems	Logging Systems	Technological Specification
A	Chainsaw & Elephant	Slope < 20%, Extraction distance < 200 m
B	Chainsaw & Skidder	Slope < 35%, Extraction distance < 600 m
C	Chainsaw & Tractor	Slope < 30%, Extraction distance < 400 m
D	Chainsaw & Toweryarder & Processor	Slope < 100%, Extraction < 800 m., DBH max 40 cm
E	Harvester & Toweryarder	Slope < 60%, Extraction < 800 m., DBH max 40 cm
F	Harvester & Forwarder	Slope < 30%, Extraction distance < 600 m, DBH max< 40 cm
G	Feller buncher & Skidder & Processor	Slope < 35%, Extraction distance < 600 m.
H	Feller buncher & Tractor & Processor	Slope < 35%, Extraction distance < 400 m.

Slope is classified into five levels: 0-20%, 20-30%, 30-35%, 35-40% and > 40%. Skid trail is classified into four levels: 0-200 m., 200- 400 m., 400-600 m. and 600-800 m. Criteria of each machine is used for analysis to get the most technically-feasible systems (Figure 2).

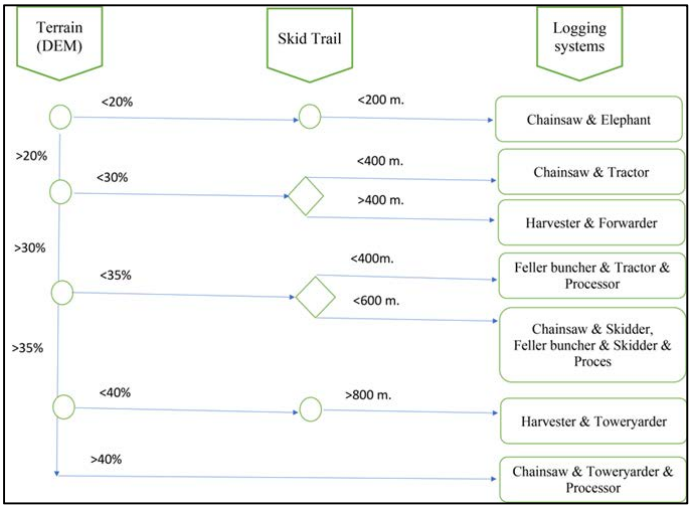


Figure 2 Model for Logging system determination.

2.4 Analysis of the sample plot's soil condition

To classify soil condition, 66 random sample plots in experimental area are analyzed by using a Skokagro static penetrometer examine soil compaction. Soil samples (500 g.) are collected from each sample plot to examine their soil type. Data obtained from the Skokago tool is soil compaction of each sampled spot. The method used is interpolation (IDW) to get soil compaction data of the entire plot no.1971. If soil compaction value is less than 2,000 it means low compaction . Type of soil sample from the area is for analysis to find consistency of soil type with soil compaction value.



Figure 3 Skokagro tool
Source: sss-labor.com

3. Results

Analysis by using logging machine limitation as a factor and physical characteristics of area shows that logging systems in use are system A (27.87% of the total logging area), system B & system G (13.33%), system C (25.91%), system D (7.95%), system E (6.95%), system F (12.31%) and system H (5.68%). Because most of area have moderate slope rate, suitable logging systems are Chainsaw-Elephant and Chainsaw-Tractor (Figure 4 and Figure5).

Analysis of plot no.1971 sample plot (Figure 6) also shows that the most soil is sandy clay loam and soil compaction is mostly low to moderate compaction (Skokagro, n.d.), soil erosion and water flow are very likely to occur (Melemez, 2015). Also, shear resistance and bearing capacity are low, which means the plot is inaccessible for heavy machinery. Technical analysis shows there are five suitable logging methods for the 1971 sample plot: system A, system B, system C, system E, system F and system G. But system E, system F and system G require heavy machinery and not applicable for the plot, so additional studies of other factors are needed to take into account.

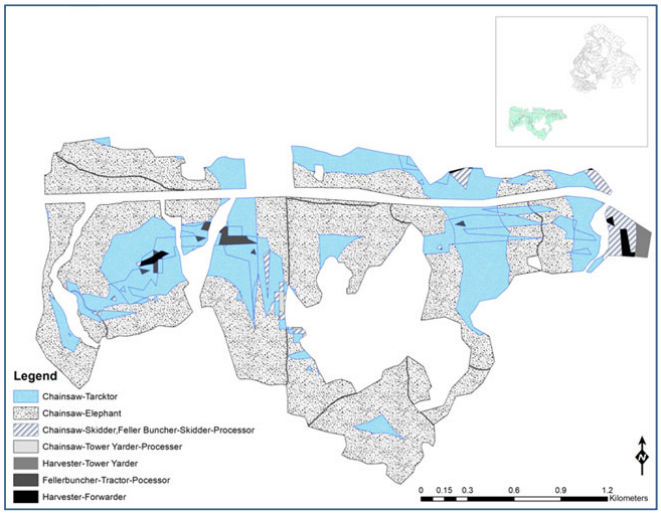


Figure 4 Technologically suitable system

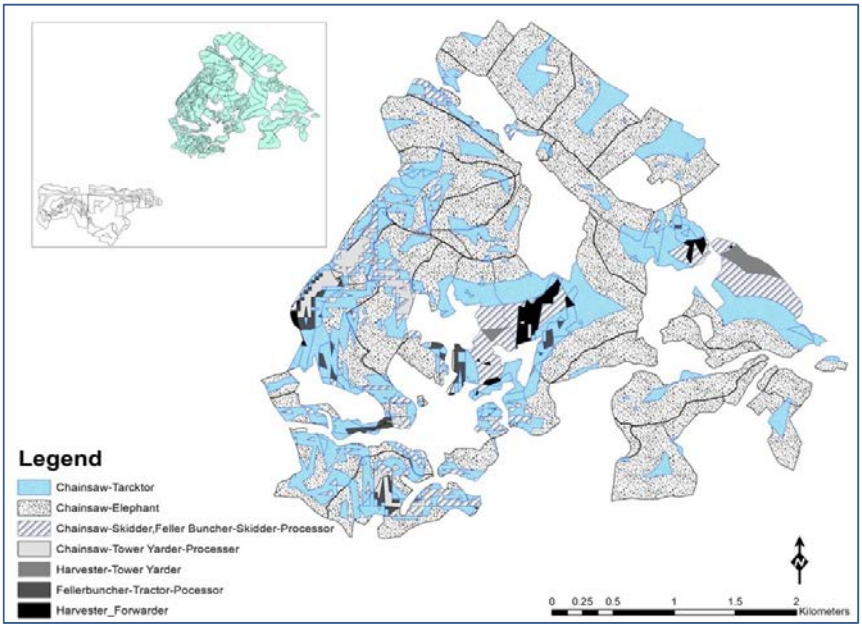


Figure 5 Technologically suitable system

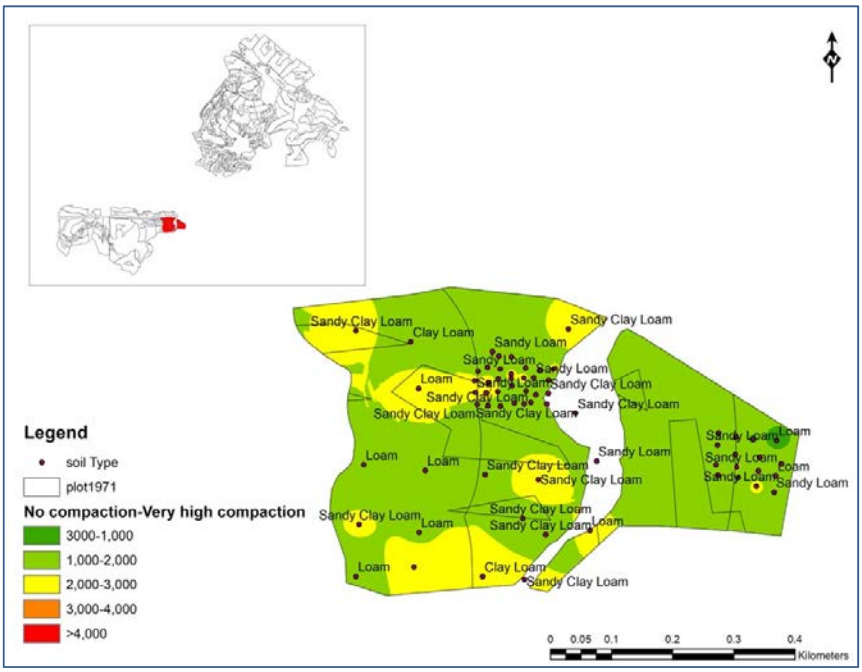


Figure 6 Soil compaction on the sample plot (planted in 1971)

4. Conclusions

Thailand never had academic planning on logging: experience and sense of the plantation owner are the main decision-making factors with relatively less concern about potential impact. Review of this study will persuade the entrepreneurs to place more attention to logging planning. This study is preliminary result on multicriteria decision analysis for selecting the sustainable logging system in Teak plantation. Information analyzed is information related with machine efficiency and physical characteristics. Technologically suitable system is the output of this study. Soil compaction is also analyzed to assess load-bearing capabilities. The preliminary results will further use for environmental analysis. Currently, it is in a process of preparing relevant factors information such as Vehicle limiting cone index (VLCI), hourly cost, productivity system and worker injury rate. So further study is necessary to investigate the best logging system based on sustainability and awareness of social, economic and environmental factors.

5.Acknowledgments

This research was supported by Kasetsart University Research Development Institute (KURDI) in research program: Applying precision forestry to teak plantation in Northern Thailand.

6. References

Anonymous. (n.d.) Soil densitometer S600 Description, Available Source: https://sss-labor.com/specializrovannoeotraslevoe-/oborudovanie-dlja-analiza-gruntov-/plotnomer-pochvi-s600.html, July 14, 2019.

Boroushaki, S. and J. Malczewski. (2008) “Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS” Computers & Geosciences, 34, 399-410.

Greulich, F., H. Donald and M. J. Baumgartner (1996) A primer for timber harvesting, Washing State University Extension.

Kuhmaier, M and K. Stampfer. (2010) "Development of a Multi-Attribute Spatial Decision Support System in Selecting Timber Harvesting Systems" Croatian Journal of Forest Engineering, 31, 75-88.

Liu, Y., X. Lv, X. Qin, G. Huaicheng, Y. Yajuan, J. Wang ang G. Mao. (2007), "An integrated GIS-based analysis system for land-use management of lake areas in urban fringe" Landscape and Urban Planning,82, 233-246.

Maclaurin, B. (2007), "Comparing the NRMM (VCI), MMP and VLCI traction models" Journal of Terramechanics, 44, 43–51.

Malczewski, J. (2006) "Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis" International Journal of Applied Earth Observation and Geoinformation, 8, 270-277.

Marchi, E., W. Chung, R. Visser, D. Abbas, T. Nordfjell, P. S. Mederski, A. Mcewan, M. Brink and A.Laschi (2018), "Sustainable Forest Operations (SFO): A new paradigm in a changing world and climate" Science of The Total Environment, 8, 1385-1397.

Melemez,K. (2015), "The influence of skidding operations on forest soil properties and soil compaction in Bartin, Turkey" Eur J Forest Eng,1,1-8.

Pentek, T., Porsinsky, T., Susnjar, M., Stankic, I., Nevecerel, H. and Sporcic, C. (2008), "Environmentally Sound Harvesting Technologies in Commercial Forests in the Area of Northern Velebit Functional Terrain Classification" Periodcum Biologorum,110,127-135.

Skokagro. (n.d.) skokagro's presentation, Available Source: https://skokagro.com/media/skok.1.pdf, October 23, 2018.

Tosatjawong, P. (2011), "Extending Standards ISO 9001 for FSC" For Quality, 18, 28-34.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

USING VIRTUAL REALITY TO IMPROVE OPERATIONAL PLANNING AND TEACHING

Dominik Roeser [1], Tim Caldecott [2], Holger Griess [1]
[1] University of British Columbia, Vancouver, Canada; [2] FPInnovations, Vancouver, Canada
dominik.roeser@ubc.ca

Abstract: *In order to advance decision making in operational planning it is vital that forest operations professionals are utilizing the most advanced tools and technologies. The forest industry, in partnership with the University of British Columbia and FPInnovations is currently experimenting with leading-edge Virtual Reality forestry planning tools to improve operational planning and decision making in forest operations. The ability to make optimal decisions is constrained primarily by access to timely, accurate, contextual information that is quickly accessible and easily understandable. The development of a Virtual Reality (VR) software representation of the forest landscape represents a 21st century step towards aligning the varying interests in how forest landscapes are planned, utilized and managed.*

Other "visually impactful" resource sectors, such as mining, are currently leading the charge towards building & leveraging VR based decision support tools. The same primary constraints in the mining sector - Mine Design and Planning, Resource Management, Community Relations, Investor Relations - hold true, almost in parallel, to the forest sector, particularly block level planning, harvesting, hauling and regeneration activities. Rapidly changing historical timber supplies, particularly in the context of unplanned natural disturbances of fire and/or disease outbreaks, bring home the necessity to evolve better "closed-loop", "supply-chain-centric" decision making tools. Forest resources in BC are largely tied to publically owned lands requiring public consultation and engagement. Additionally, Competing interests for resource extraction, animal habitat, conservation and recreation, position the varying end-use objectives of forest resources squarely under the lens of rigorous scrutiny. The developed VR forest and lands planning tool can play a facilitation role, by providing an objective, visual, conversational tool – bridging the varying, though often complimentary, forest management interests shared between stakeholders, the public and government policy. A proof of concept model was demonstrated in the fall of 2018 and a second phase is now focusing on the full integration and compatibility of the tool with GIS and RoadEng datasets into the VR tool. Upon completion of the second phase the tool will be implemted at the research forest of UBC to improve teaching for forest operations students and demonstrate its operational planning capabilities.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

MANIPULATING CHAIN TYPE AND FLAIL DRUM SPEED FOR INCREASED PRODUCTIVITY AND VALUE RECOVERY IN CFDDC OPERATIONS

Raffaele Spinelli [1,2], Rick Mitchell [2], Mark Brown [2], Natascia Magagnotti [1,2], Andrew McEwan [3]
[1] CNR IVALSA, Firenze, Italy; [2] University of the Sunshine Coast, Marochydoore, QLD, Australia; [3] Nelson Mandela University, George, Republic of South Africa
spinelli@ivalsa.cnr.it

Abstract: *Chain flail delimber debarker chippers (CFDDC) are used for producing clean bark-free chips from whole trees in one single pass. DDCs are multi-stem processing machines that integrate two functional elements: a chain-flail delimber-debarker and a chipper. The former knocks off branches and bark from whole trees by using hardened chain links mounted on fast-rotating drums, while the latter turns bark-free stem wood into clean pulp chips. These machines may achieve a productivity in excess of 40 t per productive machine hour, and easily remove all limbs and most of the bark. While somewhat coarse, flailing can be fine-tuned to minimize fiber losses, which are generally lower than 5%. However, there is an interest in increasing fibre recovery and decreasing fuel consumption, by manipulating machine settings and developing new components. A most promising intervention is the development of newly-shaped lightweight chain flails. This study compared these new chains with standard flails (control) in low productivity coppice bluegum plantations. Results point at a significantly better performance of the new chains, especially when drum speed is reduced. Compared with the control, the innovative treatment accrues a 12% improvement on fiber recovery, while productivity is increased by 20% and fuel consumption is cut by 30%. The productivity increase is probably a result of a slightly faster through flow and especially of the larger volume fed to the machine thanks to the increased recovery (e.g. flow speed is probably not much faster, but the mass is larger and therefore through flow is higher). On the other hand, reduced fuel consumption per t is likely the result of both a lower energy input (slower rotating flail) and a higher through flow (more fiber getting through to the chipvan). Slower rotating lightweight chain reduce breakage in smaller trees (e.g. low productivity bluegum) and therefore are likely to be especially suited to softer tree species, such as European SRF poplar*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

AVATAR: ADVANCED VIRTUAL APTITUDE AND TRAINING APPLICATION IN REAL TIME

Dirk Jaeger (1), Marian Schönauer (1), Bruce Talbot (2), Rolf Björheden (3), Eva Skagestad (4), Michael Corsano (5), Gerhard Rinkenauer (6), Thilo Wagner (7)

(1) Department of Forest Work Science and Engineering, Georg-August-Universität, Göttingen, Germany; (2) Norwegian Institute of Bioeconomy Research, Ås, Norway; (3) Skogforsk, Uppsala, Sveden; (4) Skogbrukets Kursinstitutt, Biri, Norway; (5) Optea, Oslo, Norway; (6) Leibniz Research Centre for Working Environment and Human Factors, Dortmund, Germany; (7) Wald und Holz NRW, Arnsberg, Germany

Project coordination: Dirk Jaeger
Department of Forest Work Science and Engineering
Faculty of Forest Sciences and Forest Ecology
Georg-August Universität Göttingen
dirk.jaeger@uni-goettingen.de

Keywords: training of forest machine operators, machine-operator interaction, forest operations

In Europe, more than 400 million m³ of timber are harvested every year. Modern forestry machinery makes the harvesting process much more efficient and safer than motor-manual harvesting. However, the operation of these forestry machines requires lengthy training in order to acquire the necessary knowledge and skills. Despite intensive practice, graduates of current training programs and even experienced machine operators show productivity differences of up to 40%. Within the project AVATAR, a digital coaching, assistance and feedback system (CAFS) is designed for improving productivity and job satisfaction of forest machine operators while reducing mental stress. In addition, it will allow for training of young and senior professionals in a more meaningful and efficient way. CAFS contributes to enhanced value adding and resource utilization in forest industry, thus, strengthening sustainable and competitive bio-economies of Europe.

The selected approach is focused on the individual improvement potential on operator level, characterized by personal work patterns. Data on work execution (i.e. joystick, crane and machine movement) will be gathered continuously and analysed in order to detect beneficial and detrimental work patterns forming together with know-how of trainers for work patterns the basis for defining quantitative measurements of work performance in timber harvesting. These experiences and already developed training measures will

be further elaborated in order to investigate possibilities, e.g. mechanical on-board systems, but also sensor- and scanner-based technologies for data generation and transfer, which can be used for the performance evaluation of the operators and integrated into an individual feedback approach for coaching. In addition, the development of an overall concept for the use of personal data for an operator-made feedback and coaching approach is an essential component of the entire AVATAR project.

Due to the direct cooperation with a forestry training centre, an exchange of experience and knowledge between research and practice as well as machine manufacturers will continue to take place via workshops. The aim is to ensure that the results of the project will in future be incorporated into training and further education via professional competence centers, but also into the daily work of machine operators via on-board systems.

S18 Harvesting operations
Incremental innovation vs. business revolution

WORK SAFETY IMPROVEMENT FOR MOTOR-MANUAL FELLING OPERATIONS - GENERAL TOUGHTS AND PRESENTATION OF A PROTOTYPE TOOL
Patrick Dietsch, Michael Starke, Martin Ziesak
Bern University of Applied Sciences (BFH) - School of Agricultural, Forest and Food Sciences (HAFL), Bern, Switzerland

ECONOMIC FEASIBILITY OF TIMBER HARVESTING IN LOWLANDS
Alex Kunnathu George [1], Anil Raj Kizha [1], Laura Kenefic [2]
[1] School of Forest Resources, University of Maine, Orono, ME-04469, USA; [2] Northern Research Station, U.S. Forest Service, ME-04411, USA

SELECTING SUCCESSFUL HARVESTER OPERATORS THROUGH APTITUDE TESTS AND DEMOGRAPHICS
Kylle Schwegman [1], Raffaele Spinelli [2], Natascia Magagnotti [2], Andrew McEwan [3], Muedanyi Ramantswana [1]
[1] Nelson Mandela University, South Africa; [2] CNR IVALSA, Italy; [3] CMO, South Africa

COMPARISON OF ELECTRIC CORDLESS AND PETROL CHAINSAWS IN TERMS OF EFFICIENCY IN REAL-WORLD CONDITIONS
Matevž Mihelič, Anton Poje
University of Ljubljana, Biotechnical Faculty, Department of Forestry and Renewable Resources, Ljubljana, Slovenia

HARDWOOD MECHANIZATION: STATE OF THE ART AND PERSPECTIVES BASED ON 20-YEARS EXPERIENCE IN FRANCE
Emmanuel Cacot, Philippe Ruch, Chloé Boldrini
FCBA, Verneuil-sur-Vienne, FRANCE

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

WORK SAFETY IMPROVEMENT FOR MOTOR-MANUAL FELLING OPERATIONS - GENERAL THOUGHTS AND PRESENTATION OF A PROTOTYPE TOOL

Patrick Dietsch*, Michael Starke, Martin Ziesak
Bern University of Applied Sciences (BFH)
School of Agricultural, Forest and Food Sciences (HAFL)
Länggasse 85, CH-3052 Zollikofen, Switzerland
patrick.dietsch@bfh.ch

Abstract: Accident statistics still show alarmingly high figures for the forestry sector. Many accidents occur during felling operations. They are often linked to an inadequate assessment of the felling and hazard area. In the following, a prototype of an application is described which provides additional information on the felling and hazard area and pursues the goal of further reducing the number of accidents.

The central idea is to provide, from a bird's eye view, valuable extra information for forest workers. This new perspective from above should allow a better identification of threats in the felling or risk zone. For this purpose, various feasibilities were tested. Based on these results, a prototype was developed to support forest workers during their tree and environmental assessment phase in motor-manual timber logging.

Information about the forest stand was obtained from remote sensing data. As a digital terrain model (DTM), swissAlti^{3D} was used. A digital surface model (DSM) was created from drone flight data. By subtracting the DTM from the DSM, a normalized surface model (nDSM) was created. With the individual tree detection program FINT, tree tops and heights were determined by using a local maxima algorithm.

Different methods were tested to generate added value from these pre-processed data. The detailing of the trees was not sufficient for three-dimensional representation of the data. In addition, high computing power was required to display the data. This led to the fact that the image of the stand disappears during rotation and zooming, and is only displayed again after a delay.

Due to the identified limitations of 3D models, the development of the support tool is based on a two-dimensional visualization. The software tool is embedded in iFOS (integrated forest operation software), as adequate localization of the forest worker is offered. A connected GNSS sensor shows the position on the map in real time and allows the identification of trees, felling and danger area. In the review of the tool, it became evident that it would be necessary to use a GNSS sensor precise enough for accurate positioning within a forest under the tree canopy. Therefore, the accuracy of two different sensors was determined in a forest unit under different situations at geodetically measured points. The analysis showed an average accuracy of 2.87m (10xx-sensor by ppm, n = 890) and 4.83m (M8N sensor by u-blox, n = 8720), which was judged suitable for the desired application.

The tool can currently be used to assess exceptional situations in motor-manual felling. These are for example harvesting situations of trees or deadwood near infrastructure such as public roads. Furthermore, the tool is recommendable for education and training, as it clearly identifies and visualizes the dimensions of felling and risk zones.

Further improvements and enhancements are envisaged in an ongoing project extension, which includes among other aspects new features such as an indication of the GNSS-sensor accuracy and some improvements in the visualization.

Keywords: work safety, motor-manual felling, drone & GNSS data, prototype

FORMEC 2019 – Exceeding the Vision: Forest Mechanization of the Future
6-9 October 2019 - Sopron, Hungary

ECONOMIC FEASIBILITY OF TIMBER HARVESTING IN LOWLANDS

Alex Kunnathu George [(1)], Anil Raj Kizha[(2)*], Laura Kenefic[(3)]
[(1,2)]School of Forest Resources
University of Maine Orono
5755 Nutting Hall, Orono, Maine, United States
[1]alex.george@maine.edu
[2]anil.kizha@maine.edu

[(3)]Northern Research Station, U.S. Forest Service
[3]laura.kenefic@usda.gov

Abstract: *Northern white-cedar (Thuja occidentalis L.) is an important commercial tree species in the New England and Great Lakes regions of the USA and adjacent Canada, yet cedar-dominated stands are comparatively less harvested. This is mainly attributed to the operational challenges associated with fragile and poorly drained soils in lowlands where the species is commonly found. In terms of forest operations, such conditions can pose safety hazards for both crew and machines and harvesting might not be economically viable. The objectives of this study were to 1) estimate cost and productivity of timber harvesting operations in a sensitive-soil stand relative to those of an operation on sturdy ground, 2) understand the effects of stand variables on productivity as expressed by delay-free cycle (DFC) times. The study was conducted in Maine, USA using cut-to-length (CTL) harvesting during the winter of 2019. Stands selected for the treatments were lowland cedar-dominated (>80% cedar, with fragile soils) and non-cedar-dominated (~10% cedar, with a sturdy soil profile). DFC times and predictor variables were recorded for the harvester and forwarder using detailed time-motion study techniques. Harvested wood timber volume was estimated from scaling data and scale tickets. Machine rate calculations to determine hourly production cost were performed utilizing information from the forest management company. The cost of the operation was found to be higher for the cedar stand (USD 31.93 m^{-3}) than the adjacent non-cedar stand (USD 24.27 m^{-3}). Cost of extraction was reduced by 34–41% when the landing was shifted to stand boundary. Apportioning methods showed that the cost of felling and processing cedar (USD 6.35 m^{-3}) was higher than hardwoods (USD 6.09 m^{-3}) and other softwoods (USD 5.66 m^{-3}). Sensitivity analysis showed that increases in predictor variables such as butt-end diameter, distance between the trees, and number of cuts per cycle increased the DFC time of the harvester. In the case of the forwarder, length and diameter of the log were inversely proportional to the DFC time, whereas an increase in forwarding distance and number of pieces increased the DFC time. Though few, if any direct effects of soils were found on winter harvesting productivity and costs, tree species composition was an influential factor and is itself related to soils. This work will allow foresters and timberland managers to make more informed decisions regarding cost-effective and sustainable forest management in lowlands.*

Keywords: cedar, cut-to-length, forest operations, sensitivity analysis, winter harvest.

1. Introduction

Northern white-cedar (*Thuja occidentalis* L.) is a commercially important tree species in the northeastern United States and southeastern Canada, seen both in pure stands and as a minor species in mixed stands (Boulfroy et al., 2012). In 2017, cedar sawlogs worth USD 5 million were harvested within the state of Maine (MFS, 2018a; MFS, 2018b). The volume of cedar growing stock has decreased over the past few years in

some parts of its range (Huff and McWilliams, 2016; Kenefic et al., 2017), mainly due to the challenges in managing cedar sustainably.

In the northeastern United States, about 75% of cedar forests are on lowlands, of these, 54% and 21% are on flatwoods and swamp or bogs, respectively (Boulfroy et al., 2012). Pure cedar stands are typically associated with "cedar swamps" characterized by deep, organic, poorly drained soils (Larson et al., 1993; Frohn, 2017). These are comparatively under-managed due to challenges associated with the fragile ecosystem where the species grows (Kenefic, 2013). In terms of forest operations, trafficability constraints such as accessibility to the stand, lack of solidity, and terrain roughness, as well as soil fragility constraints such as high-water table and high probability of erosion, rutting, and scalping can pose safety hazards to logging equipment and the ecosystem. The economic viability of the operation is also a constraint (Boulfroy et al., 2012). Above-mentioned conditions, along with the compressed length of logging seasons – a consequence of climate change – likely contribute to the 47% decline in cedar harvest in Maine since the year 2000 (Woodall et al., 2019; Berry et al., 2019).

Based on the silvics of lowland cedar, the selection or irregular shelterwood method (partial harvest) is suggested for regenerating stands with a component of cedar (Boulfroy et al., 2012; Kenefic, 2013) to retain and release well-established cedar in the stands and expedite cedar regeneration. Moreover, partial harvesting has been observed to have the smallest detrimental effect on logging sites (Jiang, 2016). To sustainably manage a healthy growing stock of lowland cedar, care should be taken to minimize residual stand damage; operations should be conducted during frozen periods of the year to avoid excessive soil compaction, rutting, root damage, windthrow (Boulfroy et al., 2012) and the chances of machine sinking. Winter harvest would be the best fit for sensitive grounds (EPA, 2005) because frozen soil during winter harvesting can ensure low soil disturbances and operational safety (Dubé et al., 1995; Dahlman and Rossman, 2010; Russell et al., 2018; West Fraser, nd; Timber harvesting, nd). It could also reduce damage to trees and thereby lessen the likelihood of spreading disease (Schira, 2013)

Conventional harvesting using full-tree or tree-length methods that employ mechanical felling and skidding are not suitable for sensitive sites (Puttock et al., 2005); cut-to-length (CTL) harvesting method is preferred (Jiang, 2016). Reasons include less impact on the environment, reduced disturbance to advance regeneration, and increased fiber recovery (Sauder, 1993; Richardson and Makkonem, 1994; Puttock et al., 2005; Cudzik et al., 2017). In CTL, the delimbing, topping and bucking occur in the stand rather than at the landing area; logs are carried, rather than dragged, during extraction; and the log trucks are configured to haul shorter log lengths (Bulley, 1999). This harvest method reduces the number of machine entries to the stand and enables on-site slash retention. From an operational viewpoint, retaining slash will help to safely and efficiently operate equipment on sensitive site and minimize potential soil disturbances (Dahlman and Rossman, 2010).

An appropriate and economically feasible timber harvesting system is essential to successfully meet management objectives (Bennett, 2010). To determine the economic feasibility of lowland cedar harvest, the experiment was carried out with specific objectives: 1. Estimate the cost and productivity of a CTL harvesting operation in a lowland cedar stand, 2. Compare the cost-effectiveness of forest operations in lowland cedar to operations on sturdy ground, 3. Understand the effect of predictor variables on the DFC time for each harvesting components.

2. Methods

2.1 Study area

Detailed time-motion study data were collected from an operational-scale experiment conducted at the Penobscot Experimental Forest (PEF) in Bradley and Eddington, Maine (44°49'56" N, 68°36' 26" W) (Figure 1) in the northeastern United States during the winter (February to March) of 2019. The study consisted of two stands, a cedar-dominated lowland with an area of 4.4 ha and a non-cedar stand on sturdy ground with an area of 12.5 ha. The temperature during the harvesting operation ranged between 1.5°C and

-20.5°C with an average of -7.4°C. The average snow depth recorded within the stands during the experiment was 16 cm, with a maximum and minimum of 21 cm and 11 cm respectively. The soil of the cedar stand was Bucksport and Wonsqueak muck with a slope ranging from 0–2%; in the non-cedar, soils of the Becket-Skerry complex and Peru-Colonel-Tunbridge association dominated with a slope ranging from 2–15% (Soil Survey Staff, 2019).

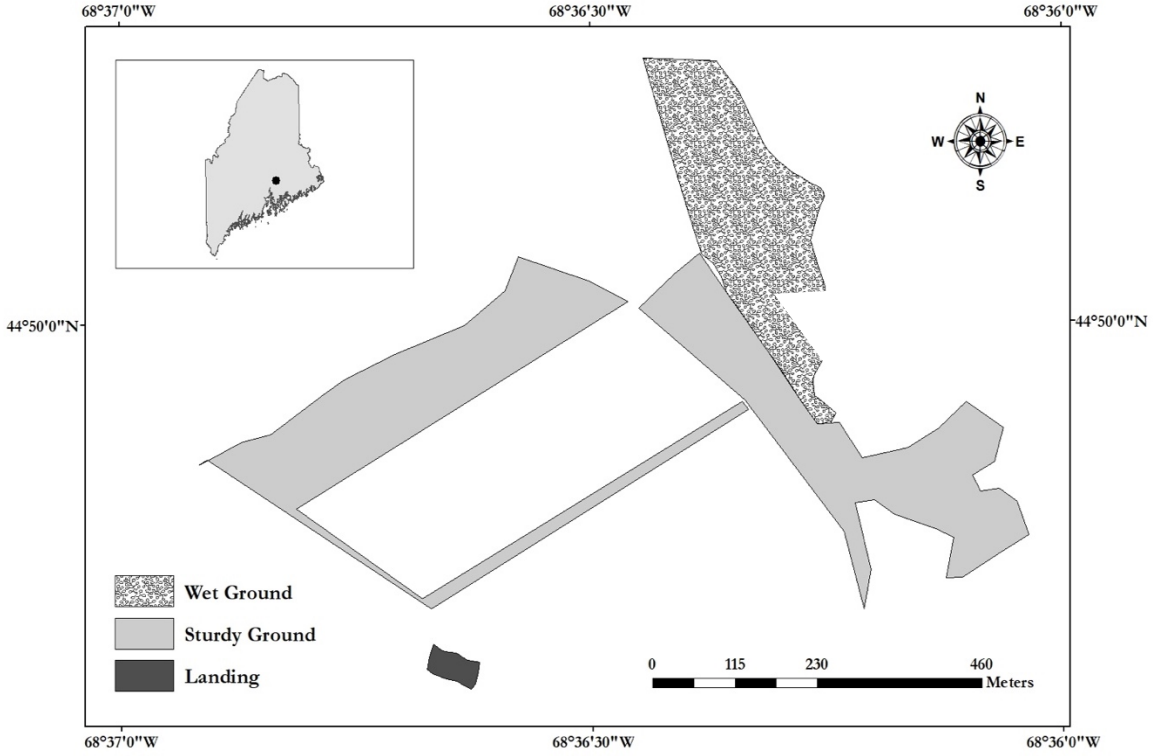


Figure 1. Map of study site showing the harvested lowland cedar and non-cedar stand

2.2 Stand Inventory

As the lowland cedar stand is a permanent experimental plot, the stand was inventoried using permanent circular plots laid out in nested plot design (Kenefic et al., 2017). A total of 9 fixed-radius plots of 0.08 ha were selected to measure diameter at breast height (DBH), tree height, height to base of the crown (bole height), species, and the spatial location of trees ≥ 15.2 cm DBH. Since the non-cedar stand constituted an industrial timberlands operation, the stand was inventoried using 24 variable-radius plots with a 20 Basal Area Factor (BAF) prism. The sample plots were measured for DBH, tree height, bole height, and species (Kanoti, 2018). Differences in stand inventory techniques was a constraint in this study. As the stands were managed by two different organizations, the preferred inventory method varied. The stand inventory was carried out by the respective managing organizations. One was research-oriented, so used permanent fixed-area plots to generate large amounts of information which can be traced back and used for future experiments. On the other hand, the variable-radius inventory method was preferred for commercial forest management as it is cost and time-efficient, in part because more time is spent measuring sawtimber-size trees.

2.3 Silvicultural prescription

2.3.1 Lowland cedar stand

The stand was partially harvested to establish and release cedar regeneration through the creation of small canopy gaps and to favor the growth of the residual pole and small sawtimber cedar though crop tree release between gaps. Removal outside the gap areas was limited to 20% of relative density, with 100% removal in gaps and trails. The irregular shelterwood treatment was prescribed to remove a BA of 20 m^2 ha^{-1} (40% of total BA, ≥15.2 cm DBH) (Kenefic et al., 2017). The lower level of merchantability was 15.2cm DBH. The stand was not actively managed before this operation. Logging residues were placed in the machine trails during harvesting to minimize site damage. Other species found in the stand were spruce (*Picea spp*.), larch (*Larix laricina* (Du Roi) K. Koch.), balsam fir (*Abies balsamea* (L.) P. Mill.), and eastern white pine (*Pinus strobus* L.).

2.3.2 Non-cedar stand

The stand was found to have species such as eastern hemlock (*Tsuga canadensis* (L.) Carr.), red maple (*Acer rubrum* L.), eastern white pine, spruce, quaking aspen (*Populus termuloides* Michx.), paper birch (*Betula papyrifera* Marsh.), balsam fir, and cedar. Irregular shelterwood and pine shelterwood establishment cuts were prescribed for the non-cedar stand. The irregular shelterwood establishment cut was meant to establish an understory of tolerant conifers and release advance regeneration. In areas dominated by hemlock that lack desirable regeneration (hemlock, spruce, or white pine) overstory BA was reduced to 23 m^2 ha^{-1}, retaining a uniform overstory of the best quality hemlock, white pine, spruce, and tolerant hardwoods. Also, quality growing stock intermediate crown class stems of any species and uncommon species such as brown ash (*Fraxinus nigra* Marsh.) and basswood (*Tilia americana* L.) were retained. There were a few patches of overstory white pine in this stand; in these areas, openings 21 m in diameter were created around the patches by removing all other species.

In areas with high-quality white pine overstory trees (first 5 m log straight, no knots over 1.2 cm and at least 40 cm in diameter at the small end), a shelterwood establishment cut was made and the overstory BA was reduced to 18 m^2 ha^{-1}. The highest priority was to remove mid-story balsam fir, red maple, and hemlock stems, along with overstory intolerant hardwoods (Kanoti, 2018).

2.4 Harvesting operation

Cut-to-length harvesting method (using harvester and forwarder) was employed to carry out the partial harvest in both lowland cedar and non-cedar stands. The operation was conducted during winter and extended for 18 days. The machines and the operators were the same for both treatments. The experience of the harvester and the forwarder operator was 8 and 6 years, respectively.

2.4.1 Felling and Processing

A Ponsse Scorpion King (2018) harvester performed felling, delimbing, and bucking within the harvest unit. DFC time was recorded in seconds using a stopwatch. The DFC time for the harvester started when the machine traveled empty to a tree (travel empty), grappled and felled a tree (cutting), moved the felled tree to a nearby deck (decking), and delimbed and bucked felled trees to logs of market-desired length (processing). Independent variables such as distance traveled between the trees (m), number of cuts per cycle, number of logs per cycle, and butt-end diameter (cm) of the felled trees were visually estimated (Table 1). The total number and dimensions of logs processed were also downloaded from the harvester's computing system for each stand.

2.4.2 Extraction

The processed timber was extracted to the landing using a Ponsse Buffalo forwarder (2016). The forwarding trails were tracked using a GPS unit mounted on the forwarder. Traveling empty from the landing to the unit initiated the DFC of the forwarder (travel empty). Travel empty ended as the forwarder stopped for picking up the first logs. Following this, the loading time initiated as the forwarder filled the bunk. While filling the bunk the machine swung empty to reach the logs (swing empty) then grappled logs (grappling or re-grappling), then the boom swung loaded (swing loaded), after which the machine sorted the logs to accommodate maximum payload. Once the bunk was filled the machine traveled back to the landing (travel loaded) and unloaded the timber at the landing. While unloading, the machine followed the reverse of loading. Travel distance (m), number of pieces, log diameter, and species constituted the independent variables recorded (Table 1).

The cedar stand had longer extraction distance to the landing compared to the non-cedar stand. To estimate the actual cost of extraction irrespective of extraction distance, a hypothetical landing was established just outside the stand (at the stand boundary). Time taken by the forwarder to cross the hypothetical landing and the distance to the actual landing was recorded. By deducting the time taken to travel from the hypothetical landing to the actual landing, cost of extraction due to the treatments were evaluated.

2.4.3 Loading

Self-loading trucks manufactured by Peterbilt and Sterling were utilized for loading and hauling the wood to the conversion facilities. The DFC components for loading were swinging empty to grapple the logs (swing empty), grappling the logs, swinging loaded, and sorting the logs. The independent variables included the number of logs, species, and length and diameter of the logs (Table 1).

Table 1. Cycle elements and predictor variables recorded for each operational phase in cut-to-length harvesting operation

Operational phases	Cycle elements	Recorded predictor variable(s)
Felling and processing (Harvester)	Travel to trees Cutting Processing Decking	Number of cuts per cycle Number of logs per cycle Butt-end diameters (cm) Distance between trees (m) Decking distance (m) Species
Extraction (Forwarder)	Travel empty Travel loaded Swing empty Grappling Swing loaded Sorting	Empty travel distance (m) Loaded distance (m) Number of pieces Diameter of log (cm) Species
Loading (Self-loading truck)	Swing empty Grappling Swing loaded Sorting	Number of pieces Diameter of log (cm) Length of log (m) Species

2.5 Operating cost calculations

Machine rates were calculated using the method developed by Miyata et al. (1980). The purchase price, salvage value of machines, economic life, and utilization rates were obtained from the forest management company which owned and operated the logging equipment (Table 2). Hourly machine costs (USD PMH^{-1},

productive machine hour) were calculated using standard machine rate calculation methods. Average DFC time, i.e. cycle time excluding operational, mechanical, and personal delays, was calculated for every operational phase separately for each treatment (Kizha and Han, 2015). The average volume of the log was estimated from the harvester-generated report, scale ticket, and log scaling. Log scaling was performed by measuring the large end diameter, small end diameter, and log length. Average volume for each piece was calculated using Huber's formula (Avery and Burkhart, 1983). By assimilating machine rate, average DFC time, and timber volume, the operating cost was calculated (Soman et al., 2019a; Sahoo et al., 2018).

Table 2. Machine rate and cost of the equipment used in the harvesting. All the information was provided by the forest management company which owned and operated the equipment

Factors	Harvester	Forwarder
Make and Model	Ponsse Scorpion King 2018	Ponsse Buffalo 2016
Purchase price (USD[a])	650,000	400,000
Salvage Value (USD)	200,000	75,000
Variable and operating cost (USD PMH^{-1}[b])	72.93	37.89
Economic life (yrs.)	6	8
Labor cost (USD PMH^{-1})	42.86	40.00
Fuel consumption (L PMH^{-1}[c])	20.57	14.96
Scheduled machine hours (SMH)	12	15
Utilization (%)	70	75
Machine rate (USD PMH^{-1})	219.28	125.77

[a] All prices are expressed in US Dollars;
[b] PMH = Productive Machine Hour;
[c] L PMH^{-1} = Liter per Productive Machine Hour

2.6 Cost allocation

There were different assortments of products from the operations. The assortments were made for different products i.e., cedar, hardwood, and softwood. To understand the cost of felling and processing different assortments, all the DFC from the entire operation were segregated and the cost and productivity were calculated for each assortment separately.

2.7 Sensitivity analysis

Sensitivity analysis helps to understand the impact of a range of independent variables on the dependent variable of interest under a set of conditions (Jovanovic, 2018). Sensitivity analysis was performed with the help of R code developed by Jovanovic (2018), to determine how predictor variables influenced DFC time for the harvester and forwarder. All predictor variables collected for each operational phase were selected (Table 1) and converted to ratios using log-log analysis before sensitivity analysis. For sensitivity analysis, input values for the predictor variables were changed by 20% and 40% in both negative and positive directions to understand the change.

2.8 Statistical analysis

Statistical analysis was performed using R software (version 3.6.0). Initially, datasets were screened for outliers with a 95% confidence interval and checked for normality. Then linear regression models were developed with DFC time as the dependent variable and predictors as independent variables (Table 1). Dummy variables were used to represent species. Backward/forward model selection with lower AIC values was used for model selection and validation using the MASS package (Venables et al., 2002). A standardized variable comparison was performed to establish the variation in cost and productivity of the treatment

regardless of the stand condition (Kizha and Han, 2016). A two-sample *z*-test was performed to compare the DBH and DFC time between the lowland cedar and non-cedar stands.

3. Results and Discussion

3.1 Stand inventory analysis

In the cedar stand, a total of 1010 trees with DBH above 15.2 cm were measured from 9 plots as part of the pre-harvest inventory. The stand was dominated by cedar (81%) with a maximum observed DBH of 41 cm, followed by hardwoods (10%), larch (7%), spruce (<1%), white pine (>1%) and balsam fir (>1%) (Table 3). From the stand, 20 m^2 ha^{-1} basal area was removed which resulted in a residual of 30 m^2 ha^{-1} (Kenefic, 2018).

Inventory data for 208 trees from the 24 sample plots in the non-cedar stand revealed the stand was dominated by hemlock (42%) followed by white pine (31%), cedar (10%), red maple (8%), ash (3%), birch (2%), aspen (2%), spruce (1%), balsam fir (>1%) and basswood (>1%). The two-sample *z*-test showed there was a significant difference (*p*-value <0.05) in DBH between the lowland cedar (21 cm) and non-cedar stand (35 cm). This may be associated with the significant difference in DFC time between the stands for different operational phases (Kluender et al., 1997).

Scale tickets showed that a total of 1431 m^3 wood was extracted from both stands (Table 3). From the lowland cedar stand, 72% of logs extracted were cedar followed by hardwood (13%), larch (10%), spruce (2%), fir (<1%), white pine (<1%) and aspen (>1%). In the non-cedar stand, hardwoods (40%) contributed the maximum, trailed by hemlock (26%), cedar (14%), aspen (8%), pine (6%), fir (4%) and spruce (2%).

Table 3. Stand inventory summarized for all standing trees of DBH above 15.2 cm for cedar and non-cedar stand

Stand Attributes	Cedar	Non-cedar stand
Area (ha)	4.4	12.5
Basal Area (m^2 ha^{-1})	50	40
Trees per ha	1196	734
QMD[a] (cm)	21.6	26.4
Species	cedar, spruce, larch, balsam fir, white pine	hemlock, red maple, white pine, spruce, aspen, paper birch, balsam fir, cedar
Total wood harvested (m^3)	419	1012

[a] QMD- Quadratic Mean Diameter

3.2 Harvesting operation

The cost of harvesting the cedar stand (USD 30.45 m^{-3}) was found to be higher than the non-cedar stand (USD 22.79 m^{-3}) (Table 6). The difference in cost of operation does not appear to be directly related to the soil condition. However, additional predictor variables like slope, forwarding trail pattern, species composition, stand density, the silvicultural prescription might have an influence on the cost of operation but were not explicitly considered in the present study (Nakagawa et al., 2007; Soman et al., 2019a). The diameter of the logs handled, and the number of logs handled per cycle were the factors that determined the cost and productivity of each operational phase. Machine productivity and fuel consumption are unlikely to explain the difference in the operation costs, as the harvesting equipment and operators employed in both stands were the same throughout the operation.

Delay-free cycle times were predicted using standardized regression models (Kizha and Han, 2016). The adjusted R^2 values ranged from 0.17 to 0.67, with operational phases for the non-cedar stands having the higher R^2 values (Table 4). The adjusted R^2 values for the regression models developed were found to be in line with other studies in the region (Hiesl and Benjamin, 2015; Soman et al., 2019a; Soman et al., 2019b). There was a little variation in adjusted R^2 values of different operational phases and stands, except for loading. Decking distance was found to have no significant effect on DFC time of the harvester in both stands. For the forwarder in the cedar stand, number of logs, species, and diameter did not contribute significantly to DFC time. In the case of loading, diameter of the log, length of log and species did not have a significant effect on DFC time. The DFC time of the harvester (felling and processing) averaged 0.53 and 0.66 minutes for cedar and non-cedar stands, respectively. For the extraction of logs from the harvest site to the landing, the DFC time was 74.27 minutes for the cedar stand and 54.00 minutes for the non-cedar stand and was directly proportional to the forwarding distance (Table 5).

Table 4. Regression models developed for predicting the delay-free cycle (DFC) time at $\alpha = 0.05$

Machine	Site	Adjusted R^2	Standardized models predicting DFC time
Harvester	Cedar	0.58	DFC = -12.69* + 1.01 (butt-end diameter) * + 6.00 (distance between trees) * + 9.13 (number of cuts per cycle) * – 4.17 (number of logs per cycle) * + 32.24 (hardwood) * + 9.30 (softwood)
	Non-cedar	0.66	DFC = -36.20 * + 1.89 (butt-end diameter) * + 1.32 (distance between trees) * + 4.34 (number of cuts per cycle) * + 7.02 (number of logs per cycle) *
Forwarder	Cedar	0.57	DFC = -53.51* + 3.33 (distance traveled) *
	Non-cedar	0.67	DFC = 21.92 * + 0.30 (butt end diameter) * + 1.07 (distance traveled) * – 2.68 (hardwood)
Loading		0.17	DFC = 20.216 + 2.79 (number of logs per cycle) *

* p-value <0.01

Table 5. Stand and operational factors that contributed to the total cost of operation

	Harvester		Forwarder	
	Cedar	Non-cedar	Cedar	Non-cedar
Average DFC[a] time (min)	0.53	0.66	74.27	54.00
Volume per log (m^3)	0.13	0.18	0.13	0.18
Average extraction distance (m)			1207	1078
Average extraction distance to hypothetical landing (m)			296	241

[a] DFC-Delay free cycle

3.2.1 Felling and processing

A total of 496 observations were collected from the two stands, 170 and 326 from the non-cedar and cedar stands respectively. For the cedar stand the average DFC time was 31.7 sec. The processing time had the largest contribution (48%) to the DFC time, followed by travel time between trees, decking time, and felling time respectively. The machine was able to produce an average of 1.88 logs per cycle, while the number of cuts per cycle averaged 2.14. The machine traveled an average distance of 1.42 m between successive felling and 0.87 m to a nearby deck. The cost of the operational phase was calculated to USD 9.98 m^{-3} (Table 6).

Similar to the cedar stand, the non-cedar stands also had processing time as the highest contributor (24.0 sec; 61%) to the DFC time and followed similar trends. The machine produced an average of 2.26 logs with an average of 2.56 cuts per cycle. The distance traveled between successive cuts was 2.68 m and to the nearest deck was 0.76 m. The cost of felling and processing was USD 8.03 m^{-3} (Table 6). The *z*-test that compared the average DFC time for cedar and non-cedar stands revealed a significant difference between the stands (*p*-value <0.05).

The cost of felling and processing trees from the lowland cedar stand was higher when compared to the non-cedar stand and is likely due in part to the significant difference in DBH between the stands. Similar observations were made by Kellogg et al., 1992; Puttock et al., 2005; LeDoux and Huyler, 2001. Also, the DFC time of the harvester was significantly different between stands. The higher productive machine hour facilitated by larger-sized trees and a greater number of logs per cycle reduced the cost of felling and processing in the non-cedar stand. These arguments can be substantiated by the regression models developed, where butt-end diameter and number of logs per cycle have a significant effect on DFC time. There was no clear evidence to show that the increased cost of felling in the lowland cedar stand was due to the fragile forest floor because the floor was frozen. But an interesting observation can be made in the travel between trees. Even though the distance between the trees was less, the travel time between the trees was higher in the cedar stand. This might be due to the roughness of the ground or the lack of solidity of the forest floor. But the presence of understory vegetation or the difference in silvicultural prescription can also be a source for more travel time between the trees. Further investigation is needed to determine the reason for this finding.

Another reason for the higher cost in the cedar stand might be due to a greater number of cuts per cycle. The relative number of cuts per cycle was observed to be higher for the lowland cedar stand, further apportioning revealed that a greater number of cuts per cycle was for the cedar trees. Due to the incidence of heart rot disease, which is common in this species (Kenefic et al., 2019), the operator was forced to make a greater number of cuts to get rid of the decayed part from the log. Sensitivity analysis showed a strong relationship between the DFC time and number of cuts per cycle.

3.2.2 Extraction

Extraction contributed about 65% to the cost of the operation (stump to landing). As the average distance of forwarding for the cedar stand was almost 130 m greater compared to non-cedar stands, it led to a 20-minute rise in the DFC time of the former (Table 5). In-woods forwarding contributed the most (48%) to the DFC time followed by travel loaded (23%), unloading (16%), and travel empty. The machine was able to extract 9.7 m^3 of logs per DFC. With a productivity of 5.89 m^3 PMH^{-1}, the cost incurred for the operational phase was USD 20.47 m^{-3} (Table 6).

The average forwarding distance was 1078 m in the non-cedar stand and the DFC time was estimated around 54 minutes (Table 5). The forwarding cycle followed similar trends to that of the cedar stand and the machine extracted 10.0 m^{-3} of logs per non-cedar DFC. The cost of extraction was decreased by 34–41% when the logs were extracted to the landing (hypothetical) just outside the stand (Table 6).

Table 6. Cost and productivity of different operational phases in cedar and non-cedar stands. Values in the parentheses show the cost and productivity to extract wood to the hypothetical landing (excluding the distance to actual landing)

Operational phase	Cost (USD m^{-3})		Productivity (m^3 PMH^{-1}[a])	
	Cedar	**Non-cedar**	**Cedar**	**Non-cedar**
Felling and Processing	9.98	8.03	20.64	25.60
Extraction	20.47 (13.58)	14.76 (8.75)	5.89 (8.88)	8.16 (13.78)
Loading[b]	1.48		61.21	
Total	**30.45**	**22.79**		

[a] PMH- productive machine hour

[b] Products from both treatments were combined at the landing.

In the present study, the forwarding distance was more than one kilometer (1207 and 1078 m), which can be considered to be the limit for operational-scale logging. The higher forwarding distance costs the operational phase USD 20.47 m^{-3} (lowland cedar) and USD 14.76 m^{-3} (non-cedar). The forwarding cost was dropped to USD 13.58 and 8.75 m^{-3} for lowland cedar and non-cedar stands respectively when the logs were forwarded to a hypothetical landing just outside the stand or at the stand boundary. Having the hypothetical landing helped to understand the change in cost of extraction as the forwarding distance varies and for a meaningful comparison of the cost of extraction between the lowland cedar and non-cedar stands.

At the landing, it took more time to unload logs from the cedar stand due to a larger percentage of small-diameter trees compared to that of the non-cedar stand. During the in-woods movement, loading logs from the lowland cedar (2140 sec) stand took more time than non-cedar (1153 sec). The difference can be attributed to the greater number of logs per handle, distance between the decks and time for segregating different products. This argument is substantiated by the regression models and sensitivity analysis, which showed that when the diameter of log handled increases the number of logs per cycle will decrease and thereby the DFC time will also decrease.

Even though the distance to travel from one stop to another for loading logs in the cedar stand was lesser, the travel time was higher when compared to the non-cedar stand. This change might be due to the difference in forest soil and forest floor conditions.

3.3.3 Loading

A total of 153 loading cycles were observed. On average, it took 49 minutes to load a truck. The average DFC time was calculated as 32 sec which includes 12 sec (37.2%) sorting time. With an average productivity of 61.21 m^3 PMH^{-1}, the loader had the highest productivity for all the operational phases (Table 6 and 7). However, the regression model for the loader had the lowest R^2 values (Table 4) and showed that predictor variables such as length of log, diameter of log and species could only explain part of the variability in the DFC time. The varying operators and the difference in products might be the reason for a lower R^2 value.

Table 7. Cost and productivity of loading operation for different assortments from the harvest

Product	DFC[a] (sec)	Cost (USD m^{-3})	Productivity (m^3 PMH^{-1}[b])
Cedar pulp	25.88	1.93	44.96
Hardwood pulp	44.83	1.39	62.40
Pine saw log	28.88	1.13	76.28

[a] DFC- Delay free cycle time
[b] PMH- Productive machine hour

The DFC and loading times varied for different products. For loading hardwood pulpwood, it took 46 minutes to load a truck; the average DFC time was 45 sec where the sorting time contributing 59% (27 sec). It took 68 minutes to load a truck with cedar pulpwood. The average DFC time was 26 sec; where sorting time was 8 sec (32%). For loading pine sawlogs, it took 32 minutes, with an average DFC time of 29 sec where the sorting time was 7 sec (24%) (Table 7).

Even after a higher DFC time for loading hardwood pulp, the cost of loading cedar pulpwood (USD 1.93 m^{-3}) was found to be slightly higher than hardwood pulp (USD 1.39 m^{-3}). It took an extra 16.4 minutes to load a sawlog truck of equal payload with cedar pulpwood. The extra time requirement was directly related to the sawmill requirement regarding the orientation of the logs. For cedar logs, the sawmills need the butt-ends to be aligned to a single direction. Other studies have also observed similar trends (Kizha

and Han, 2016). Additionally, for cedar pulpwood, the operator loaded a fewer number of pieces each cycle, as he had to orient the logs.

3.4 Sensitivity analysis

3.4.1 Harvester

The sensitivity analysis showed that butt-end diameter has a greater influence on DFC time when compared to other predictor variables. A 20% increase in the butt-end diameter may increase the DFC time from 39.4 sec to nearly 50 sec (7.8%). Similarly, a change in number of cuts per cycle was found to slightly increase the DFC time. The change in the predictor variables like distance between the trees and distance to the deck did not have much effect on DFC time. A 40% increase in the distance between the trees could increase the DFC time to 42 sec (1%) (Fig 2a).

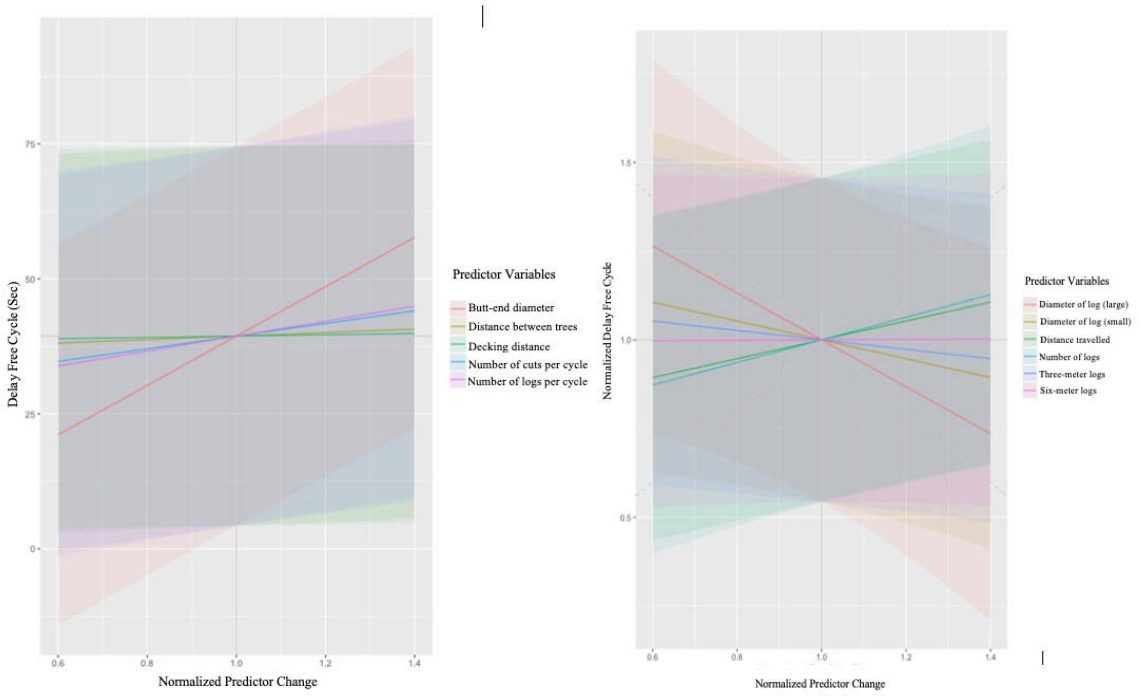


Fig 2a. DFC of harvester **Fig 2b. Normalized DFC of forwarder**

Figure 2. Sensitivity analysis on DFC time of harvesting (cedar stand) equipment at a normalized predictor variable change of 20% and 40%

3.4.2 Forwarder

The change in predictor variables like distance and number of pieces increased the DFC time, thereby reducing the productivity of the operational phase. A 40% increase in diameter of the handled log and number of 3-m length logs could decrease the DFC time by 25 and 10% respectively. Increase in the number of 6-m length logs did not seem to have much change in the DFC time. For the predictor variables, forwarding distance and number of pieces forwarded, a 40% change could increase the DFC time by approximately 12% (Fig 2b).

3.5 Cost allocation based on DFC

While considering the DFC time for producing different assortments, the cost of felling cedar (USD 6.35 m^{-3}) was found to be higher than hardwood (USD 6.09 m^{-3}) and softwood (USD 5.66 m^{-3}), even though it had the lowest DFC time among the three (Table 8). This difference can be connected to the smaller diameter of the cedar trees from the selected stands when compared to hardwoods and softwoods harvested. Smaller diameter leads to lower machine productivity and thereby higher harvesting cost. The smaller diameter of the lowland cedar may be attributed to the muck soil found in the lowland cedar stand, which cannot support larger trees.

Table 8. Cost of felling and processing different assortments available in the harvesting operation

Assortments	DFC[a] (sec)	Cost (USD m^{-3})	Productivity (m^3 PMH^{-1}[b])
Cedar	27.23	6.35	32.45
Hardwood	56.35	6.09	33.83
Softwood	40.06	5.66	36.40

[a] DFC- Delay free cycle time
[b] PMH- Productive machine hour

3.6 Managerial considerations while winter harvesting

Although winter harvesting can be the most ideal for environmental and cost considerations (Berry, 2019), there may be difficulties. Once the snow gets too deep, it is difficult to maneuver machinery. Also, fewer daylight hours during winter will pose challenges to the operators in terms of selecting the trees to be felled and maneuvering across the site (West Fraser, nd). This can additionally create a safety hazard. There is also the need for tire chains to enhance traction of the machines while moving across the frozen ground.

As the logging operation was carried out in the winter season, it was essential to plow the road and landing for providing access for the equipment to the harvesting sites and the smooth functioning of the operation. Therefore, it is necessary to add the cost of snow plowing to the final harvesting cost. In the logging contract, the responsibility for snow plowing was with the landowner. The distance from the primary road to the landing was about 2.7 km with a width of 8 m. The cost for snow plowing the road for a single time was USD 675 (USD 225 hr^{-1}) using a 3.7-m blade. The total cost of snow plowing the road during the operation period was USD 2025. The landing had an area of 2709 m^2. It was plowed three times during the period of operation, and it took a total of five hours using a 2.5-m blade. With the labor cost for snow plowing at USD 70 hr^{-1}, the cost of plowing the landing was USD 350. All together snow plowing incurred an additional expense of USD 2375. The snow plowing has added an extra USD 1.66, 2.35 and 5.67 to every cubic meter of wood harvested from the entire harvesting operation, non-cedar stand and cedar stand respectively.

4. Conclusion

Lowland cedar is an important tree species with great economic implications. Due to the risk in accessibility and forest floor condition, it is challenging to harvest the cedar. Being a fragile ecosystem, harvests should be planned such that there is a minimal detrimental impact on the stand and soil, and also considering the safety of the logging crew. A cut-to-length harvesting method during winter with frozen ground is the most appropriate logging strategy. This study analyzed the economic feasibility of this type of timber harvesting operation in a lowland cedar stand and compared it to a non-cedar stand on sturdy grounds. The cost of harvesting was higher for the lowland cedar stand. There was little evidence of a direct effect of soils on operational costs, likely because the harvest occurred on frozen ground. Nevertheless, soils had an indirect effect on costs due to the role they play in determining tree species composition; cost of harvesting cedar was higher than hardwoods and softwoods. Overall, cost of extraction constituted 65% of the total cost of

operation. It was decreased by 34–41% when the landing (hypothetical) was assigned just outside the stands. Sensitivity analysis revealed the change in DFC time with changes in the predictor variables. Quantitative understanding on the effect of predictor variables can help in efficient planning of harvest operations considering the uncertainties.

5. Acknowledgement

We would like to express our gratitude to Libin T Louis, David Holmberg, Lauren Keefe, and Aaron Malone for assisting in data collection. Our appreciation goes to Keith Kanoti, Robin Avery (University Forest, University of Maine System), Andrew Richley (US Forest Service) and Scott Barnes (Prentiss & Carlisle Forest Resource Management and Timberland Service) for their involvement in the operational aspect of the study.

6. Funding

This project was supported by United States Department of Agriculture National Institute of Food and Agriculture (McIntire-Stennis project number #ME041909 through the Maine Agricultural and Forest Experiment Station); Cooperative Forestry Research Unit (CFRU); United States Forest Service, Northern Research Station and Northeastern States Research Cooperative.

7. References

Avery, T.E. and Burkhart, H.E. 1983. Forest Measurements. Third Ed. McGraw-Hill, New York. 331pp.

Bennett, K. P. editor. 2010. Good forestry in the granite state: recommended voluntary forest management prectises for New Hampshire (second edition). University of New Hampshire Cooperative Extension, Durham, N.H. 227p.

Berry, A., Bick, S., Frederick, P., Steele, A., Mclarty, M. and Hollinger, D. 2019. Warmer, wetter logging. The Northern Logger: 20-24.

Boulfroy, E., Forget, E., Hofmeyer, P.V., Kenefic, L.S., Larouche, C., Lussier, J.M., Pinto, F., Ruel, J.C. and Weiskittel, A. 2012. Silvicultural guide for northern white-cedar (eastern white cedar). Gen. Tech. Rep. NRS-98. Newton Square, PA: U.S. Dept. of Agric, Forest Service, Northern Research Station. 74 p.

Bulley, B. 1999. Effects of tree size and stand density on harvester and forwarder productivity in commercial thinning. For. Eng. Res. Inst. Can., Vancouver. TN-292. 8pp.

Cudzik, A., Brennensthul, M., Bialczyk, W. and Czarnecki, J. 2017. Damage to soil and residual trees caused by different logging systems applied to late thinning. Croat. J. for. Eng. 38(1): 83-95.

Dahlman, R. and Rossman, D. 2010. Timber harvesting and forest management guidelines on public and zprivate forest land in Minnesota. Minnesota Department of Natural Resources. 57 p. Available: https://mn.gov/frc/docs/MNDNR_FMG_monitoring_2009_report.pdf. (Accessed July 9, 2019).

Dubé, S., Plamondon, A. P. and Rothwell, R. L. 1995. Watering up after clear-cutting on forested wetlands of the St. Lawrence lowland. Water Resources Research, 31(7), 1741-1750.

Frohn, J. 2017. Looking for northern white cedar. University of New Hampshire Cooperative Extension. Available:

Huff, S.E. and McWilliams, H.W. 2016. Forests of Maine, 2015. Resource Update FS-86. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 4p.

Hiesl, P. and Benjamin, G.J. 2015. Estimating processing time of harvesters in thinning operations in Maine. Forest Products J., 65(3): 180-186.

Jiang, S. 2016. Forest harvesting impacts on forested wetland ecosystem functions in North America. University of British Columbia, Canada. 34p.
Jovanovic, M. 2018. Simple sensitivity analysis with R. Available: https://complementarytraining.net/simple-sensitivity-analysis-with-r/
Kanoti, K. 2018. Harvest plan OP_ID: 195. University Forest, University of Maine, Orono, 9p.
Kellogg, L., Bettinger, P., Robe, S. and Steffert, A. 1992. Mechanized harvesting: A compendium of research. Forest Res. Lab., Oregon State Univ., Corvallis. 401 pp.
Kenefic, L.S, Kizha, R.A., Fraver, S., Greig, H. and Roth, B.E. 2017. Silviculture and operations in northern white cedar lowlands: A pilot study. CFRU project proposal, University of Maine, Orono, 25p.
Kenefic, L.S. 2013. New management strategies for northern white cedar. Research Review, US Forest Service Northern Research Station(21), 6p. Available: https://www.nrs.fs.fed.us/news/review/review-vol21rv2.pdf.
Kenefic, L.S. 2018. Marking guidelines MU55, irregular shelterwood. Northern Research Station, U.S. Forest Service. 6p.
Kenefic, L.S., Fraver, S., Wason, J. and Kizha, A. 2019. Lowland white-cedar ecology and operations, and white-cedar old growth, NEFIS Publication 15942, Center for Research on Sustainable Forests, University of Maine, Orono, ME. Available: https://nefismembers.org/documents/lowland-white-cedar-ecology-and-operations-and-white-cedar-old-growth/
Kizha, A.R. and Han, H-S. 2015. Productivity and cost of processing and sorting forest residues. 38th Council on Forest Engineering Annual Meeting. July 19 -22, 2015. Lexington, Kentucky. http://www.cofe.frec.vt.edu/documents/2015/abstracts/akizha_hhan.pdf
Kizha, A.R., Han, H-S. 2016. Processing and sorting forest residues: cost, productivity and managerial impacts. Biomass and Bioenergy. 93, 97-106.
Kluender, R., Lortz, D., McCoy, W., Stokes, B. and Klepac, J. 1997. Removal intensity and tree size effects on harvesting cost and profitability. Forest Products Journal. 48(1): 54-59.
Larson, D.W., Matthes-Sears, U. and Kelly, P.E. 1993. Cambial dieback and partial shoot mortality in cliff-face Thuja occidentalis: Evidence for sectored radial architecture. International Journal of Plant Sciences. 154:496-505.
LeDoux, C.B. and Huyler, N.K. 2001. Comparison of two cut-to-length harvesting systems operating in eastern hardwoods. Inter. J. of Forest Eng. 12(1):53-59.
Maine Forest Service [MFS]. 2018a. 2017 Stumpage price. Augusta, ME: Department of Conservation, Maine Forest Service, Forest Policy and Management Division. 17p. Available: file:///Users/alex.george/Downloads/2017%20Stumpage%20Price%20Report.pdf
Maine Forest Service [MFS]. 2018b. 2017 Wood processor report. Augusta, ME: Department of Conservation, Maine Forest Service, Forest Policy and Management Division. 10p. Available: file:///Users/alex.george/Downloads/2017_Woodprocessor_Report.pdf
Miyata, E.S. 1980. Determining fixed and operating costs of logging equipment, USDA Forest Service general technical report NC. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station.
Nakagawa, M., Hamatsu, J., Saitou, T. and Ishida, H. 2007. Effect of tree size on productivity and time required for work elements in selective thinning by a harvester. Int. J. For. Eng. 18, 24-28.
Puttock, D., Spinelli, R. and Hartsough, R.B. 2005. Operational trials of cut-to-length harvesting of poplar in a mixed wood stand. Int. J. For. Eng. 16:1, 39-49. DOI: 10.1080/14942119.2005.10702506.
Richardson, R. and I. Makkonen. 1994. The performance of cut-to-length systems in Eastern Canada. For. Eng. Res. Inst. Can., Pointe Claire. TR-109. 16pp.
Russell, M., Blinn, C. and Gupta, A. 2018. Harvesting timber: Why do we harvest trees in the winter? University of Minnesota, Available: http://www.myminnesotawoods.umn.edu/2018/01/why-do-we-harvest-trees-in-the-winter/.
Sahoo, K., Bilek, E.M., Bergman, R., Kizha, A.R. and Mani, S. 2018. Economic analysis of forest residues logistics options to produce quality feedstocks. Biofuels, Bioproducts and Biorefining 13(3)514-534. DOI:10.1002/bbb.1958
Sauder, E.A. 1993. Techniques that protect understory in mixed wood stands: summary of harvesting trials. For. Eng. Res. Inst. Can., Pointe Claire. TN-198. 12pp.
Schira, M. 2013. Winter weather conditions may be the ideal time for timber harvest activities. Michigan State University Extension. Michigan State University, USA. Available:

https://www.canr.msu.edu/news/winter_weather_conditions_may_be_the_ideal_time_for_timber_harvest_activiti. (Accessed July 9, 2019).

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online. Accessed [June/05/2019].

Soman, H., Kizha, A.R. and Roth, B.E. 2019a. Impacts of silvicultural prescriptions and implementation of best management practices on timber harvesting costs. Int. J. For. Eng. 30, 14–25. https://doi.org/10.1080/14942119.2019.1562691

Soman, H., Kizha, A.R., Munoz, B., Kenefic, L. and Kanoti, K. 2019b. Production Economics: Comparing Hybrid Tree-Length with Whole-Tree Harvesting Method. Forestry: International Journal of Forest Research (Forestry-2019-082) In press.

Timber harvesting. nd. Timber harvesting. Northern Research Station, Forest Service, USDA. Available: https://www.nrs.fs.fed.us/fmg/nfmg/docs/mn/harvesting.pdf. (Accessed July 9, 2019).

U.S. Environmental Protection Agency [EPA]. 2005. National management measures to control nonpoint source pollution from forestry. Office of Wetlands, Oceans and Watersheds, U.S. Environmental Protection Agency, Washington DC, EPA-841-B-05-001, 276p. Available: https://www.epa.gov/sites/production/files/2015 10/documents/2005_05_09_nps_forestrymgmt_guidance.pdf.

Venables, W.N., Ripley, B.D. and Venables, W.N. 2002. Modern applied statistics with S, 4th ed. ed, Statistics and computing. Springer, New York.

West Fraser. Nd. Sustainably harvesting trees in the winter. West Fraser. Available: https://www.westfraser.com/responsibility/stories-responsibility/sustainably-harvesting-trees-winter. (Accessed July 9, 2019).

Woodall, C., Munoz, D.B., Kenefic, L.S. and Kern, C.B. 2019. Status and Trends of Northern White-Cedar in the U.S., NEFIS Publication 15940, Center for Research on Sustainable Forests, University of Maine, Orono, ME. https://nefismembers.org/documents/status-and-trends-of-northern-white-cedar-in-the-u-s/

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

Selecting successful harvester operators through aptitude tests and demographics

K Schwegman[1*], R Spinelli[2], N Magagnotti[2], A McEwan[3] and M Ramantswana[1]

[1]Nelson Mandela University, George, Western Cape, South Africa
[2] CNR, Institute for the Bio-Economy, Italy
[3]CMO Group, George, Western Cape, South Africa
*Correspondence: Kylle.Schwegman@mandela.ac.za

Abstract: *Simulators are used worldwide for various applications in different industries (e.g. aviation and medicine), to better prepare learners or trainees for actual work situations. The forest industry is no exception, as numerous studies have shown that simulator-based training has many added values one being improved learning. Most of these studies were conducted in countries such as Finland, Switzerland, America, and Norway. Little information is available relating to the pre-selection of harvesting operators prior to simulator-based training. The aim of this study was to determine whether harvesting simulators could be used in conjunction with the Vienna Test System to identify potential harvesting operators.*

A mixed methods approach (quantitative work study data and qualitative questionnaire data) was used to determine differences among 14 volunteer students. Each student spent a total of 10 hours on the simulator. Once the demographic questionnaires were completed the students then completed the Vienna Test System. The test was designed to measure hand-eye coordination, the ability to concentrate for long periods of time, as well as the candidates cognitrone and is used within the mining industry as a pre-selection tool for heavy machine operators.

Preliminary results show that the Vienna Test System results were able to pre-identify individuals that are fast and productive. Although many studies have indicated that effective and efficient operators require these abilities and more. Noting that as the students completed the 10 hours on the simulator their learning improved at different rates for the different students. This is as expected since previous studies have shown the same results.

Keywords: psychometric tests, pre-selection tool, harvesting operator, Vienna test system

1. Introduction

Recent studies within South Africa have proven that the forestry industry has been shifting towards the use of fully mechanised harvesting systems (Krieg *et al*. 2010; Hogg *et al*. 2011; Ackerman *et al*. 2017; Wenhold 2019; Mathelele 2018). The major factors influencing this shift are the global market, the health and safety act (85 of 1993), the increases in minimum labour wage from 2010-2014 and urbanisation (Grobbelaar and Manyuchi 2000, Spinelli *et al*. 2002; WFSP Forestry Programme 2004; Steenkamp 2007, Gardiner 2008). Due to these changing factors, the forest industry has had to increase productivity and improve health and safety of the work area, whilst attempting to reduce costs associated with large labour forces. Furthermore, the willingness of labourers to work under challenging work conditions has decreased in many countries specifically for the agriculture and forestry sectors (Spinelli *et al*. 2013).

Because of these changing factors there is an evident need for mechanization within the forest industry. A fully mechanised cut-to-length (CTL) harvesting system consists of two machines, a harvester and a forwarder (Kellog and Bettinger 1994; Längin *et al*. 2010). The harvester fells, de-barks, de-branches, and cross-cuts the tree infield (Kellog and Bettinger 1994; Längin *et al*. 2010), while the forwarder extracts the logs from infield to roadside (Kellog and Bettinger 1994; Längin *et al*. 2010). Fully mechanised harvesting systems are associated with high capital investment and require particularly skilled operators (Rummer and Klepac 2002; Ovaskainen and Heikkila 2007; Purfürst 2010; McEwan 2012).

Numerous studies have shown that the skills of operators have become a significant concern, as over 40% differences in harvesting productivity have been observed among forest machine operators (Kirk *et al*. 1997; Ovaskainen and Heikkila 2007; Purfürst and Erler 2011; McEwan *et al*. 2016). Specific human abilities such as decision making, concentration, motor coordination, memory, motivation, pattern recognition, logic reasoning, planning capacity, and spatial perception

have been identified in various research studies, over the past 60 years, as abilities that result in successful harvesting work (Hansson 1965; Andersson *et al*. 1968; Gellerstedt 2002; Parise 2004; Ovaskainen & Heikkilä 2007; Tervo *et al*. 2010; Ager 2014; Häggström 2015), although it is still difficult to determine exactly which specific skills and abilities and/or combination thereof will result in a more effective and efficient harvesting machine operator (Andersson *et al*. 1968; Garland 1990; Ovaskainen and Heikkilä 2007; Häggström 2015).

Studies have shown that the pre-selection of machine operators using their psychometric and cognitive abilities can be used for reducing variation amongst selected operator candidates and for choosing those that are most likely to succeed in their future jobs (Kirk *et al*. 1997; Purfürst 2007; Hogg *et al*. 2010, 2011; Purfürst and Erler 2011; Palander *et al*. 2012; Häggström 2015). However, little information is available on the use of a specific psychometric test system known as the Vienna Test System on the pre-selection of potential harvesting machine operators in South Africa and whether it has the ability to disseminate the difference between an effective and efficient harvesting machine operator.
Using a simulated work environment as a level test-bench equal for all study subjects, this experiment aimed at determining if a psychometric test among those most commonly used for selecting forest machine operators actually delivers what it promises. In particular, the study aimed at testing: 1) if different test scores reflect different performance results, in terms of both productivity and work quality, 2) if specific demographics are statistically related with a better or worse performance expectation and 3) what specific components of a complex aptitude test are best at emerging forest machine operators with a high performance potential.

2. Materials and Methods

2.1 Candidate selection and process

The candidates consisted of a variety of forestry students (1st year of study through to senior levels such as B Tech and Masters) who volunteered to join the study. Each student was informed of the requirements of the study which was to complete the Vienna Test System (psychometric test), followed by a harvesting course, offered by an experienced and qualified operator trainer and assessor. Each candidate was then required to complete at least 10 hours of simulator training over a two-month period. In addition to this the candidates also completed a demographic questionnaire which aided with identifying the sampled population. Additional information formed part of the questionnaire such as current year of study (Third year, B-Tech and Masters), whether the students' game or not, and the general demographics (i.e. age, gender etc.).

2.2 The Vienna Test System

According to Schuhfried (1996) the Vienna Test System (VTS) is a computer-assisted application of many highly diverse psycho-diagnostic tests, measuring reaction times in tasks that require choosing among complex stimuli. There are five subtests which are incorporated within the VTS namely: Signal Detection; Two-Hand Coordination; Cognitrone; Determination Test and ZBA (Time/Movement Anticipation). A description of the five subtests developed by Schuhfried (1996; 2000a; 2000b; 2000c; 2000d) is provided below as described by Jehkonen *et al*., (2012) and Olivier (2015).

Signal Detection - Is used for evaluating long-term selective attention, namely the visual differentiation of a relevant signal within irrelevant signals. The candidate's task is to press a response button when a target stimulus (constantly changing pattern of four white dots on a black background) forms a square in any part of the computer screen. The main variable calculated is the sum of correct reactions in each quadrant of the visual field. The accepted performance for the correct reactions is >60% according to the reference data of the Vienna Test System (Schuhfried 1996; Schuhfried 2000a; Jehkonen *et al*., 2012).

Two-hand Coordination - Assesses hand-eye and hand-hand coordination (Schuhfried 1996; Schuhfried, 2000b). Candidates are required to move a cursor on a given track with the aid of two joysticks, one that can move forward and backward and one that can move right and left (Schuhfried 1996; 2000b). Candidates must therefore use both hands in a coordinated way to move the cursor along the track within acceptable accuracy limits (Schuhfried 1996; Schuhfried 2000b). The track consists of three sections varying in the demands made on the left and right hands. The scores yielded are total mean duration (the speed dimension) and total percentage error duration (the accuracy dimension) (Olivier 2015).
Cognitrone - Assesses the candidate's ability to concentrate and to adjust his/her work tempo to different stimuli patterns (Schuhfried 1996; Schuhfried 2000c). Candidates are required to indicate as fast, and as accurately as possible,

whether any of four figures presented on a computer screen is similar to the figure in the test question. The test yields various options in terms of differentiated results (Schuhfried 1996; 2000c; Olivier 2015).

Determination Unit - Assesses a candidate's reaction speed, reactive stress tolerance and ability to demonstrate sustained multiple-choice reactions to rapidly changing stimuli (Schuhfried, 1996). Its focus is on the operators' appropriate and fast responses in rapidly changing environments that may involve various stressors and stimuli (Schuhfried, 1996). The Determination Unit requires the discrimination of colours and acoustic signals, memorisation of the relevant characteristics of stimulus configurations and response buttons, and also memorisation and application of assignment rules (Schuhfried, 1996). Individuals have to react to differently coloured visual stimuli as well as acoustic stimuli that require either finger or foot responses. The test starts off slowly, gains speed to a very fast response requirement (approximating high stress situations, such as accident or near-accident situations) and then slows down marginally (approximating the period just after the accident/near accident) (Schuhfried, 1996; Olivier 2015).

Time Movement/Anticipation Test (ZBA) - The ZBA sub-test assesses an individual's ability to imagine the effect of a movement and correctly estimate the movement of objects in space (Schuhfried, 1996; Schuhfried, 2000d). As the individual watches a ball move across the computer screen, the ball suddenly disappears, and they are required to indicate when and at what position the ball would have crossed a line. Data is recorded on the time and position accuracy (Olivier 2015).

Once the students had completed the tests an overall performance rating was allocated in the form of categories or classes indicated by A+ (Excellent), A (Very Good) B+ (Good), B (Fair), B- (Below Average) or C (poor). Three classes were prominent *Class* A, B+ and B from the 20 tested students. In addition to the overall *Class* categories the raw *Scores* were also provided for each of the tests conducted

2.3 Harvesting Simulator Course and Training

Regardless of the *Class* rating achieved in the Vienna Test System, each student received training from a professional harvester trainer. The students were taught how a harvester operator would work through a compartment (work phases). In addition to these workshops, the individual students were shown how to operate the simulator controls and worked through a 30 min session with the professional harvesting trainer.

Each student then completed at least 10 hours (made up of 10 one-hour sessions) on the John Deere laptop simulator over a two-month period (John Deere 2010). After each one-hour simulator session the data would be captured using the John Deere simulator software and exported as a pdf. The simulator software generates various outputs such as total time, pause time, drive time, boom usage, process time, stem count, cabin damage, machine damage, stumps over 30 cm and productivity (m^3 PMH^{-1}). Once the data has been captured the John Deere software would be reset to zero prior to the follow up session.

2.4 Data collection and Analysis

As each student completed the 10 simulator hours, the data could be consolidated into a master data set using Microsoft Excel. The master data set contained all students that completed at least 10 hours as well as the individual *Classes* and *Scores* from the Vienna Test System and Demographic data. Of the initial 20 students, 14 were able to complete the required hours on the simulator.

Prior to statistical analysis, the data was checked for any possible outliers or errors, which were removed if appropriate justification was found for doing so (i.e. evidence was found that the outlier was an artefact). Additional variables could then be calculated, including: productivity (m^3 PMH^{-1}), move time as a percent of total work time, processing time as a percent of total work time, number of stumps taller than 30 cm. These variables were obtained from the John Deere simulator software and were extracted separately for the first hour and the tenth hour, so that one could determine the eventual changes obtained through practice (i.e. learning).

Descriptive statistics were used to determine which derived variables may have any stratification worth exploring further. A standard statistical program (SAS Institute Inc. 1999) was then applied to analyse the data, in terms of determining whether the distributions of results for different treatments were significantly different. Standard tests for normality of the data was carried out. Where data was not normally distributed, non-parametric tests were used. In particular, differences between three or more groups were tested using the Kruskal-Wallis test, while differences between two groups were tested using the Mann-Whitney U test (SAS Institute Inc. 1999).

3. Results

3.1 Vienna Test System

Based on the results provided by the contracted and trained industrial psychologist, it was noted that the lowest overall Vienna Test System *Class* score obtained from the 14 students was a B. Therefore, none of the students was within the C *Class* (C=Poor). Of the 14 students nine were male (with ages ranging from 20-27 years) and five were female (with ages ranging from 22-25 years). Descriptive statistics was used to determine whether there is any stratification for the various Performance Indicators (Table 1).

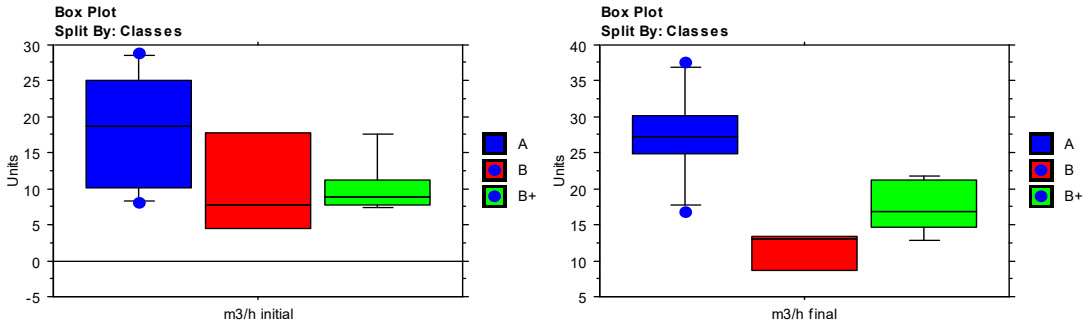


Figure 1: Box and whisker plots illustrating simulator work productivity

Notes. m^3/h Initial = productivity recorded after one hour on the simulator; m^3/h Final = productivity recorded after 10 hours on the simulator; Units = m^3/h or cubic meters under bark per hour of productive work.

No significant (0.05 level) differences were found for the remaining work productivity and quality indicators, and namely: Increment of m^3PMH^1; *%Move* (Initial and Final); *%Process* (Initial and Final; number of stumps taller than 30 cm (Initial, Final and Increment); Machine Damage. However, the results for "Machine Damage final" were particularly interesting, with a clear stratification between the A-class score group (damage events per bout averaging at 14) and the other two groups (damage events per bout averaging at 50). This difference was denoted by a P-value of 0.1, which was still higher than the significance threshold of 0.05, but close enough to be suggestive of a possible real difference. In fact, if one potential outlier was removed from the data set, then the P-value would change to 0.04 and the difference would become statistically significant.

Table 2: The Kruskall Wallis p-values for different Classes (A, B+ and B)

Kruskall Wallis p-value for different Classes **(A, B+ and B)**	**p-value**	**Comments**
m^3/PMH initial	0.1144 ^{nsd}	-highly suggestive
m^3/PMH final	0.0098**	-Significant
m^3/PMH Increment	0.7451^{nsd}	
% move initial	0.4309 ^{nsd}	
% move final	0.8102 ^{nsd}	
%process initial	0.6858 ^{nsd}	
% process final	0.5288 ^{nsd}	
Stump 30 initial	0.5164 ^{nsd}	
Stump 30 final	0.5139 ^{nsd}	
Increment Stump 30	0.2120 ^{nsd}	
Machine damage initial	0.6242 ^{nsd}	
Machine damage final	0.1048**	- highly suggestive
Increment Mach. dam.	0.4309 ^{nsd}	

Since attribution to a discrete score class was based on a continuous score figure, the same performance indicators were regressed against Vienna Test Scores, as a further check. The regression coefficients are reported in Table 3 and basically repeat the same story already told by the Kruskal-Wallis test (Table 2).

Table 3**:** Regression coefficients for the relationship between the various performance indicators (dependent variable) and the Vienna test scores (independent variable)

Performance Indicators	**Vienna Test Scores regression coefficients**
m^3/PMH initial	**0.114**
m^3/PMH final	**0.479**
m^3/PMH Increment	0.021
% move initial	0.008
% move final	0.066
%process initial	0.056
% process final	0.072
Stump 30 initial	0.067
Stump 30 final	**0.133**
Increment Stump 30	0.009
Machine damage initial	0.010
Machine damage final	**0.215**
Increment Mach. dam.	0.002

Notes. Values in red indicate that there is a strong regression coefficient relationship, Values that are in bold show that there is a potential regression coefficient relationship.

3.2 Work productivity and work quality vs. demographics

This part of the study aimed at determining if performance was affected by three main demographic indicators extracted from the study admission forms, and namely: education (Third year, B-Tech and Masters level), gender (Male and Female) and gaming habit (no gaming at all, less than 1 hour per day, up to 3 hours per day). Since data were not distributed normally, the analysis was conducted again with the Kruskal-Wallis technique. Of all tested variables, only gender and gaming habits resulted to have a significant effect on productivity after 10 hours of work (Table 4). In particular, male subjects were 60% more productive than female subjects (23.5 m^3 PMH^{-1} vs. 14.7 m^3 PMH^{-1}) and non-gamers were about 40% less productive than subjects who spent gaming at least one hour per day (11.7 m^3 PMH^{-1} vs. 19.1-24.8 m^3 PMH^{-1}). The higher performance of gamers was independent of the time they spent gaming, so that subjects engaged with gaming three hours per day did not perform any better than those who spent gaming less than one hour per day.

Table 4: Statistical significance of the performance differences between different groups for Education, Gender and Gaming habits: P-Values resulting from the Kruskal-Wallis test

Performance Indicators	**Education**	**Gender**	**Gaming**
m^3/PMH initial	0.6930	0.0532	0.2012
m^3/PMH final	0.8899	**0.0388***	**0.0503**
m^3/PMH Increment	0.4890	0.2173	0.5815
% move initial	0.1709	0.8415	0.7809

% move final	0.2256	0.5485	0.1782
%process initial	0.2759	**0.0136***	0.1088
% process final	0.7592	0.6407	0.2025
Stump 30 initial	0.5773	0.2023	0.4221
Stump 30 final	0.1479	0.3426	0.2813
Increment Stump 30	0.1962	0.7375	0.8822
Machine damage initial	0.4305	0.8413	0.5448
Machine damage final	0.1328	0.5582	0.4779
Increment Mach. dam.	0.1908	0.6407	0.6926

Note: * = Statistically significant

The only other significant difference was for the % of time spent processing, which was higher for male subjects compared with female subjects and likely reflected better dexterity, since a longer time share spent on processing may imply a faster and more precise positioning of the head on the tree before processing commences (of course, this deduction is only valid if productivity is the same or higher, which is the case here).

Education level had no effect on any of the selected performance indicators.

3.3 Main performance indicator vs. specific components of the Vienna Test Assessment

This part of the study aimed at determining if any specific pre-existing cognitive and motorial abilities had a stronger effect on forest machine operator performance than all the remaining such abilities. The analysis targeted those performance indicators that were associated to the Vienna test scores by a significant or quasi-significant relationship. In particular, initial and final m^3 PMH^{-1} were used as the main indicator for work productivity, whereas the number of stumps taller than 30 cm and the number of machine damage events recorded after the 10^{th} one-hour work bout were taken as the main indicators of work quality. These indicators were used as dependent variables and regressed against the test scores for each component of the Vienna test assessment.

Relatively strong relationships ($R2 \geq 0.2$) are obtained between productivity and reaction time, cognitive time, correct hits and signal correct, whereby the first two relationships are negative and the following two positive (Table 5). That points at the most productive operators being the fastest and the most accurate. Concerning work quality, the strongest relationships were with hand time and hand error, possibly pointing at dexterity as a prevailing tract of those operators that achieved better work quality scores than the rest.

Table 5: Regression coefficients for the relationship between the various performance indicators (dependent variable) and the scores obtained for specific components of the Vienna test

	m^3/PMH Initial	**m^3/PMH Final**	**Stump 30 Final**	**Machine damage Final**
React time	-0.079	**-0.233**	0.012	0.024
Correct hits	0.134	**0.456**	-0.153	-0.128
Signal correct	0.014	**0.307**	-0.004	-0.015
Signal time	0.148	-0.065	-0.004	-0.001
Hand time	-0.115	-0.035	**0.502**	**0.389**
Hand error	-0.035	-0.133	**-0.404**	-0.048
Cogn Hits	0.003	0.006	0.004	-0.001

Cogn time accept	-0.184	**-0.251**	-0.001	0.165
Cogn time reject	-0.134	-0.162	-0.001	0.134
Direction time	-0.029	-0.094	0.347	0.166
Direction error	-0.040	-0.057	-0.003	-0.093

Note: In bold are the regression coefficients that denote the strongest relationships in the test battery

4. Discussion

4.1 Limitations of the Study

Before discussing the results of the study, it is important to define its limitations and frame the validity of any statements made in the following paragraphs. In particular, the main limitations of this study are: the relatively small number of participants, their motivation and interest, and the degree to which a simulated environment may reflect actual machine operation.

Obviously, one would have liked to include a larger number of participants within the study, but student availability and budget limitations did not allow recruiting more than 20 subjects, and the high dropout rate did the rest. However, the final number (n=14) is within the norm reported for similar studies that eventually were validated through peer-review and publication, often with as few as 6 subjects and never more than 35 (see Freedman 1998; Ovaskainen 2005 and Wenhold *et al*. 2019).

Concerning subject motivation and interest, the main witness to the commitment of test subjects comes from the high dropout rate, which points at the natural "weeding" of those subjects who did not have the necessary motivation and interest: those who reached the end of the test proved to be motivated and interested enough, because they could drop out at any point, but they kept going until completion of the experiment. In any case, much care was paid to planning the experiment in such a way as to stimulate interest and motivation, as suggested by Wiklund (1999).

Finally, the capacity of simulator work to reflect real work has been demonstrated in many studies that show how simulator training has a strong effect on real work performance (Freedman 1998, Yates 2000): if simulator work did not reflect real work, then it is unlikely it would make an impact on real work performance, and training centres would not use it simulators in such a pervasive way (Wiklund 1999, Ranta 2009). For what concerns specifically harvester simulators, one may quote the conclusions of a study that specifically addressed this issue and demonstrated that:

> *"the harvester simulator has all the main elements and restrictions set by the real forest, under which the real harvester work must be performed in the real forest. For example, in thinning, the remaining trees set a limit for the operator. Therefore, the basic principles of harvesting must be known so that high productivity and good quality can be obtained. Steering the crane and driving the harvester were the most realistic phases of the simulator environment*". (Ovaskainen 2005).

4.2 Vienna test system vs. performance indicators

Students that scored an A in the Vienna test system were first visible in the Initial m^3 PMH^{-1}. There could be various factors that have influenced this such as innate dexterity or better pre-existing motivation to work with the simulator for these individuals. As stated by Tervo *et al*. (2010); Ovaskainen & Heikkilä, (2007); Parise (2004); Gellerstedt (2002) and Andersson *et al*. (1968) concentration, decision making, memory, motivation, pattern recognition, logic reasoning, special perception and motor-coordination are abilities that have been identified as important for successful harvesting work. Therefore, the Vienna test

system could only test for some of these different abilities such as hand-eye coordination, dexterity, and mental focus which are only some of the important abilities for a successful harvesting machine operator.

The Vienna test system was able to select a fast and productive machine operator but as mentioned there are more qualities to becoming a productive machine operator which were not covered by the Vienna test system or the simulator.

4.3 Demographics (Gender, Gaming and Education) vs. performance indicators

Gender

Males were found to be two-times more productive than females for Initial m^3 PMH^{-1} and Final m^3 PMH^{-1} (**Figure 2**). This could be due to various reasons such as the fact that females are less aggressive when handling the controls on the machine and therefore take longer to complete a task (Bonnano & Kommers 2005). It is also possible that males are more likely to have played videogames and are therefore more familiar with the simulated environment (understand that there is no real consequence to movement). Males spent less time with head positioning initially when compared to females. This initial difference is lost after 10 hours on the simulator. Therefore, females seem learn as the productivity margin of males shifts from 100% to 60% after 10 hours although the time was not enough to close the gap completely.

With training, however, the significance of gender differences increases, indicating that the two groups seem to pack tighter. One reason could be that the less productive subjects are likely able to pick up the pace as learning continues. As for work quality, no visible gender differences were found as this test could not confirm anecdotal evidence about the better work quality (less damage, better cuts) achieved by female operators.

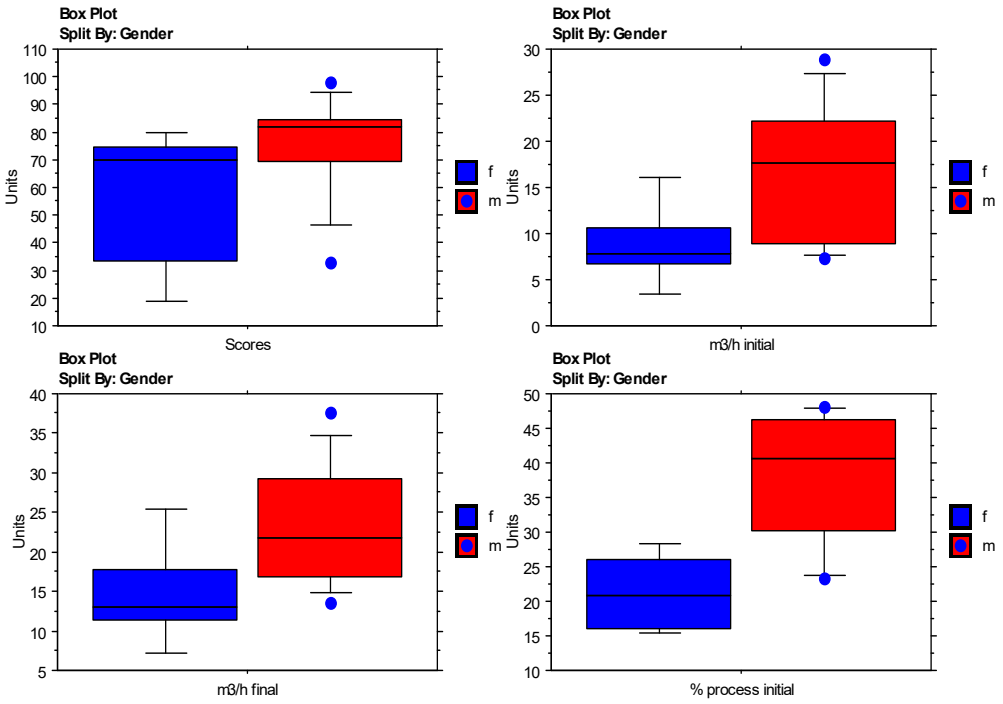


Figure 2: Differences between male and female students, *Scores* (in percentage)**,** productivity (*m^3 PMH^{-1} Initial* and *m^3 PMH^{-1} Final*) and *%Process Initial* for work productivity and quality

Gaming

Although gamers performed 40% better than those that gamed less than one hour per day there was no significant difference between gamers that played for more than 3 hours a day and those that played less than one hour per day. This could be due to the fact that there are multiple platforms for gaming each with their own unique controls (e.g. computers use a keyboa57rd and mouse; consoles use a controller and mobile phones and/ or tablets use a flat touch screen). Also, various studies have indicated that male gamers and female gamers do not necessarily prefer the same types of games (Mehrabaian and Wixen, 1986; Barnett *et al*. 1997; Yates and Littleton, 1999), which may hint at a combination effect between gender and gaming habit. Therefore, one may assume that playing games in general would assist the individual with realising that there are no real consequences to the simulator as it is a virtual environment and therefore, they may be more willing to be less cautious and more aggressive.

Education

No significant differences were found for education groups (Third year, B-Tech and Masters). Which is what was expected as education may possibly affect motivation but not dexterity which is primarily what has been tested with the Vienna test system. However, if the students were attending a specific school that specialized in training harvesting machine operators one would assume that differences would then be found.

4.4 Vienna components vs. performance

Gellerstedt (2002) and Hansson (1990) describe forest harvesting as joystick-intense, mentally demanding work in which visual information and supervision are important. This is confirmed in the study, which found a significant association between harvester productivity (Final m^3 PMH^{-1}) and the individual scores for reaction time, cognitive time, correct hits and signal correct. These individual scores are associated with the following subtests: Signal Detection, Cognitrone, and Determination Test. Therefore, it could be said that the operator's ability to focus and/or concentrate for long periods whilst being able to adjust to different work tempos without becoming distracted by external elements is important alongside the ability to react when prompted or stimulated. This potentially revolves around the operator's ability to work within the "work environment"

5. Conclusion

To conclude, the different test classes (A; B+; and B) that were obtained from the Vienna test system was able to determine significant differences for the Final m^3 PMH^{-1}, where those that obtained an A class were significantly different to those that obtained a B+ and B. However, for work quality the results were highly suggestive, if a valid reason was available for removing the individual outlier one would have obtained similar results for the Work quality as found for Productivity, where the damage caused to machines was lowest in the A class when compared to that of B+ and B. As for the remaining productivity and work quality indicators, no significant differences were found for each of the classes (A; B+; and B).

As for the specific demographics (Gender, Gamers and Education), significant differences were found only for Gender and Gaming final m^3 PMH^{-1} where males were 60% more productive than females and non-gamers were 40% less productive than gamers. Therefore, it could be said that males were able to be more productive than females although fast and productive does not necessarily mean better machine operators as other factors such as machine downtime and repair costs have not been included in this study and should be taken into consideration. As for Education no significant differences were obtained which was expected as the individuals that took part in the study are not studying specifically to become machine operators.

As for the specific test components that were best for identifying machine operators. Reaction time, cognitive time, correct hits and signal correct were all identified as potential indicators however they were all essentially testing the same thing and that is the ability to quickly make a decision in a complex environment.

It is clear that the Vienna Test System is able to pre-identify individuals that are fast and productive. However, there are many additional abilities that make up a productive and effective machine operator that have not been tested in this paper. The variability found amongst different machine operators needs to be reduced in order to reduce the overall variation in machine productivity amongst machine operators (which is approximately 40%). This may only be possible through the careful pre-selection of new harvesting machine operators as it may already be too late to remove bad habits and/or work techniques in experienced harvesting machine operators. Therefore, future research should focus of the pre-selection of harvesting machine operators through a process of elimination starting with identifying specific human (personally types) 8 or 16 broad categories. Additionally, one should potentially identify individuals that prefer specific environments associated to that of a harvesting machine operator. Generally speaking, this personally type should be a person that is able to work for long periods of time in an isolated environment and be able to continually perform a similar task without losing interest or focus.

6. Acknowledgements

The authors would like to thank all that took part in this study conducted at Nelson Mandela University. This project was funded by The Rupert Family Trust and FP&M SETA.

7. References

Ackerman, P. Williams, C. Ackerman, S. Nati, C. (2017) "Diesel consumption and carbon balance in South African pine clear-felling CTL operations: a preliminary case study," Croatian Journal of Forest Engineering. 38 (1):65–72.

Ager, B. (2014) Skogsarbetets humanisering och rationalisering från 1900 och framåt [Forestry labors' humanization and rationalization from 1900 onwards]. Diss. Luleå, Sweden: Luleå tekniska universitet.

Andersson, L. Bergström, L. Krantz, A. Lennerheim, G. Pettersson, B. (1968) Urval av skogstraktorförare med psykologiska test. (Selection of tractor operators by means of psychological tests). (Redogörelse nr 7) Stockholm, Sweden: Forskningsstiftelsen Skogsarbeten. (In Swedish with English abstract).

Barnett, M. A. Vitaglione, G. D. Harper, K. K. G. (1997) "Late adolescents' experiences with and attitudes towards videogames," Journal of Applied Social Psychology, 27, 1316-1334.

Bonnano, P. Kommers, P. (2005) "Gender differences and styles in the use of digital games," In Educational Psychology, 25(1), (pp. 13-41).

Freedman, P. (1998) "Forestry machine simulators: looking for added value in training," Canadien Woodlands Forum Annual Meeting, Quebec, Canada March 23–25. 1998.

Gardiner, M. (2008) "Education in Rural Areas," Issues in Education Policy 4: 1-34. Johannesburg: Centre for Education Policy Development.

Garland, J. J. (1990) "Assessing gains from woodsworker training," International Journal of Industrial Ergonomics, 5(3), pp. 227-242.

Gellerstedt, S. (2002) "Operation of the single-grip harvester: motor-sensory and cognitive work," International Journal of Forest Engineering, 13(2), pp. 35-47.

Grobbelaar, F. R. Manyuchi, K. T. (2000) "*Eucalyptus* debarking: an international overview with a southern African perspective," South Africa: Forest Engineering Southern Africa.

Häggström, C. (2015) “Human Factors in Mechanized Cut-to-Length Forest Operations,”. Ph.D. Thesis, Swedish University for Agricultural Sciences, Acta Universitatis Agriculturae Sueciae, Umeå, Sweden, 2015.

Hansson, J. E. (1965). “Samband mellan personvariabler och prestation vid huggningsarbete,” (The Relationship between individual Characteristics of the Worker and Output of Work in Logging Operations). (Studia Forestalia Suecica Nr 29) Stockholm: Skogshögskolan. (In Swedish, with English summaries).

Hogg, G. Pulkki, R. Ackerman, P. (2010) “Multi-stem mechanized harvesting operational analysis – application of Arena 9 discrete event simulation software in Zululand, South Africa,” International Journal of Forest Engineering. 21 (2):14–22.

Hogg, G. Pulkki, R. Ackerman, P. (2011) “Excavator-based processor operator productivity and cost analysis in Zululand, South Africa,” Southern Forests: A Journal of Forest Science. 73(2):109–115.

Jehkonen, M. Saunamäki, T. Alzamora, A. K. Laihosalo, M. Kuikka, P. (2012) “Driving ability in stroke patients with residual visual inattention: a case study,” *Neurocase* 18, 160–166. doi: 10.1080/13554794.2011.568504.

John Deere. (2010). *Forestry Machine Simulators* [online pdf]. Available at: http://common.jd-ssl.com/common/docs/products/equipment/simulators/brochure/JD_Simulators_EN_2010_brochure.pdf [accessed 10 September 2017].

Kellog, L. Bettinger, P. (1994) “Thinning productivity and cost for mechanized cut-to-length system in the Northwest Pacific coast region of the USA,” International Journal of Forest Engineering. 5(2):43–52.

Kirk, P. M. Byers, J. S. Parker, R. J. Sullman, M. J. (1997) “Mechanisation developments within the New Zealand forest industry: the human factors,” International Journal of Forest Engineering. 8(1):75–80.

Krieg, B. de Wet, P. Olsen, G. McEwan, A. (2010) South African Ground Based Harvesting Handbook. 1st ed. D. Längin, P. Ackerman, B. Krieg, J. Van Rooyen, A. Immelmann, C. Potgieter, & S. Upfold, Eds. Scottsville Pietermaritzburg: Forest Engineering Southern Africa.

Längin, D. Ackerman, P. Olsen, G. (2010) Introduction to ground based harvesting systems and methods. In: Längin DW, Ackerman PA, Krieg B, Immelman A, van Rooyen J, Upfold S (eds), *South African Ground Based Harvesting Handbook*. Institute for Commercial Forestry Research, Pietermaritzburg, South Africa.

Mathelele, F. (2018) “A technical survey of the South African harvesting machine population,” MSc. Thesis. Nelson Mandela University, South Africa.

McEwan, A. (2012) “The effect of tree and bundle size on the productivity and costs of Cut-To-Length and multi-stem harvesting systems in *Eucalyptus* pulpwood,” MSc. Thesis. University of Pretoria, South Africa.

McEwan, A. Magagnotti, N. Spinelli, R. (2016) “The effects of number of stems per stool on cutting productivity in coppiced *Eucalyptus* plantations,” Silva Fennic*a* 50: 2 article id 1448. http://dx.doi.org/10.14214/sf.1448.

Mehrabian, A. Wixen, W. J. (1986) “Preference for individual video games as a function of their emotional effect on players,” Journal of Applied Social Psychology, 16, 3-15.

Olivier, L. P. (2015) “Psychomotor ability and learning potential as predictors of driver and machine operator performance in a road construction company,” MA. Thesis. University of South Africa, South Africa.

Ovaskainen, H. (2005) “Comparison of harvester work in forest and simulator environments,” Silva Fennica. 39(1): 89–101.

Ovaskainen, H. Heikkila, M. (2007) “Visuospatial cognitive abilities in cut-to-length single-grip timber harvester work,” International Journal of Industrial Ergonomics. 37: 771–780. doi: 10.1016/j.ergon.2007.06.004.

Palander, T. Ovaskainen, H. Tikkanen, L. (2012) “An adaptive work study method for identifying the human factors that influence the performance of a human-machine system,” Forest Science. 58(4):377–390.

Parise, D. (2004) “The competence of forest-machine operator and tacit knowledge case study,” In: Proceedings of the International Seminar on Simulator-based Training of Forest Machine Operators, Joensuu, Finland 2004.

Purfürst, F. T. (2007) “Human influences on harvester operators,” In: Austro2007/FORMEC’07 – Meeting the Needs of Tomorrows’ Forests – New Developments in Forest Engineering; BOKU: Vienna. p. 1–9.
Purfürst, F. T. (2010) “Learning curves of harvester operators,” Croatian Journal of Forest Engineering. 31(2):89–97.

Purfürst, F. T. Erler, J. (2011) “The human influence on productivity in harvester operations,” International Journal of Forest Engineering. 22(2):15–22.

Ranta, P. (2009) “Added values of forestry machine simulator-based training,” Proceedings of the International conference on multimedia and ICT education; Lisbon, Portugal.

Rummer, R. Klepac, J. (2002) Mechanized or Hand Operations: Which Is Less Expensive for Small Timber? Pages 183-189 in D. Baumgartner, L. Johnson, and E. DePuit, Eds. Small Diameter Timber: Resource Management, Manufacturing, and Markets, Spokane, WA.

SAS Institute Inc. (1999) StatViewReference. SAS Publishing, Cary, NC, pp.84–93. ISBN-1-58025-162-5.

Schuhfried, G. (1996). Vienna Determination Test. Release 25.00. Moedling: Author.

Schuhfried, G. (2000a). Signal Detection. Release 21.00. Moedling: Author.

Schuhfried, G. (2000b). Two-Hand Coordination. Release 22.03. Moedling: Author.

Schuhfried, G. (2000c). Cognitrone. Release 26.01. Moedling: Author.

Schuhfried, G. (2000d). Time-Movement Anticipation. Release 22.00. Moedling: Author.

Spinelli, R. Owende, P. M. Ward, S. M. (2002) “Productivity and cost of CTL harvesting of *Eucalyptus globulus* stands using excavator-based harvesters,” Forest Products Journal 52: 67–77.

Spinelli, R. Magagnotti, N, Facchinetti, D. (2013) “Logging companies in the European mountain: an example from the Italian Alps,” International Journal of Forest Engineering 24:109–120

Steenkamp, J. C. (2007) “The effect of HIV and AIDS on the viability and management of forestry contracting businesses in South Africa,” DBA thesis, Nelson Mandela Metropolitan University, South Africa.

Tervo, K, Palmroth, L. Koivo, H. (2010) “Skill evaluation of human operators in partly automated mobile working machines,” IEEE transactions on Automation Science and Engineering. 7(1), pp. 133-142.

Wenhold, R. Ackerman, P. Ackerman, S. Gagliardi, K. (2019) “Skills development of mechanized softwood sawtimber cut-to-length harvester operators on the Highveld of South Africa,” International Journal of Forest Engineering. DOI: 10.1080/14942119.2019.1578561.

WFSP Forestry Programme (2004). Roundwood supply and demand to 2030. Document prepared by LHA Management Consultants for WFSP Forestry Programme. Available at http://www2.dwaf.gov.za/webapp/ResourceCentre/Documents/Publications_And_Media/Roundwood_supply_and_demand_-_Final_report_181404.pdf [accessed 1 April 2011].

Wiklund, T. (1999). Simulatorteknik! Examsarbete. Lärarhögskolan i Malmö, Lunds Universitet. 34 p. [In Swedish].

Yates, B. (2000) “High tech training of high-tech workforce in the forest industry,” Canadian Woodlands Forum 81st Annual Meeting” Technologies for New Millennium Forestry”, Session 3B” Workforce Development and Issues”, September 13, 2000. Kelowna, Canada.

Yates, S. J. Littleton, K. (1999) “Understanding computer game cultures: A situated approach,” Information, Communication and Society, 2, 566-583.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

COMPARISON OF ELECTRIC CORDLESS AND PETROL CHAINSAWS IN TERMS OF EFFICIENCY IN REAL-WORLD CONDITIONS

Matevž Mihelič, Anton Poje
University of Ljubljana
Biotechnical Faculty
Department of Forestry and Renewable Resources
Večna pot 83, 1000 Ljubljana, Slovenia
matevz.mihelic@bf.uni-lj.si , anton.poje@bf.uni-lj.si

Abstract: *We have compared three electrical cordless chainsaws with a petrol powered one. The experiment was conducted in pure stands of spruce, by three professional fellers. In the trial 28,43 m^3 of wood was felled, with trees ranging from 10-30 cm diameter breast height (DBH_{ob}). We have established, that the petrol powered chainsaw had significantly higher efficiency with 12.26 min/$m^3_{(ub)}$ than electrical chain saws' efficiency, which ranged between 15.01 and 21.28 min/$m^3_{(ub)}$. Although there are still serious drawbacks of electrical cordless chainsaw use for professional forestry applications, the results show that the efficiency of these machines is seriously challenging the use of petrol saws in small wood conditions.*

Keywords: forestry, efficiency, motor-manual felling, electrical cordless chain saw, forest operations

1. Introduction

Due to its multifunctional use, flexibility and a relatively low financial investment, the chainsaw remains the main tool for harvesting in majority of the world's forests. However the use of chainsaws in forestry presents a risk to workers safety and health. In addition to the highest accident rate in professional and non-professional work, the main problems are exposure to environmental hazards, and in particular noise and hand-arm vibration (Lipoglavšek, 1997, Neri et.all, 2018).
In recent years, the producers of power tools have systematically shifted the majority of their products range to battery power. The reason for such transition was the improved performance of battery tools, which means less maintenance, no air pollution on site and no cables. The last tools to be tackled in outdoor applications were blowers and chainsaws, due to the very difficult working environment and high power requirements. Electrical cordless chainsaws, however are showing great potential in limiting the exposure of workers to hand-arm vibration and noise (Poje et.all, 2018). The question however remains; how do electrical cordless chainsaws perform in real life forest operations.

2. Materials and methods

The experiment was conducted in South Eastern Slovenia, in pure stands of spruce. In total 93, trees were felled, ranging from 10-30cm diameter breast height (DBH_{ob}).The electrical chainsaws in the experiment are the best available in terms of power and technological development, however with similar weight, length of the blade and chain type. The saws used were Husqvarna 536 LiXP, Stihl MSA 200C, Makita DUC353Z, and a petrol powered chainsaw Husqvarna 445 for experiment control. All components (bars, chains, lubrication) were provided by the respective manufacturer. The chainsaws were operated by three experienced fellers, certified and with formal high school education for the profession. The felling and processing of all trees was recorded on digital camera, for detailed time study examination. The work cycles were divided into eight work elements of productive work time where petrol chainsaws typically run. In addition to standard work elements (Jourgholami et al. 2013) chainsaws were also used during log measuring and cross-cut marking as preparation of a cut into which a release nail of a logger tape is attached.

The logs were cut on 4,10 m length, and DBH_{ob} was measured overbark for every log. All felled trees were alive and without broken tops, ensuring full length of trees. The worker stopped delimbing, when the DBH fell under 5 cm.

3. Results

In the trial, 28.43 m^3 of wood was cut, and the average efficiency of work amounted to 4.20 $m3/h_{ub}$, for which 468 min of productive time was required. The workers' skill did not significantly influence the results of efficiency. In general work efficiency increases with felled trees' diameter, while the highest efficiency was achieved using the gas powered chainsaw (12.26 $min/m^3_{(ub)}$). The electrical chain saws' efficiency was in range between 15.01 and 21.28 $min/m^3_{(ub)}$. With trees of DBH between 25 and 30 cm for instance the efficiency was 44.6% higher than in with trees of 10-15cm DBH, while the difference was significant.

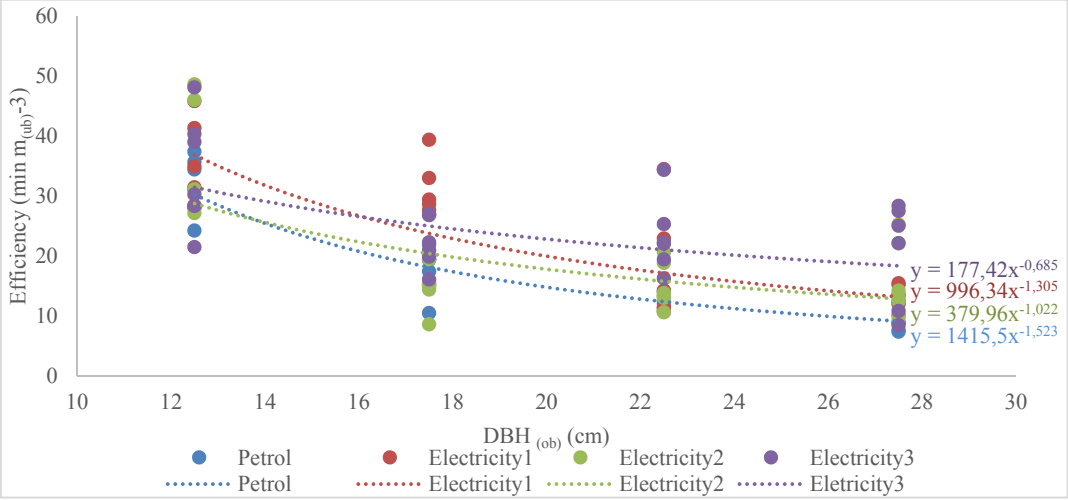


Figure1: Efficiency of chain saws in regard to tree DBH class

4. Conclusions

The results show that, although electrical cordless chainsaws are in the very beginning of technological development, their efficiency is already challenging the use of petrol applications. There are still however serious drawbacks of electrical cordless chainsaw's use for professional forestry. The biggest disadvantage is relatively short battery lifespan, which is further amplified by the absence of charging infrastructure in the forests.

4.7 Acknowledgements

We would like to thank the Pahernik foundation for supporting the research and publishing of the results and the project CRP V4-1624 for the publishing of the results.

4.8 References

Jourgholami, M., Majnounian, B., Zargham, N., (2013) "Performance, capability and costs of motor-manual tree felling in Hyrcanian hardwood forest", Croat J for Eng, 34, 283-293

Lipoglavšek, M., 1997, "Logger's loads at work with power saws" in Proceedings of: "Forest operations in Himalayan forests with special consideration of ergonomic and socio-economic problems", Bhutan, 105-111

Neri,F., Laschi, A., Foderi, C., Fabiano, F., Bertuzzi, L., Marchi, E. (2018) “Comparison of electric and petrol chainsaws in terms of efficiency and safety when used in young spruce stands in small-scale private forests”, Forests, 9, 8, 1-13
Poje, A., Potočnik, I., Mihelič, M. (2018), “Comparison of electric and petrol chainsaws in terms of efficiency and safety when used in young spruce stands in small-scale private forests”, Small-scale Forestry, 17, 3, 411 – 422

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

HARDWOOD MECHANIZATION: STATE OF THE ART AND PERSPECTIVES BASED ON 20-YEARS EXPERIENCE IN FRANCE

Philippe RUCH, Chloé BOLDRINI
Institut Technologique FCBA
Pôle Première transformation - Approvisionnement
60 route de Bonnencontre, F-21170 Charrey sur Saône, France
Philippe.ruch@fcba.fr

Abstract: *The lack of manual workforce and the need for better safety and ergonomic conditions have been the 2 main drivers of the development of the mechanization in broadleaved stands. This was initiated in the late 90s in France, boosted by the 2 storms Lothar and Martin in 1999 and has continued to progress since. Currently the mechanization rate in hardwood harvesting is estimated around 15% in France but reaches 75% in southwest. As the shortage of lumberjacks is worsening, forest companies are compelled to turn to mechanization but still have many questions dealing with technical, organizational, human factors...*

During these years, FCBA had the opportunity to carry out 70 time studies of mechanized harvest in broadleaved stands (chestnut, oak, beech…), mostly in clearcuts but also in thinnings, with tree volume from 0.026 to 0.459 m3. Different logging organizations were thus monitored:
(i) single harvester for tree felling then processing,
(ii) single harvester teamed up with a lumberjack who thins the clumps by cutting the dead and smallest stems. This facilitates the work of the following harvester which can be more efficient at felling trees,
(iii) 2-machine system with a feller-buncher for felling then a harvester for processing.

However, these methods, based on the intervention of a harvester, are not adapted to the full diversity of broadleaved stands (species, diameter, coppice/regular forest...). Other harvesting systems have been developed in last decade, monitored also by FCBA: full-tree harvest for energy, semi-mechanization in large trees (DBH > 50 cm) with manual felling and stem processing, then mechanized crown processing...

Finally, size of the logging site, tree density per hectare, tree volume and shape (straightness), rate of non-commercial stems are key parameters in determining the most appropriate system.

To keep on developing hardwood mechanization, two paths have to be further explored. The first focuses on machinery with the development of harvesting heads really adapted to hardwoods, the prototype ribbed knives are a step in this direction. The second path concerns organization and the capacity to choose the appropriate system(s) according to the characteristics of the forest stands and the desired products (logs, chips).

Keywords: hardwood mechanization, harvest in broadleaved stands

PO E-Posters

MECHANIZATION STRATEGY OF SMALL-SCALE CONTRACTORS IN JAPAN
Akie Kawasaki [1], Katsuhisa Kohroki [2]
[1] Kyushu University, Japan; [2] University of Tsukuba, Japan

ESTIMATING AVAILABILITY OF FOREST BIOMASS RESOURCES IN THE WHOLE OF JAPAN
Kazuhiro Aruga [1], Battuvshin Biligt [2], Yusuke Matsuoka [1], Takahisa Yamamoto [1], Hiroaki Shirasawa [3]
[1] Utsunomiya University, Japan; [2] Tokyo University of Agriculture and Technology, Japan; [3] Forestry and Forest Products Research Institute, Japan

DOSING OF PHYSICAL LOAD FOR HIKING INFRASTRUCTURE USERS IN THE FORESTS OF THE KRKA NATIONAL PARK
Matija Landekić, Ivan Martinić, Mario Šporčić
Forestry Faculty of Zagreb University, Department of Forest Engineering, Zagreb, Croatia

LOW-COST GNSS APPLICATIONS TO AREA SURVEYING UNDER FOREST CANOPY: POSSIBILITIES AND LIMITATIONS
Tetsuhiko Yoshimura [1], Yasushi Suzuki [2]
[1] Faculty of Life and Environmental Science, Shimane University; [2] Faculty of Agriculture and Marine Science, Kochi University

AUTOMATIC GENERATION OF SHALLOW DITCH NETWORK IN FOREST USING LIDAR DATA AND MULTICPECTRAL SATELLITE IMAGERY
Raitis Melniks, Janis Ivanovs, Andis Lazdins
Latvian State Forest Research Institue "Silava", Salaspils, Latvia

SMART SENSING TECHNOLOGY FOR PREDICTING FOREST ROAD´S BEARING CAPACITY
Franz Holzleitner [1], Michael Fritz [1], Wolfgang Sokol [2], Fritz Zott [3], Christian Kanzian [1]
[1] Institute of Forest Engineering, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences, Vienna, Austria [2] Institute of Hydraulics and Rural Water Management, Department of Water, Atmosphere and Environment, University of Natural Resources and Life Sciences, Vienna, Austria [3] Institute of Mountain Risk Engineering, Department of Civil Engineering and Natural Hazards, University of Natural Resources and Life Sciences, Vienna, Austria

AN INNOVATIVE TIMBER FELLING SYSTEM BASED ON JAPAN'S TRADITIONAL TECHNIQUE
Yuko Shirai
Keio University, Tokyo, Japan

APPLICATION OF MODERN TECHNOLOGY FOR TREE GROWTH MONITORING
Narongdet Detkong, Nopparat Kaakkurivaara, Roongreang Poolsiri
Department of Forest Engineering, Faculty of Forestry, Kasetsart University, Bangkok, Thailand 10900

NATURAL LANGUAGE PROCESSING AND IDENTIFYING CHARACTERISTICS OF JAPAN'S REGIONAL FORESTS, FORESTRY AND POLICIES
Ryotaro Okada, Yuko Shirai
Keio University, Tokyo, Japan

THE EFFICACY OF CHONDROSTEREUM PURPUREUM IN THE SPROUT CONTROL IN MECHANIZED PRE-COMMERCIAL THINNINGS
Tiina Laine [1], Leena Hamberg [2], Veli-Matti Saarinen [1], Timo Saksa [1]
[1] Natural Resources Institute Finland (Luke), Suonenjoki, Finland [2] Natural Resources Institute Finland

(Luke), Helsinki, Finland

LOGGING PLANNING VIA AERIAL FOREST SURVEY
Angkana Thongkam, Nopparat Kaakkurivaara, Payattipol Narangajavana
Department of Forest Engineering, Faculty of Forestry, Kasetsart University, Bangkok, Thailand

INCORPORATING STAND PROPERTIES AND BUCKING OBJECTIVES FOR BUCKING-TO-DEMAND HARVESTING
Jukka Malinen, Markus Mennala
University of Eastern Finland, School of Forest Sciences, Joensuu, Finland

THINNING OPTIMIZATION IN BEECH POLE STANDS
Domen Arnič [1], Jurij Diaci [2], Janez Krč [3]
[1] Slovenian Forest Institute, Department of Forest technique and Economics, Ljubljana, Slovenia, [2] Universiti of Ljubljana, Biotechnical Faculty, Department of Forestry and Renewable Forest Resources, Ljubljana, Slovenia

LOG DETECTION BASED ON DEEP CONVOLUTIONAL NEURAL NETWORKS
Kengo Usui, Masahiro Mozuna, Takumi Uemura, Masahiko Nakazawa
National Research and Development Agency Forest Research and Management Organization Forestry and Forest Product Research Institute, Tsukuba, Japan

BEST PRACTICE HARVESTING PROCEDURES TO MEET NATURE PROTECTION REQUIREMENTS IN GERMANY
Ute Seeling, Hans-Ulrich Dietz
Kuratorium fur Waldarbeit und Forsttechnik, Gross-Umstadt, Germany

UNLOCKING THE POTENTIAL OF HARVESTER ON-BOARD-COMPUTER DATA IN THE SOUTH AFRICAN FORESTRY VALUE CHAIN
Marius Terblanche, Simon Ackerman, Pierre Ackerman
Stellenbosch University, Stellenbosch, South Africa

ESTIMATION OF FOREST ROAD NETWORK MAINTENANCE COST CONSIDERING COLLAPSE RISK : AN APPLICATION IN THE JAPAN MOUNTAINOUS REGION
Masaru Watanabe, Masashi Saito, Hiroaki Shirasawa, Tatsuhito Ueki
Shinshu University Graduate School, Ina, Japan;

OAK LACE BUG IN EASTERN SLAVONIA (CROATIA), INTEGRATED FOREST PROTECTION IN FSC CERTIFIED FORESTS AND PRECAUTIONS IN OAK TIMBER PRODUCTION
Milivoj Franjević, Antonija Kolar, Andreja Đuka, Boris Hrašovec
Faculty of Forestry, University of Zagreb, Zagreb, Croatia

THE EFFECT OF TREE PLANTATION-MANAGING TECHNOLOGIES ON BIODIVERSITY
Nóra Szigeti, Imre Czupy, Andrea Vágvölgyi
University of Sopron, Faculty of Forestry, Institute of Forests- and Environmental Techniques, Sopron, Hungary

TIMBER HARVESTS DUE TO ABIOTIC AND BIOTIC DAMAGE BY THE EXAMPLE OF EGERERDŐ PLC.
Viktória Papp [1], László Babiczki [2], Szilárd Grédics [2], Dóra Szalay [1]
[1] University of Sopron, Sopron, Hungary; [2] Egererdő Plc., Eger, Hungary

DATENBASIS WALDARBEIT - PLANNING TOOL FOR AVERAGE TIME CONSUMPTION AND COSTS OF STANDARDISED FOREST WORKING PROCEDURES
Markus Dög [1], Andrea Hauck [2], René Maxeiner [3]
[1] Georg-August-Universität Göttingen, Abt. Forstökonomie, Göttingen, Germany; [2] Kuratorium für

Waldarbeit und Forsttechnik e.V., Groß-Umstadt, Germany; [3] Georg-August-Universität Göttingen, Abt. Arbeitswissenschaft und Verfahrenstechnik, Göttingen, Germany

DEVELOPING AND EVALUATING LOGISTICS CHAINS WHEN USING DEBARKING PROCESSOR HEADS (DEBARKING HEADS II)

Andrea Hauck [1], Jochen Grünberger, [1], Bernd Heinrich [1], Joachim B. Heppelmann [2,3], Ute Seeling [1], Stefan Wittkopf [2]

[1] Kuratorium für Waldarbeit und Forsttechnik e.V., Gross-Umstadt, Germany; [2] University of Applied Science Weihenstephan-Triesdorf, Freising, Germany; [3] Department of Ecology and Ecosystem Management, Technical University of Munich, Freising, Germany;

FOREST WORK IN THE TROPICS IN THE FOCUS OF WORK SCIENCE

Siegfried Lewark

Chair of Forest Work Science, University of Freiburg, Germany

DENDROMASS4EUROPE (D4E) - SECURING SUSTAINABLE DENDROMASS PRODUCTION WITH POPLAR PLANTATIONS IN EUROPEAN RURAL AREAS

Natascia Magagnotti, Raffaele Spinelli

CNR Ivalsa, Sesto Fiorentino (FI), Italy

MULTI-FUNCTION MACHINE'S WORK QUALIFICATION

Katalin Szakálosné Mátyás, Ferenc János Sudár, Attila László Horváth

Institute of Forest- and Environmental Techniques, Sopron, Hungary

COST AND PRODUCTIVITY OPTIMIZATION USING DIFFERENT MOUND PREPARATION METHODS

Kristaps Makovskis, Dagnija Lazdina, Edgars Dupuzs

Latvian State Forest Research Institute "Silava"

INDICATOR BASED ASSESSMENT OF TRAFFICABILITY OF FOREST ROADS

Marian Schönauer [1], Franz Holzleitner [2], Dariusz Pszenny [3], Jarosław Kikulski [3], Gernot Erber [2], Dirk Jaeger [1], Markus Riegler [2], Stephan Hoffmann [1,4]

[1] Department of Forest Work Science and Engineering, Burckhardt-Institute, Georg-August-Universität Göttingen, Germany; [2] Institute of Forest Engineering, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences, Vienna, Austria; [3] Warsaw University of Life Sciences, Forest Utilisation department, Warsaw, Poland; [4] Chair of Forest Operations, University of Freiburg, Germany

APPLICABILITY OF HARVESTERS IN SELECTIVE CUTTING

Attila László Horváth, Mihály Rátky, Katalin Szakálosné Mátyás

University of Sopron, Hungary

NEW METHOD OF YOUNG STANDS TENDING OF DOUGLAS FIR IN NORTH RHINE-WESTPHALIA

Marian Schönauer, Dirk Jaeger

Department of Forest Work Science and Engineering, Georg-August-Universität, Göttingen, Germany

OPTIMIZATION OF WOOD TRANSPORTATION THROUGH TRUCKS FROM WOOD CUTTING AREAS TO CUSTOM CENTER USING GIS TECHNOLOGIES

Tihomir Krumov

University of Forestry, Bulgaria

OPPORTUNITIES AND CHALLENGES OF FOREST BIOMASS UTILIZATION

Dóra Szalay, Viktória Papp

University of Sopron, Faculty of Forestry, Institute of Forest - and Environmental Techniques, Sopron, Hungary

THE CURRENT STATE OF THE RUSSIAN FOREST INDUSTRY COMPLEX AND CALCULATION OF COSTS OF FOREST OPERATIONS ON THE BASIS OF ACTIVITY-BASED COSTING IN THE RUSSIAN FEDERATION.

Evgeny A. Tikhomirov [1], Maxsim A. Bykovskiy [2]
[1] Bauman Moscow State Technical University, Russia; [2] Faculty of Forestry, Forest Harvesting, Wood Processing Technologies and Landscape Architecture, Moscow State Forest University, Russia

INFLUENCE OF ENVIRONMENTAL FACTORS ON SEDIMENTARY SAND OF CROSS DRAIN IN OPERATION ROAD

Masashi Saito, Tokito Takezawa, Masaru Watanabe, Shirasawa Hiroaki, Tatsuhito Ueki
Shinshu University, Minamiminowa, Japan

INFORMATION-SHARING SYSTEM FOR A NEW HARVESTER EQUIPPED FOR AUTOMATIC ASSESSMENT OF LOG QUALITIES

Masahiko Nakazawa [1], Yukari Matsumura [1], Wataru Tanaka [1], Takumi Uemura [1], Hideo Kato [1], Hiroko Muneoka [1], Chikashi Yoshida [1], Seishiro Taki [1], Kengo Usui [1], Yuji Ikami [1], Kiyohiko Fujimoto [1], Yosuke Matsuda [1], Yutaka Kanazawa [2], Norio Shirai [3]
[1] Forestry and Forest Products Research Institute; [2] Nansei machine Co. Ltd.; [3] Komatsu Ltd.

BIOMASS YIELD AND FUEL PROPERTIES OF DIFFERENT POPLAR SRC CLONES

Dinko Vusić, Davorin Kajba, Ivan Andrić, Ivan Gavran, Tin Tomić, Ivana Plišo Vusić, Željko Zečić
University of Zagreb, Faculty of Forestry, Zagreb, Croatia

SOIL COMPRESSION DEGREE IN STUDIES OF VIBROCOMBINATOR TILLAGE TECHNOLOGIES

Nicusor Boja [1], Florin Boja [1], Dan Vidrean [1], Alin Teuşdea [2], Adrian Pica [3], Ilie Popescu [3]
[1] "Vasile Goldiş" Western University of Arad, Faculty of Economics, Informatics and Engineering, Department of Engineering and Informatics, 91-93 Liviu Rebreanu Street, AR 310414, Romania. [2] University of Oradea, Faculty of Environmental Protection, Department of Animal Science and AgroTourism, Gen. Magheru 26, 410396 BH, Oradea, Romania [3] Transilvania University of Brasov, Faculty of Silviculture and Forest Engineering, Department of Forest Engineering, Forest Management Planning and Terrestrial Measurements, nr. 1, Sirul Beethoven Street, 500123 Brasov, Romania

ASSESSMENT OF COSTS IN HARVESTING SYSTEMS USING THE WOODCHAINMANAGER WEB-BASED TOOL

Matevž Triplat, Nike Krajnc
Slovenian Forestry Institute, Ljubljana, Slovenia

COMBINED RAIL AND TRUCK TRAFFIC FOR RAW WOOD - RESULTS AND RECOMMENDATIONS FROM A SWISS CASE STUDY

Lorenz Diefenbach, Martin Ziesak
Bern University of Applied Sciences (BFH) - School of Agricultural, Forest and Food Sciences (HAFL), Bern, Switzerland

THE IMPACT OF WEATHER CONDITIONS ON PRODUCTION OF COST OF WOOD FUELS IN ESTONIAN CONDITIONS - A CASE STUDY

Marek Irdla, Allar Padari, Peeter Muiste
Estonian University of Life Sciences,Tartu, Estonia

SOIL PREPARATION MECHANIZATION - DEVICES MADE IN LATVIA FOR FUTURE FORESTS.

Dagnija Lazdina, Andis Lazdins, Karlis Dumins, Toms Arturs Stals, Kristaps Makovskis, Janis Liepins
LSFRI Silava, Riga street 111,Salaspils, Latvia, LV 2169

INFORMAL WORK IN A NEW BOOK ON TROPICAL FORESTRY

Siegfried Lewark
Chair of Forest Work Science, University of Freiburg, Germany

QUANTIFICATION OF METABOLIC STRAIN DURING CABLE WORKS WITH A MINI FORESTRY CRAWLER

Ferréol Berendt [1], Stephan Hoffmann [1,2], Dirk Jaeger [2], Stephan Prettin [3], Janine Schweier [1]
[1] University of Freiburg, Chair of Forest Operation, Germany; [2] University of Göttingen, Department of Forest Work Science and Engineering, Germany; [3] Medical Center of the University of Freiburg, Institute for Exercice and Occupational Medicine

FORMULATION OF THE IMPACT ON YARDING CABLE USING SPRING-DASHPOT MODEL

Midori Uenohara [1], Takeshi Matsumoto [2], Masahiro Iwaoka [2]
[1]United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Tokyo, Japan; [2] Institute of Agriculture, Tokyo University of Agriculture and Technology, Tokyo, Japan

MECHANIZED HARVESTING OPERATION IN WINDTHROW DAMAGED STANDS: A CASE STUDY IN THE NORTHEAST ITALY

Alberto Cade [1], Omar Mologni [2], Stefano Grigolato [1], Raffaele Cavalli [1]
[1] Department of Land, Environment, Agriculture and Forestry, Università degli Studi di Padova, 35020 Legnaro PD, Italy; [2] Department of Forest Resources Management, University of British Columbia, Vancouver BC, Canada

ANALYSIS OF THE BLACK LOCUST STANDS' BIOMASS PRODUCT IN HUNGARY

Tamás Major, Richárd Iski, Tamás Pintér, Andrea Tünde Kiss, Imre Czupy
Institute of Forest and Environmental Techniques, Faculty of Forestry, University of Sopron, Hungary

FORESTRY EDU TRAINER - COOPERATION FOR INNOVATION AND THE EXCHANGE OF GOOD PRACTICES

Andrea Teutenberg, Joachim Morat, Ute Seeling
KWF e.V. - Kuratorium für Waldarbeit und Forsttechnik e.V., Groß-Umstadt, Germany

HOW CAN AGROFORESTRY IMPROVE THE SUCCESS OF AFFORESTATION AND CONTRIBUTE TO MEETING THE GROWING DEMAND FOR WOOD?

Klaudia Kovács, Andrea Vityi
University of Sopron, Institute of Forest and Environmental Techniques, Sopron, Hungary

CALCULATING THE COST OF INTEGRATED HARVESTING OF SMALL-DIAMETER TREES DOMINATED STAND USING VARIOUS APPORTIONING METHODS

Libin Thaikkattil Louis, Anil Raj Kizha
School of Forest Resources, University of Maine, Orono, Maine, USA

PLANNING OF FOREST ROADS NETWORK: CASE STUDY IN THE MOUNTAIN NATURAL FORESTS AREA OF BOSNIA AND HERZEGOVINA

Vladimir Petković [1], Igor Potočnik [2], Dane Marčeta [1]
[1] University of Banja Luka, Faculty of Forestry, Bosnia and Herzegovina [2] University of Ljubljana, Biotechnical faculty, Department of Forestry and Renewable Forest Resources, Slovenia

DISTRIBUTION OF DEAD WOOD AT DIFFERENT DISTANCES FROM FOREST ROADS

Mohsen Mostafa [1], Aidin Parsakhoo [2], Sima Mohtashami [3]
[1] Mazandaran Agricultural and Natural Resources Research and Education Center, AREEO, Sari, Iran [2] Assistant Professor, Department of forestry, Faculty of Forest Science, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran [3] The forestry research institute of Sweden (Skogforsk)

A QGIS PLUGIN FOR OPTIMIZED CABLE ROAD LAYOUT PLANNING

Leo Bont [1], Patricia Moll [2], Laura Ramstein [1], Hans Rudolf Heinimann [3]
[1] WSL, Birmensdorf, Switzerland; [2] Patricia Moll, Zurich, Switzerland, [3] ETH, Zurich, Switzerland

COPPICE AFTER 3 DIFFERENT CUTTING SYSTEMS: GROWTH CAPACITY AND

MORTALITY
Carolina Lombardini, Raffaele Spinelli
CNR IVALSA, Sesto Fiorentino, Italy

A COMPARATIVE LIFE CYCLE ASSESSMENT (LCA) OF FOSSIL OIL AND A NEW INNOVATIVE SOLID BIOMASS CHAINS FOR SMALL-SCALE SPACE HEATING SYSTEM
Raghu KC, Jarno Föhr , Tapio Ranta
Lappeenranta-Lahti University of Technology LUT, Laboratory of Bioenergy, Mikkeli, Finland

MANUAL CULTIVATION OPERATIONS IN POPLAR STANDS: A CHARACTERIZATION OF JOB DIFFICULTY AND RISKS OF HEALTH IMPAIRMENT
Tiberiu Marogel-Popa [1], Marius Cheţa [1], Marina Viorela Marcu [1], Cristian Ionuţ Duţă [1], Florin Ioraş [2], Stelian Alexandru Borz [1]
[1] Department of Forest Engineering, Forest Management Planning and Terrestrial Measurements, Faculty of Silviculture and Forest Engineering, Transilvania University of Braşov, Romania [2] Buckinghamshire New University, Queen Alexandra Road, High Wycombe, Buckinghamshire, UK

OPERATIONAL PERFORMANCE OF PARTLY MECHANIZED PLANTING IN WILLOW SHORT ROTATION COPPICE
Nicolae Talagai [1], Marina Viorela Marcu [1], Andrea Rosario Proto [2], Stelian Alexandru Borz [1]
[1] Department of Forest Engineering, Forest Management Planning and Terrestrial Measurements, Faculty of Silviculture and Forest Engineering, Transilvania University of Braşov, Romania [2] Laboratory of Wood Technology and Forest Mechanization, Department of AGRARIA, University Mediterranea of Reggio Calabria, Italy

SIMULATION OF HARVESTER LOGGING PROCESSING AND DYNMIC DRIVING MOTION USING UNITY3D
Zhang Jianting, Huang Qingqing, Liu Jinhao, Cheng Bowen, Xie Danmu
Forest Engineering, Engineering Institute, Beijing Forestry University, China

FORMEC 2019 – Exceeding the Vision: Forest Mechanization of the Future
6-9 October 2019 - Sopron, Hungary

MECHANIZATION STRATEGY OF SMALL-SCALE CONTRACTORS IN JAPAN

Akie Kawasaki *[1] and Katsuhisa Kohroki [2]
[1] Faculty of Agriculture, Kyushu University
Moto'oka744, Nishi district, Fukuoka city, Fukuoka, Japan
kawasaki.akie@gmail.com

[2] Faculty of Life and Environmental Sciences, University of Tsukuba
Tennodai1-1-1, Tsukuba-shi, Ibaraki, Japan

Abstract: *Forestry machinery is expensive and always presents a financing problem for logging firms. Additionally, it is difficult to find an affordable financial strategy for small-scale contractors who have just started their business and have little budget or bank credit. This study shows, however, that many of them have mechanized gradually, as illustrated by research and interviews with four small-scale logging contractors in 2017 regarding how they arrived at an appropriate financial strategy and process for mechanization.*

These four small-scale firms started their businesses between 2006 and 2011. All owners are also chainsaw and machine operators. Five types of mechanization financing were utilized by these four contractors, depending on the owners' preferences. Their experiences show small-scale contractors' difficulties in obtaining finance; for two firms, particularly, the owners initially had to borrow funds for machines in the form of personal loans from consumer loan companies.

Keywords: small-scale contractor, mechanization, financing

1. Introduction

The artificial forests planted in Japan after World War II have grown large enough to harvest; therefore, the country is now in the midst of a logging boom. Forestry machinery such as processors or harvesters are essential for harvesting grown timber today. However, these machines are expensive compared with machinery used in the past, and their acquisition presents a financing problem for logging contractors worldwide (Lidén, 1995). Forest owners cooperatives and large-scale contractors can obtain subsidies from the government for mechanization; they are also able to use bank financing and can lease machinery from machine companies. However, these financial strategies are not usually affordable for small-scale contractors who have just started their business and have little in the way of operating funds or bank credit. Nevertheless, some small-scale contractors have managed to mechanize gradually.

Domestic timber production volume has been increasing in Japan since the beginning of the 2000s, reaching 21,410,000 m3 in 2017. More than 60% of that timber was harvested in the northern part of the Hokkaido and Tohoku area and the southern part of Kyushu area, with Kyushu contributing to 24% of the total production. In this study, research was conducted in Ooita prefecture, where forestry and lumber industryare major industries; in 2017, the prefecture ranked third in terms of the production volume of Japanese cedar, *Cryptomeria japonica*.

In Ooita prefecture, the Forest Owners Cooperatives do not have enough employees to operate their forest work, and therefore, they rely on contractors for harvesting (Kawasaki, 2016). Even so, there is a tendency

among new forestry employees of the cooperatives to become independent as contractors soon after finishing their training (Kohroki, 2015). According to a survey in 2006, most of the self-employed forestry contractors use hand machines such as chainsaws or small-scale forwarders, which most of the forest farmers own for shiitake mushroom production (Kawasaki, 2010). However, forestry mechanization seems to have advanced even among small-scale or middle-scale private contractors since the end of the 2000s. According to the administrative records of Ooita prefecture, the number of certified forestry contractors who have an improvement plan for employment management and business rationalization has increased from 27 firms in 2005 to 87 firms in 2017. The number of owned forestry machines has also increased, and clear-cutting productivity has improved from 6.3 m3/person day in 2010 to 8.1 m3 in 2015. Certified contractors enjoy an advantage, as they can use government subsidies for mechanization, even though they need to pay at least half the price of the machinery. However, the financing strategy for mechanization among self-employed or small-scale contractors has not been clarified.

2. Purpose and methods

Interviews were held in September 2017 with four small-scale contractors to find out their processes for mechanization and financial strategy. The four contractors were selected through the Forest Owners Cooperative in the area, meeting the requirement that they all started their own forestry contracting business during the prior decade.

3. Results

3.1 Characteristics of contractors and owners

The five owners of the four firms joined the Green Employment Project, through which the forestry agency trains beginners in forestry techniques, at the forest owners cooperative between 2002 and 2008, starting their own contracting businesses between 2006 and 2011 (Table 1). Each owner is also a chainsaw and machine operator, and they work with crews of two to four operators including the owner. They were certified between 2011 to 2016, and the purpose, for all four firms, in becoming certified contractors was to apply for subsidies for mechanization.

Table 1. Characteristics of contractors.

Contractor	A	B	C	D
Production volume per year	Under 4,000 m3	9,800-10,000 m3	10,000-11,000 m3	11,000-12,000 m3
Age of owner Number of employees	36 y/o 2 employees	28 y/o 1 employee	57 y/o 3 employees	57 y/o and 58 y/o 0 employee
Year started forestry as main job	2002	2008	2007	2002
Year of independence as contractor	2008	2011	2008	2006
Year certified by prefecture	2016	2015	2013	2011
Purpose of certification	To apply for subsidy for forestry machinery			
Business description	Logging (mainly clear cutting, and mainly contract work for a Forest Owners Cooperative)			

3.2 Process of mechanization

Mechanization history and methods of financing are shown in Table 2, with the method of financing and the year shown on the top line in each cell, and the type of machinery on the next line. The contractors introduced log forks or grapples at the beginning, and they started to use processors or harvesters after three to seven years. Five methods of financing are seen among the four contractors: 1) Lump-sum payment or two payments, 2) Loan from consumer finance lender, 3) Lease (60 payments over five years), 4) 50% subsidy and 50% loan from public financial institution, and 5) 50% subsidy and 50% loan from private financial institution. In regard to types of loan seen in this study, reasonable interest rates are available from public financial institutions because they have financial products for agriculture or forestry companies that are enhanced by government policy; by contrast, consumer finance provides only high-interest-rate loans.

Table 2. Process of mechanization.

Contractor	**A**	**B**	**C**	**D**
Introduced / sold or disposed	2) 2009 0.3 m3 used grapple		3) 2009 Log fork	2) 2011 * 0.3 m3 grapple
			3) 2009 0.2 m3 grapple	
Introduced /using	2) 2011 0.2 m3 grapple	3) 2012 0.3 m3 grapple	4) 2013 * 0.3 m3 grapple	4) 2014 Harvester
	5) 2016 * Processor	3) 2015 * Bucket grapple	4) 2013 * Forwarder	4) 2014 Base machine
	3) 2017 0.45 m3 grapple	4) 2015 Processor	4) 2015 Processor	2) 2015 0.45 m3 grapple
		3) 2016 Forwarder	1) 2015 0.2 m3 grapple	3) 2016 0.45 m3 grapple
Notes	* Year contractor was certified by prefecture Financing code: 1) Lump-sum payment or two payments 2) Loan from consumer finance lender 3) Lease (60 payments) 4) 50% subsidy and 50% loan from public financial institution 5) 50% subsidy and 50% loan from private financial institution			

The difficulty of financing for small-scale contractors can be seen, especially for the two contractors (A and D) that had to get their funds from consumer loan companies as personal loans at the beginning of their business. According to the interview, the manner of financing that was chosen tended to depend on contractors' preference based on their situation. Each method has its advantages and disadvantages: a loan from consumer finance is the easiest and most instant way of financing, but comes with a high interest rate. Public financial institutions provide loans at reasonable interest rates, but the product is limited. Subsidies are also limited and have many disadvantages, e.g., the types and models of equipment are limited, machines bought on subsidy are not allowed to be sold, the chance of subsidization is very low, and fifty percent or more of the contractor's own funds is required. With a subsidy, however, the contractor has a better chance to buy expensive machinery, such as a harvester, compared with the other financing methods.

3.3 The case of contractor A

In the case of contractor A, the owner started mechanization in 2009 at age 36 (Figure 1). At that time, he got consumer financing as his personal loan to buy a 0.3 m3 bucket-class used grapple. In 2011, a machine company supported his financing and introduced him to a local bank; by this good fortune, he succeeded in getting a loan from the bank. His company was certified by the prefecture, with one of the requirements being to apply to the government for a mechanization subsidy, and his company was subsidized in 2016. He used three different financing strategies up to 2017.

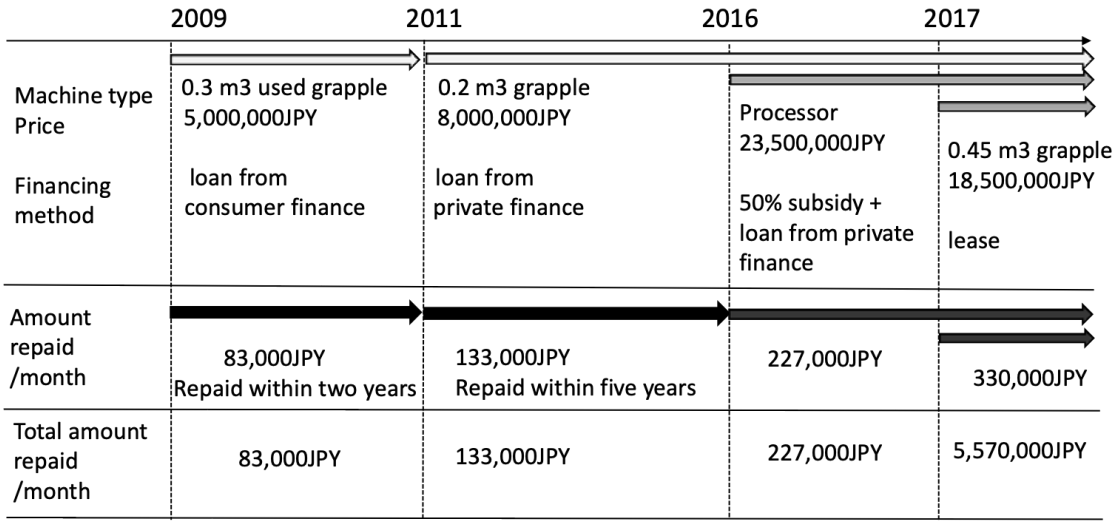


Figure 1. Mechanization history: the case of contractor A.

It is a reasonable question whether there are any advantages to being independent with the high-risk-loan mechanization strategy that is required. The yearly balance of payments of contractor A was estimated from production volume and average contract fee in this area, and number of trainees (Figure 2). The estimated yearly income of the company is 1,599,000JPY; definite spending (from the interview responses) is 1,112,100JPY; and other spending for business, company reserve, and owner's private income is included in the amount of difference, approximately 4,870,000JPY. According to the statistics, the average yearly salary of an employee in this area is approximately 2,900,000JPY. It thus seems that there is enough advantage in income if the company doesn't have other large expenditures.

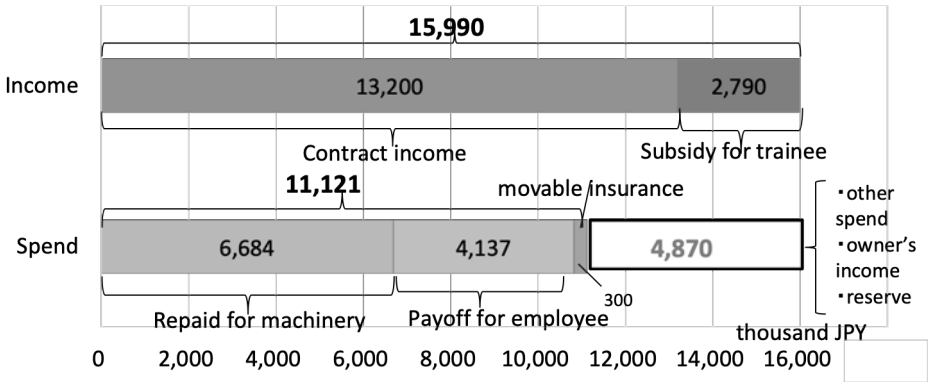


Figure 2. Estimated yearly balance of payments: the case of contractor A.

4 Conclusion

The results show that although the four contractors have been certified for subsidies, they have had to use other financing strategies based on the timing of their need for new machinery, as well as the advantages and disadvantages of each financing mode. A disadvantage of subsidy for small-scale contractors is that they still require a loan to cover half the cost of the machinery even when they are subsidized; however, subsidy is beneficial for introducing expensive machinery such as a processor or harvester. This area has one of the highest densities of timber per hectare in Japan, and thus receives favorable economic terms for forestry. Even so, it can be said that small-scale contractors need policy support at the initial stages of becoming independent contractors as well as for further mechanization.

5 Acknowledgments

This work was supported by JSPS: Japan Society for the Promotion of Science, KAKENHI Grant Number JP17K15332.

6 References

Lidén, E. (1995). Forest machine contractors in Swedish industrial forestry, Sveriges lantbruksuniversitet, Institutionen för skogsteknik Rapport nr 195.

Kawasaki, A. (2016). Employment and training of new forest workers for the Forest Management Centers: The case of Ooita prefecture, the Green Employment promotion and research project report, National Federation of Forest Owners' Cooperative Associations [in Japanese].

Kawasaki, A. (2010). Current status of self-employed forestry contractors and problem of labor policy [in Japanese], doctoral dissertation at the Graduate School of Bioresource and Environment Science, Kyushu University.

Kohroki, K. (2015). Relation of the Green Employment Project and employment and contracting: The case of Ooita prefecture, All about the Green Employment Project, J-FIC [in Japanese].

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

ESTIMATING AVAILABILITY OF FOREST BIOMASS RESOURCES IN THE WHOLE OF JAPAN

Kazuhiro Aruga*, Battuvshin Biligt, Yusuke Matsuoka, Takahisa Yamamoto, Hiroaki Shirasawa
Institute of Forest Engineering
Department of Forest Science
Utsunomiya University
350 Mine, Utsunomiya, Tochigi 321-8505, Japan
aruga@cc.utsunomiya-u.ac.jp

Abstract: *We developed the model to estimate availability of forest biomass resources from each forestry operation site with appropriate forest operation system according to road networks and geography using GIS data processed by MATLAB in Tochigi prefecture, Japan (Yamamoto et al. 2019). We are expanding the model to the whole of Japan by obtaining GIS data for private and communal forests from other 46 prefectures and for national forests from the Japan Forestry Agency. The estimated availability will be verified with the statistical data compiled by the Japan Forestry Agency obtained from each prefecture. Then, the model will be used to project future availability of each forestry operation site for sustainable forest management. Forest GIS data were developed separately for national forests by the Forestry Agency, and for private and communal forests by each prefecture. This is the first study of this kind combining private and communal forests with national forests, in the whole of Japan. Furthermore, existing studies developed similar models, but their units of forests were defined using 1 km2 mesh or municipality. MATLAB could be used to make estimations for the whole of Japan, within a reasonable timeframe, defining units as forestry operation sites.*

Acknowledgements

This study was supported by a research grant from The Yanmar Environmental Sustainability Support Association, JSPS KAKENHI grant number 15H04508, 16KK0168, and 17K12849.

References

Yamamoto, T., Aruga, K. and Shirasawa, H. (2019) Availability for Small-Scale Woody Biomass Power Generation from the View of Forest Resources in Tochigi Prefecture, Japan. Int. J. For. Eng., 29: online first.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

Dosing of physical load for hiking infrastructure users in the forests of the Krka national park

Matija Landekić, Ivan Martinić, Mario Šporčić
Faculty of Forestry
Department of Forest Engineering
University of Zagreb
Svetošimunska 25, 10002 Zagreb, Croatia
mlandekic@sumfak.hr, martinic@sumfak.hr, sporcic@sumfak.hr

Abstract: *In protected nature areas the visitors may be, due to activities of walking and climbing, elevated temperature and wearing of equipment, exposed to the unwanted influence of physiological stress. Significant additional impact in this has an individual health status, the level of physical fitness, the use of medicaments, the level of hydration and so on. The use of park infrastructure, especially hiking trails, requires increased attention and physical engagement of visitors (especially for length, longitudinal slope, altitude etc.). The stated can result in undesirable consequences for visitors (e.g. injury) and for the management of protected areas (e.g. claim compensation). For assessing the risk of physical (over)load, when overcoming the hiking trail "Niz ploču" in the Krka national park, heart rate measurement method was applied with using the Garmin Forerunner 910XT and metronome BOSS DB-3. Field measurements and data collection were carried out during the summer of 2017. The class of physical load, and the corresponding level of general physical fitness, for each subject were determined by calculating the percent increase in heart rate during the overcoming of hiking trail "Niz ploču". The research results show the optimal risk assessment matrix with the elaborated Take a Break (TaB) scheme for the specific case study. Suggested TaB scheme for each visitor, based on the age group and the self-determined physical fitness, defines a regime for overcoming the trail, where the same includes the type and number of resting points and the minimum duration of the brake/rest in minutes.*

Keywords: forestry, protected area, hiking trail, physical load, heart rate method

1. Introduction

Contemporary tourism trends today include increasing consumer awareness and advocate the concept of "return to nature" and proactive consummation of "green tourism". This refers to the creation of the touristic offer, which is based on a combination of healthy and organic food, unspoiled natural environment, recreation, historical and cultural values (Landekić et al. 2018). The increase in the number of visitors of protected areas in the Croatia Republic causes an increase in environmental footprint. Also, a large number of visitors and differences of interest to the protected areas confronts public institutes/park management with a numerous issues related to the management of visitors and maintaining high standards of their safety.

Increased awareness of the need for visitor risk management in visiting and recreational activities in protected areas is the result of significant cases of responsibility of the protected areas administrations in developed countries: Australia (WACALM 1997a), New Zealand, United States (Stephens et al 2005, Forrester and Holstege 2009, Stock et al. 2012) but also in other countries, which resulted in significant costs. Namely, just visiting, and especially some forms of recreation, have hidden dangers, moreover for many recreational activities, the risk and challenge are their feature and component (Martinić et al. 2008). Accordingly, visitor risk management in developed state parks is an important element of the protected

area management plan. In recent years Croatian system of parks is more seriously confronted with a greater number of injuries and, unfortunately, cases of deaths by visitors in protected areas. Information's on the most common cases of such an injury in national park "Plitvice Lakes" and national park "Paklenica" are known from the media. In these circumstances it is necessary to emphasize a new aspect of the tasks of park management aimed at reducing the potential damage in case of accidents and / or fatal injuries of visitors (Martinić et al. 2015).

Safety and protection of the visitor's health must be ensured in the protected area considering different aspects of the visit, equally taking into account the prevention of dangerous situations, the prevention of accidents, the elimination of dangers, the maintenance of technical equipment and infrastructure safety, as well as health-related situations such as excessive physical load of visitors (Martinić et al. 2015). It is the responsibility of the administration to ensure that visitors are not exposed to situations where there is a likely risk of injury, or where it is not possible, to ensure that visitors are adequately informed for potential dangers (PWCNT 1995). The strategic approach of every park management in Croatia must be the development of a visor risk management model, which is defined as "systematic identification, analysis and control of a wide spectrum of risks, visits and recreational activities of visitors, which are threatening park management or their ability to achieve their goals "(WACALM 1997b). The pioneering step in problematization of visitor risk management model in protected area of Croatia has been made by the Krka national park in the period 2014-2017 in the framework of research on safety and requirements in the use of hiking infrastructure on the site "Roški slap". Conducted research of a hiking infrastructure categorization in terms of the demanding requirements due to the physical engagement of the visitors in overcoming the trail represents only a small segment of the overall risk management system for visiting and recreational activities within the protected area. Bearing in mind the above, the basic setting of the paper involves the development of "Take a Break" (TaB) scheme on the uphill section of the hiking trail "Niz ploču" in the Krka national park with the aim of introducing effective measure to protect users from physical (over)load risk.

2. Materials and methods

2.1 Research area

Field research, i.e. the main experiment was conducted on the hiking trail "Niz ploču" at the site "Roški slap" in the Krka national park. Hiking trail "Niz ploču" (hereinafter: trail) was opened to the public in August 2015. Due to the needs of the field research, the trail was divided into three sections (Figure 1), where besides the extraordinary natural environment the trail further enriches the beautiful lookout point and additional educational content related to the Suza pit located at D-1 section of the trail in question (Figure 1). The purpose of the construction of trail was (a) the spatial distribution of visitors to the upstream part of Krka national park and the reduction of visitors' pressure at Skradinski buk, (b) the stimulation of rural development of upstream part of national park and (c) education of visitors and local population. The total length of the track is 1560 m, the altitude difference is 155 m and the time to walk is about 45 min (Figure 1).

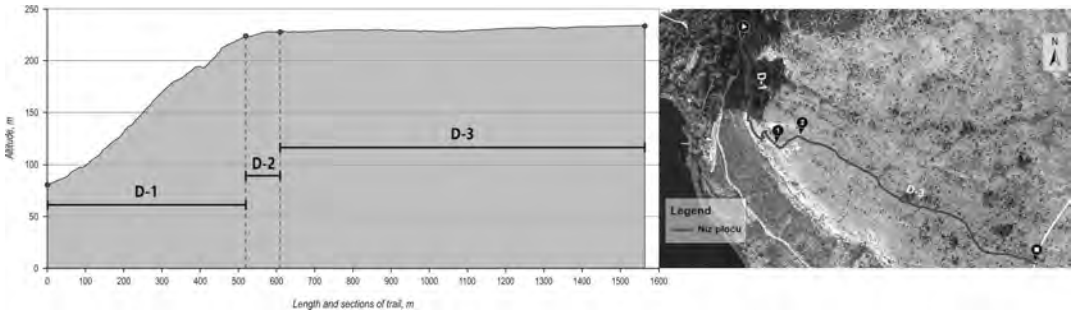


Fig. 1 Researched hiking trail "Niz ploču" in Krka national park

In the framework of existing hiking trails, as a new product of Krka national park, some infrastructure elements are very demanding in terms of technical aspect (slope, average and maximum longitudinal slope, height differences, etc.), and the use of the trail requires increased visitor attention regarding safety and very often increased physical ability (Figure 1). Particularly physically demanding is considered the D-1 section where the trail follows a naturally formed stone plate that vertically rises to a small fault and to a top plateau (a beautiful viewpoint) with a total length of 520 m and the altitude difference of 143 m. The procedure of numerical quantification of physical load, i.e. the difficulty to overcome the subject trail, was carried out for the D-1 section only.

2.2 Research method

For field measurement a heart rate method was used. Heart rate measurement (HR, beats/min) was performed individually for each examinee using the Garmin Forerunner 910XT and a soft belt with a heart rate sensor. The BOSS DB-30 metronome was used to define a consistent pace at overcoming the trail section. The limitation of method and models is that the workload, beside the heart rate, is influenced by age, health, body weight, smoking, internal experiences, mental condition, and so on. However, it is considered that despite these limitations, the average, aggregate level of heart rate on a visiting day provides a very useful and sufficiently reliable data on the physical load of hiking infrastructure users.

Based on the measured heart rate frequency in a activity it is possible, according to the recognized classifications (Ronay 1975, Kaminsky 1971, Grandjean 1980), to classify certain types of work activity according to the workload categories. The physical load assessment was based on the methodology proposed by Grandjean (1980) as shown in Table 1. The percentage of heart rate increase was calculated as shown in Equation 1.

$$PHRI = [(WHR - RHR) / RHR] \times 100 \quad (1)$$

Where: PHRI – Percentage of heart rate increase, %; WHR – Work heart rate, beats/min; RHR – Resting heart rate, beats/min

Table 1 Classification of workload based on the percentage of heart rate increase (Grandjean 1980)

Workload	Percentage of heart rate increase (PHRI)
Very low	0
Low	0 – 36
Moderate	36 – 78
High	78 – 114
Very high	114 – 150
Extremely high	> 150

The level of general physical fitness as an indication of the physical potential of an individual with a higher or lower average heart rate to overcome the corresponding load is defined in the range of 1 to 5 on the principles of the Likert scale, with the lowest level of physical fitness being marked with 1 and the highest level of 5 (Table 2).

Table 2 Classification of general physical fitness

General physical fitness class	
Low	1
Under average	2
Average	3
High	4
Extremely high	5

Classes of general "objective" physical fitness (Table 2) obtained from the percentage of heart rate increase (Table 1) are used to compare and verify the estimated level of the general "subjective" physical fitness of subjects (self-assessment) before being subjected to test on the trail section. The purpose stated is to select the optimal risk matrix for the categorization of the trail section D-1, according to the level of difficulty in overcoming the ascent, within three alternative matrices A, B and C (see Martinić et al. 2015). In the process of designing the A, B and C variants of risk matrix (Martinić et al. 2015), the structural form of the German BG model for risk assessment according to Nohlu (1989) was applied. According to this structure, the height of the risk is expressed in values from 0 to 10 derived from estimates of the probability of realization of physical overload of the examinees / visitors for each level of general physical fitness in relation to each of the four programmed age groups. Tested three alternative matrixes differ in the distribution of risk values within 20 fields where the x-axis has four age groups, and the y-axis has five classes of the general physical fitness. Matrix A advocates a low risk alternative where over 50% of the fields have a risk value of 0 to 1. Matrix B represents the moderate risk alternative where 40% of the fields have a risk value of 2 to 4 and 35% of the low risk field while the C matrix represents the sharpest alternative where 40% of the fields have the value of increased to high risk and 35% of the moderate risk field.

2.3 Design of research and data analysis

Field measurements and data collection were carried out during the summer of 2017. Before the field measurement, the following parameters needed to be determined for each subject: gender, height (in centimetres), body mass (in kilograms), heart rate at rest (RHR) and maximum theoretical heart rate (tHRmax). Heart rate at rest was determined by counting the individual heart rate for 1-minute (a) in the morning after waking up, or (b) measurement site after 20 minutes without activity (pause). The maximum theoretical heart rate was calculated by the formula tHRmax = 210 - (0.65 x years) (Heimer et al. 1997). Defined personal parameters are entered into the Garmin XT910 memory as the input profile of the respondent (Table 3) before starting field measurements. In the selection process, a quota sample was used where different subgroups of the baseline group are represented in the sample according to their important features just as the investigator determines. In the study of the physical load of the respondents on the section D-1 of the trail “Niz ploču” as a controlling feature the gender and the age of the respondents was used. According to their age, respondents were classified into four age groups (1 group: subjects ≤ 20 years of age, 2 group: subjects from 21 to 45 years of age, 3 group: subjects from 46 to 60 years of age and 4 group: subjects ≥ 61 years of age). The sample encompassed a total of 23 respondents, 7 females and 16 males, and descriptive values are presented in Table 3.

Table 3 Average values of sampled operators

Age group	Number of respondents, N	Average age, years	Average height, cm	Average body weight, kg	Resting heart rate (RHR)	Maximum theoretical heart rate (tHRmax)
≤ 20	5	18	173.60	68.60	75	192
21 – 45	12	30	179.50	71.00	70	185
46 – 60	6	51	182.83	85.50	65	177
≥ 61	0	-	-	-	-	-

3. Results

Collected data and measurement results in further processing were used to test the optional risk matrices A, B and C (according to Martinić et al. 2015). Each of the matrix in dependence puts the level of risk and the size of the measured physical load on the D-1 section of the hiking trail “Niz ploču”. The level of risk

is a function of age group of subjects (4 age groups) and self-evaluated level of general physical fitness (5 classes) - Table 2.

The choice of the optimal risk matrix for the requirement categorization of the D-1 trail section was made based on data from Table 4. First, for each respondent based on the age group (Table 4, column 2) and personal subjective grade of general physical fitness (Table 4, column 3) a numeric value of the potential risk was determined - for the A, B and C optional matrices (Table 4, columns 7, 9 and 11). Then, for each respondent, the same was done based on the level of physical fitness determined through the test (Table 4, column 6) and objective numeric value of the potential risk was determined - for the A, B and C optional matrices (Table 4, columns 8, 10 and 12). Finally, at the level of each respondent, the risk values were compared based on personal subjective assessment and measurement on the test. The optimal risk matrix is the one where the highest number of respondents recorded the correlation between the risk value and the trail section demands category determined by subjective estimation and measurement. As the input matrix of the risk distribution, for defining the regime of "Take a Brake" (TaB) scheme, the B version was chosen as the most optimal because the matching of the personal subjective grade and the test was 82.61% (Table 4).

Table 4 Selection of the optimal risk matrix in the demand's classification process for D-1 section of the hiking trail "Niz ploču"

IN	A_y	SRFF	WHR_a	PHRI	$OAFF_m$	Testing of matrix A		Testing of matrix B		Testing of matrix C	
						SD_{sr}	SD_{tr}	SD_{sr}	SD_{tr}	SD_{sr}	SD_{tr}
1	2	3	4	5	6	7	8	9	10	11	12
1	33	3	169	145	2	green (1)	yellow (3)	yellow (2)	yellow (3)	yellow (3)	yellow (4)
2	25	4	130	81	3	green (0)	green (1)	green (1)	yellow (2)	green (1)	yellow (3)
3	20	3	159	112	3	green (0)	green (0)	green (0)	green (0)	green (1)	green (1)
4	33	3	172	146	2	green (1)	yellow (3)	yellow (3)	yellow (3)	yellow (3)	yellow (4)
5	29	3	136	86	3	green (1)	green (1)	yellow (2)	yellow (2)	yellow (3)	yellow (3)
6	56	3	133	105	3	yellow (2)	yellow (2)	yellow (4)	yellow (4)	red (5)	red (5)
7	29	3	177	142	2	green (1)	yellow (3)	yellow (2)	yellow (3)	yellow (3)	yellow (4)
8	23	3	149	148	2	green (1)	yellow (3)	yellow (2)	yellow (3)	yellow (3)	yellow (4)
9	27	2	167	193	1	yellow (3)	yellow (4)	yellow (3)	yellow (4)	yellow (4)	red (5)
10	51	3	142	106	3	yellow (2)	yellow (2)	yellow (4)	yellow (4)	red (5)	red (5)
11	47	4	138	106	3	green (1)	yellow (2)	yellow (2)	yellow (4)	yellow (4)	red (5)
12	14	4	157	109	3	green (0)	green (0)	green (0)	green (0)	green (0)	green (1)
13	15	4	142	69	4	green (0)	green (0)	green (0)	green (0)	green (0)	green (0)
14	29	3	146	100	3	green (1)	green (1)	yellow (2)	yellow (2)	yellow (3)	yellow (3)
15	44	4	143	104	3	green (0)	green (1)	green (1)	yellow (2)	green (1)	yellow (3)
16	48	4	110	75	4	green (1)	green (1)	yellow (2)	yellow (2)	yellow (4)	yellow (4)
17	51	2	163	172	1	red (5)	red (7)	yellow (3)	yellow (4)	yellow (4)	red (5)
18	38	3	161	104	3	green (1)	green (1)	yellow (2)	yellow (2)	yellow (3)	yellow (3)
19	22	4	146	103	3	green (0)	green (1)	green (1)	yellow (2)	green (1)	yellow (3)
20	49	3	130	100	3	yellow (2)	yellow (2)	yellow (4)	yellow (4)	red (5)	red (5)
21	25	4	138	92	3	green (0)	green (1)	green (1)	yellow (2)	green (1)	yellow (3)
22	20	3	183	147	2	green (0)	green (1)	green (0)	green (1)	green (1)	yellow (2)
23	20	3	132	91	3	green (0)	green (0)	green (0)	green (0)	green (1)	green (1)
COMPATIBILITY LEVEL						18 / 23(78,26 %)		19 / 23 (82,61 %)		15 / 23 (65,22 %)	

IN = identification number; A_y = age in years; SRFF = subjective ratings of physical fitness; WHR_a = average heart rate during activity; PHRI = percent increase in heart rate; $OAFF_m$ = objective assessment of physical fitness determined by measurement; SD_{sr} = demands of section (input self-rating); SD_{tr} =– demands of section (input test result)

In accordance with the selected risk matrix B and the defined range of the same, three modes of overcoming the D-1 trail section are categorized: green, yellow and red (Table 5). Within each category, based on the range of risk size (Table 5, column 3), associated regime of overcoming trail section was presented descriptively and with colour: the regime "green" means a small risk; the regime "yellow" - moderate or medium risk and regime "red" increased or high risk (Table 5, column 2). Regime for

overcoming D-1 trail section includes the number, type and location of resting places and minimum duration of the break in minutes (Table 5).

Table 5 Categories of demands for the trail section D-1 with a range of risk size and recommendations

Category of demands	Risk	Value	Suggested number of rests
1	2	3	4
Green	Small	0 – 1	2 rests
Yellow	Moderate or medium	2 – 4	3 rests
Red	Amplified or high	5 – 10	6 rests

The practical application of the TaB scheme (Figure 2) in the implementation includes the following elements: (1) educational board at the beginning of the D-1 trail section, on the basis of which each visitor can determine the personal optimal regime for overcoming trail section as a green, yellow or red; (2) constructed resting points on the trail section, where resting locations are determined according to the restriction requirements of the most risky regime (red) and the possibilities of constructing a resting point on micro location level; (3) a notice board on each resting point whereby one of the two activities is defined for certain overcoming regime: "passage without stopping" or "rest", where in the case of necessary rest on the board, the duration of rest in minutes is prescribed.

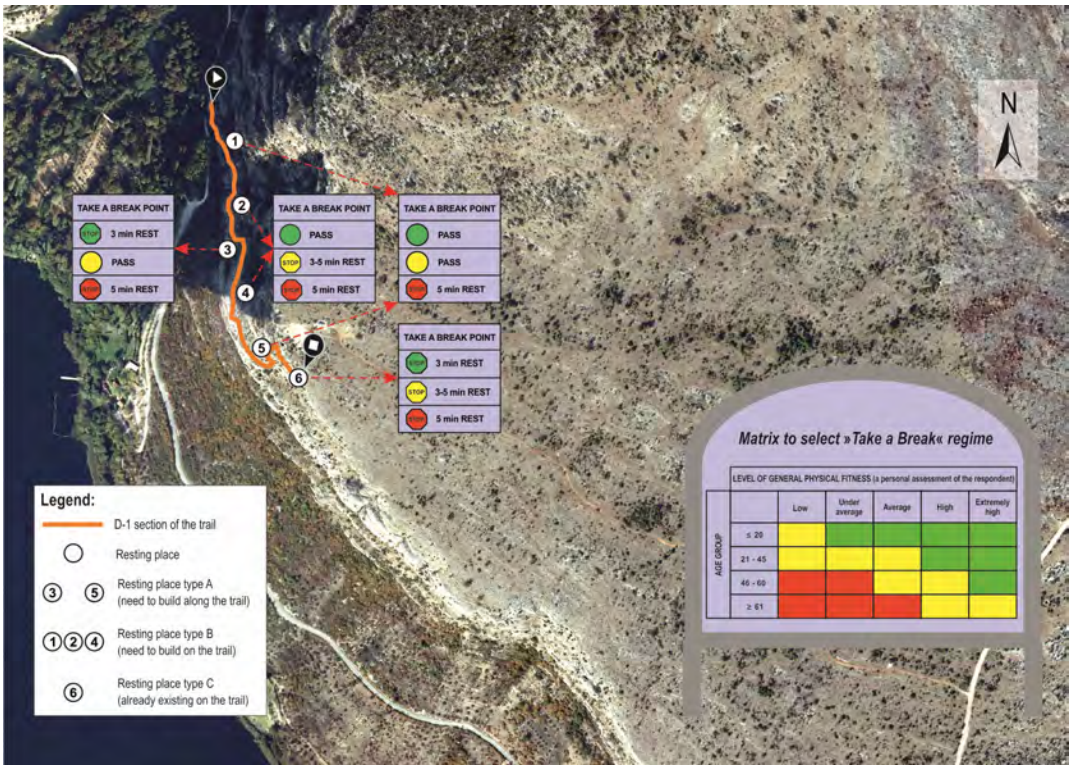


Fig. 2 Take a Brake scheme for overcoming the D-1 section of the hiking trail "Niz ploču"

4. Discussion and conclusion

It is not possible to predict all the hazards and associated risks in protected areas and categorically claim that outdoor recreation is completely risk free. Hazards and related risk elements are always present in spending time and use of the natural environment, as well as visiting the protected areas, and the challenges posed to park management are related to balancing the requirements of visitors with experience

that is safe and fulfilling. In the domain of recreational activities and visitor risk management in protected areas, the example of good practice includes: (a) identifying and prioritizing risks; (b) implementation of preventive measures to reduce risk; (c) monitoring preventive measures with a view to assessing their effectiveness; and (d) controlling the feedback of the risk assessment to determine the degree of experienced risk (Landekić et al. 2019).

Considering the increasing number of older visitors, the methodological concept for determining the physical load of visitors on D-1 section of the trail "Niz ploču" was tested, mainly in terms of the requirements for overcoming the D-1 section and required physical engagement of the visitor. The purpose is to prevent situations that could potentially endanger the visitor's health such as excessive physical overload due to disproportion of physical condition and load that the visitor is exposed to during climbing over the D-1 trail section. Based on the results obtained, the following conclusions are drawn:

- Results of risk assessment determined based on field measurements and self-assessment of physical fitness confirmed that physical fitness self-assessment can be accepted as credible input element in regime programming for overcoming the D-1 trail section.
- Programmed resting scheme (TaB scheme) for the decrease of physical (over)load risk when overcoming the hiking trail is an initial step towards establishing a visitor risk management system for protected areas of nature in Croatia.
- The foundation of the TaB scheme is possibility to choose between three modes of overcoming the trail section, where the choice of regimes is based on a matrix that includes four age groups and five levels of visitors' general physical fitness.

The key to successful governing of visitations and use of protected nature areas lies in developing a safety culture, whereby the preparation of a visitor risk management plan by park administration is essential. It is important, therefore, for park personnel to provide visitors with comprehensive information on the level of residual risk for specific activities. If there are visually highlighted information about existing risks with a particular activity (e.g. hiking or mountaineering), the visitor is able to independently view the requirements of such activity and determine whether there is sufficient skill and psychophysical readiness (fitness, vitality, mental stability) to engage in the same.

Acknowledgments

The study was carried out within the framework of the project "Safety and visitors load on hiking trails in Krka national park (VRM model) - rating the trail Niz ploču at Roški slap" financed by the Krka National Park.

5. References

Department of Conservation & Land Management, Western Australia (WACALM) (1997a) Policy Statement No. 53, Visitor Risk Management.

Department of Conservation & Land Management, Western Australia (WACALM) (1997b) Visitor Risk Management – Operational Guidelines.

Forrester, J. D. and Holstege, C. P. (2009) Injury and illness encountered in Shenandoah National Park. Wilderness Environ Med. 2009 Winter, 20 (4), pp. 318–26.

Grandjean, E. (1980) Fitting the Task to the Man: An ergonimic approach. Taylor and Francis Ltd. London, pp. 205

Heimer, S., Matković, B., Medved, R., Medved, V., Žučkin, E., Oreb, G. (1997) Praktikum kineziološke fiziologije. Fakultet za fizičku kulturu, pp. 168 , Zagreb.

Kaminsky, G. Arbeitsphysiologische Grundlagen für die Gestaltung der Fostarbeit, Reinbek bei Hamburg, 1960.

Landekić, M., Martinić, I., Galić, F. (2018) Development of a Take a Break scheme on the hiking trail »Podgarić-Garić town« in the Moslavačka Gora regional park. Nova mehanizacija šumarstva, 39, pp. 13-23

Martinić, I., Kosović, M., Grginčić, I. (2008) Outdoor Activities and Visitor Risk Management in Protected Areas. Šumarski list 132 (1–2), pp. 33–42

Martinić, I., Landekić, M., Bakarić, M., Marguš, D., Jurković, A. (2015) Visitor risk reducing during hiking in protected areas by use the of Take a Break scheme. Šumarski list: znanstveno-stručno i staleško glasilo Hrvatskoga šumarskog društva. 139 (5–6), pp. 233–244

Nohl, J. (1989) Verfahren zur Sicherheitsanalyse, Wiesbaden: Deutscher Universitäts-Verlag Physical Activity and Health, 1999: Chapter 4 - The Effects of Physical Activity on Health and Disease. A report of the surgeon general. National Center for Chronic Disease Prevention and Health Promotion, Division of Nutrition and Physical Activity

Northern Territory Parks and Wildlife Commission (1995) Risk Management Strategy. PWCNT, Darwin.

Ronay, E. Ergonomia. Učebne texty, VŠLD Zvolen, 1975.

Stephens, B. D., Diekema, D. S., Klein, E. J. (2005) Recreational injuries in Washington state national parks. Wilderness Environ Med. 2005 Winter,16(4):192–7.

Stock, G. M., Collins, B. D., Santaniello, D. J., Zimmer, V. L., Wieczorek, G. F., Snyder, J. B. (2012) Historical rock falls in Yosemite National Park (1857–2011): U.S. Geological Survey Open–File Report (in review), pp. 1–24.

Authors' address

Asst. Prof. Matija Landekić, PhD. *
e-mail: mlandekic@sumfak.hr
Prof. Ivan Martinić, PhD.
e-mail: imartinic@sumfak.hr
Prof. Mario Šporčić, PhD. *
e-mail: sporcic@sumfak.hr
Forestry Faculty of Zagreb University
Department of Forest Engineering
Svetošimunska 25
HR – 10 000 Zagreb
CROATIA
* Corresponding author

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

LOW-COST GNSS APPLICATIONS TO AREA SURVEYING UNDER FOREST CANOPY: POSSIBILITIES AND LIMITATIONS

Tetsuhiko Yoshimura
Faculty of Life and Environmental Science
Shimane University
1060 Nishikawatsu-cho, Matsue, Shimane 690-8504, Japan
t_yoshimura@life.shimane-u.ac.jp

Yasushi Suzuki
Faculty of Agriculture and Marine Science
Kochi University
200 Monobe-otsu, Nankoku, Kochi 783-8502, Japan
ysuzuki@kochi-u.ac.jp

Abstract: The Global Navigation Satellite System (GNSS) is used to determine the coordinate anywhere on the surface of the earth. *It is commonly known that GNSS receivers with post-processing differential correction functions determine positions more accurately than low-cost GNSS receivers for the use of vehicle and personal navigation, but they are relatively unaffordable for small-scale forest owners in Japan. In this study, we propose the use of low-cost GNSS receivers for area measurement in forestland and validate it through field trials. Area measurement was conducted in the forest stand of 0.237 ha with and without the correction by the multi-functional satellite augmentation system (MSAS). The results showed that the areas measured with the MSAS and without the MSAS were 0.226 ha and 0.278 ha corresponding to 95.2 % and 117.9 % of the actual area, respectively. Furthermore, this study validated the results of the field trials by the Monte Carlo simulation, and the results showed that the error rates of area estimation could be -9.0 to +3.6 % of the true area (0.24 ha), and that this error rate could be improved to range between -5.2 to +2.2 % when the true area is four times more (0.95 ha).*

Keywords: GNSS, forest canopy, area measurement, error rate

1. Introduction

The Global Navigation Satellite System (GNSS) is the general term used to identify several satellite navigation systems such as the Global Positioning System (GPS), Global Navigation Satellite System (GLONASS), BeiDou, Galileo, Navigation with Indian Constellation, and the Quasi-Zenith Satellite System (QZSS) operated by the United States, Russia, China, the EU, India, and Japan, respectively. Currently, this system is widely used to determine the geographic location of GNSS receivers anywhere in the world. The GNSS is a key technology for ICT-based forestry, aiming to increase the efficiency of resource management and wood production and distribution. In addition, it is an essential tool for designing and constructing forest roads, including spur roads, and for navigating forestry machines and vehicles. However, large positional errors using GNSS receivers in dense-canopy forests, which block and attenuate GNSS signals, have posed a significant challenge since the 1990s. Therefore, many studies have been conducted to evaluate the performance of GNSS receivers under forest canopies. Sawaguchi et al. (2001) discussed the effect of stand conditions on positioning precision with real-time differential GPS (DGPS) and identified the factors that affected positional precision using multiple regression analysis. Yoshimura and Hasegawa (2003) evaluated the positional errors due to autonomous GPS and DGPS with respect to precision and accuracy, and concluded that tree canopies greatly affected positional errors and that DGPS improved horizontal accuracy not horizontal precision. On the other hand, this study focused on the use of

low-cost GNSS receivers for area measurement in forestland because GNSS receivers with post-processing differential correction functions are relatively unaffordable for small-scale forest owners in Japan. There are only some previous studies on the area measurement of forestland with GNSS receivers despite the importance of this work in forest management. Liu and Brantigan (1995) showed that DGPS survey of forest stand boundaries could meet or exceed the 1 acre and 5 % area determination accuracy standards and is more cost-effective than the traditional compass-and-chain traverse. Unger et al. (2013) showed that the average area RMSE observed ranged from 0.07 acres (0.22% of total acreage) in the 3-year-old plantation to 1.32 acres (4.67% of total acreage) in the 13-year-old pine plantation, and these levels of accuracy should be more than sufficient for many forestry applications.

2. Materials and Methods

2.1 Field trials

The study site was located in the Tane block of Sanbe University Forest, Shimane University, Japan. The field trials were conducted on November 8, 2013, in a Japanese cedar (*Cryptomeria japonica*) plantation forest (planted in 1956). The average tree height and diameter at breast height were 21.1 m and 26.6 cm, respectively. The stand density was 975 trees/ha. Figure 1 shows the stand conditions of the study site, and as shown, standing trees limited the visibility in the horizontal direction as well as in the vertical direction. The low-cost or consumer-grade GNSS receivers used in this study were two sets of Garmin GPSMAP 62SJ (Figure 2), which receives L1 signals from the GPS, GLONASS, QZSS and multi-functional satellite augmentation system (MSAS) satellites. The MSAS is a Japanese satellite-based augmentation system that supports real-time DGPS and is designed to supplement the GPS system. A similar service is provided in North America by WAAS and in Europe by the European Geostationary Navigation Overlay Service (EGNOS). The device did not have post-processed differential correction functionality. With the two devices on one tripod, we measured a polygonal area of 0.24 ha surrounded by 13 vertex points (Figure 3). At each of the 13 vertex points, we conducted the GNSS measurements for five minutes with the logging interval of one second. One of the two devices was used with the MSAS correction while the other was used without the MSAS correction.



Figure 1. Stand conditions of the study site (left: horizontal direction; right: vertical direction)



Figure 2. Low-cost GNSS receiver (Garmin GPSMAP 62SJ) used in this study

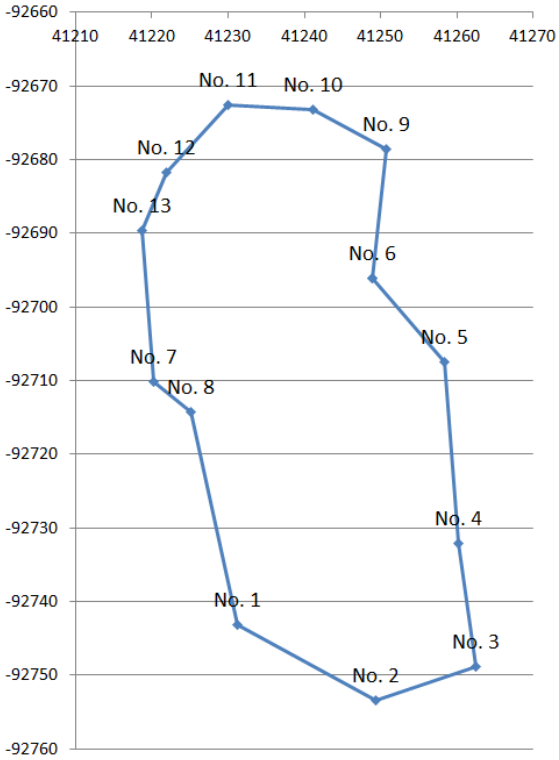


Figure 3. Illustration of the polygonal area for area measurement (coordinate: Japan Plane Rectangular Coordinate System Zone III; unit: m)

2.2 Method of analysis

We calculated the accuracy of GNSS measurements at each of the 13 vertex points surrounding the polygon. Figure 4 shows the calculation method of the accuracy of GNSS measurements in this study. As shown in this figure, accuracy was calculated as the distance between the average point of all the measured points

and true point. Subsequently, we calculated the area determined by the results of GNSS measurements at each of the 13 vertex points, and compared it to the actual area of the polygon (0.24 ha). We assume that GNSS measurements for larger areas would produce better results in terms of the error rate of area measurement. Therefore, this study validated this assumption by the Monte Carlo simulation, which can estimate the probability of different outcomes in a process that cannot easily be predicted due to the intervention of random variables. In this process, area measurements were conducted in a four times larger virtual polygon with an area of 0.95 ha (Figure 5), and the error rates of area measurements were compared between the two polygons.

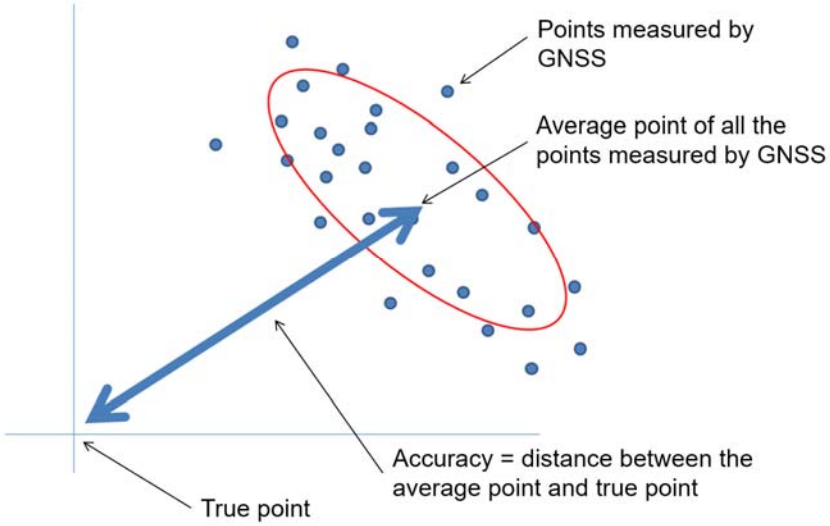


Figure 4. Definition of accuracy and its calculation

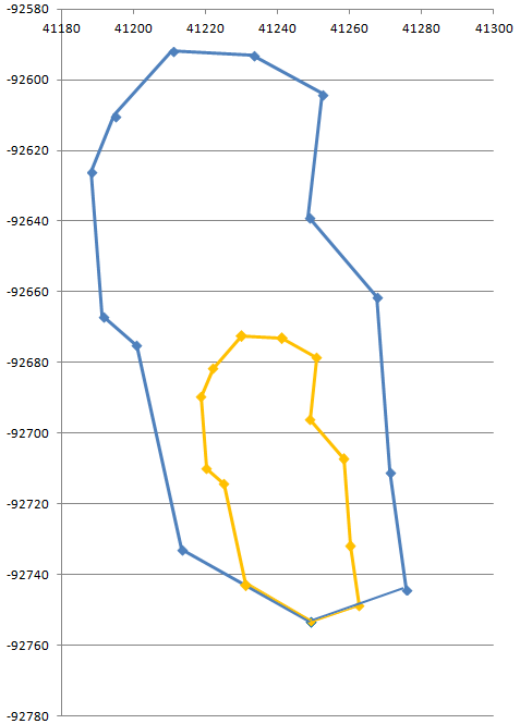


Figure 5. Actual and virtual polygons (large: virtual polygon; small: actual polygon)

3. Results and Discussion

3.1 GNSS measurements

Figure 6 shows the results of GNSS measurements at the 13 vertex points. Positional accuracy with the MSAS correction is higher than that without the MSAS correction except at the points of Nos. 1, 6 and 8. It seems that the MSAS correction is effective even under forest canopy. It should be also noted that positional accuracy is sometimes more than 10 m regardless of the MSAS correction most probably due to the effects of forest canopy and tree stems.

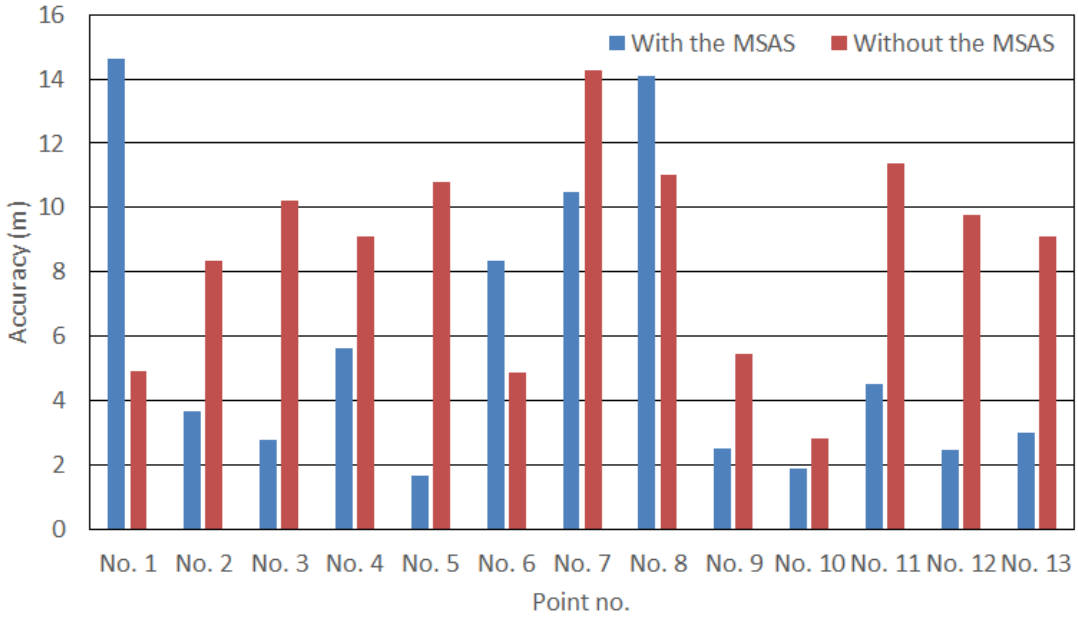


Figure 6. Summary results of GNSS measurements at the 13 vertex points

3.2 Area measurement

Figures 7 shows the results of area measurements with and without the MSAS correction. As shown in this figure, it was obvious that the MSAS correction was effective to improve the accuracy for area measurements with low-cost GNSS receivers. Actually, the areas measured with the MSAS and without the MSAS were 0.226 ha and 0.278 ha corresponding to 95.2 % and 117.9 % of the actual area (0.24 ha), respectively. It should be also noted that the results of area measurements were acceptable in terms of accuracy or error rates despite the low accuracy of the coordinates measured at each vertex point. This shows the high possibilities of area measurements in forestland with low-cost GNSS receivers.



Figure 7. Results of area measurements with and without the MSAS correction (left: with the MSAS correction; right: without the MSAS correction)

3.3 Monte Carlo simulation

The results of the Monte Carlo simulation showed that the error rates of area estimation could be -9.0 to +3.6 % of the true area (0.24 ha), and that this error rate could be improved to range between -5.2 to +2.2 % when the true area is four times more (0.9 5ha). As a result, it was suggested that there would be more possibilities of area measurement with low-cost GNSS receivers in forestland especially when larger areas were measured.

4. Conclusions

This study has shown that low-cost GNSS receivers can measure polygonal areas in forestland with sufficiently high accuracy for general forestry purposes. It was also suggested that better accuracy would be achieved when larger polygonal areas were measured with low-cost GNSS receivers. According to the results of the Monte Carlo simulation, the error rate of area measurements for an area of 0.95 ha ranged between -5.2 to +2.2 % only. Further research will be conducted to clarify the accuracy of area measurements for a shorter measurement time to enhance the efficiency of GNSS surveying.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Numbers 20580155 and 18KT0090.

References

Liu, C. J. and Brantigan, R. (1995), "Using differential GPS for forest traverse surveys," Canadian Journal of Forest Research, 25(11), 1795-1805.

Sawaguchi, I., Watanabe, S. and Shishiuchi, M. (2001), "The effect of stand conditions on positioning precision with real-time DGPS," Journal of the Japan Forest Engineering Society, 16(1), 35-42. (in Japanese with English summary)

Unger, D. R., Hung, I. K., Zhang, Y., Parker, J., Kulhavy, D. L. and Coble, D. W. (2013), "Accuracy assessment of perimeter and area calculations using consumer-grade Global Positioning System (GPS) units in southern forests," Southern Journal of Applied Forestry, 37(4), 208-215.

Yoshimura, T. and Hasegawa, H. (2003) "Comparing the precision and accuracy of GPS positioning in forested areas," Journal of Forest Research, 19(2), 135-140.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

AUTOMATIC GENERATION OF SHALLOW DITCH NETWORK IN FOREST USING LIDAR DATA AND MULTICPECTRAL SATELLITE IMAGERY

Raitis Melniks, Janis Ivanovs, Andis Lazdins
Latvian State Forest Research Institue "Silava", Salaspils, Latvia
raitis.melniks@silava.lv

Abstract: *Aim of this study is to develop methods for automatic surface drainage system generation using LiDAR (Light detecting and ranging) data and Sentinel-2 multispectral satellite imagery. LiDAR data is used for mapping of depressions in DEM (digital elevation model), for generation of surface water runoff and CHM (canopy height model) raster maps. Multispectral satellite imagery is used for detecting and separating coniferous forest stands, deciduous forest stands and other land cover types. Study area is more than 150 km2 large and consists of areas on various quaternary sediment types. Three factor cost surface wich includes previously mentioned data layers has been made and it is used to calculate least cost surface raster. Least cost surface connects DEM depressions and already existing drainage ditches. Least cost paths then represents best areas for shallow ditch network creation. Different methods then are applied to determine segments where it is suitable to create shallow ditches to improve water runoff. Resulting method produces acceptable results on different relief conditions with incomplete ditch network. In conditions when existing ditches and culverts are fully mapped, methods shows good results.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

SMART SENSING TECHNOLOGY FOR PREDICTING FOREST ROAD´S BEARING CAPACITY

***Franz Holzleitner[1], Michael Fritz[1], Wolfgang Sokol[2], Friedrich Zott[3], Christian Kanzian[1]**
[1]Institute of Forest Engineering, Department of Forest- and Soil Sciences,
University of Natural Resources and Life Sciences Vienna
Peter-Jordan-Strasse 82/3, A-1190 Vienna, Austria
franz.holzleitner@boku.ac.at
michael.fritz@students.boku.ac.at
christian.kanzian@boku.ac.at
[2]Institute of Hydraulics and Rural Water Management,
Department of Water, Atmosphere and Environment
University of Natural Resources and Life Sciences, Vienna, Austria
wolfgang.sokol@boku.ac.at
[3]Institute of Mountain Risk Engineering, Department of Civil Engineering and Natural Hazards,
University of Natural Resources and Life Sciences, Vienna, Austria
friedrich.zott@boku.ac.at

Abstract: *Accessibilityof forest roads is an important factor to ensure effective harvesting and transporting activities the whole year round. However, water in construction layers of unpaved forest roads decreases bearing capacity measurable. Thus, trafficability as well as the overall access to the forest is restricted. Especially during thawing season, forest roads are very sensitive in case of excessive strain due to reduced load bearing capacity. Additionally, heavy or intensive rain could also lead to water penetration into the forest road´s layers. The aim of this study is to suggest an appropriate measurement approach in the field, determine the needed modelling parameters and develop a smart model for predicting bearing capacity of forest roads. The proposed contribution presents the ongoing work with its experimental set up details on used sensors, preliminary results and experiences from the field trial.*

Keywords: smart sensing technology, hydra probe, soil moisture, forest road network, bearing capacity

1. Introduction

Water in construction layers of unpaved forest roads is decreasing their bearing capacity and thus trafficability as well as the overall access to the forest is restricted. Even highly compacted and well-constructed forest roads will have limited access during spring in the Northern hemisphere. Especially during thawing season, forest roads are very sensitive in case of excessive strain due to reduced load bearing capacity.

Additionally, heavy rain or intensive raining occurrence over the year could also lead to water penetration into the forest road´s layers. Depending on their intensity, recovering of saturated forest roads or sections until drying up again will take several days or even weeks. This will automatically lead to necessary closings and cause bottlenecks in the logistic of forest enterprises especially if it happens unexpected.

Therefore, accessibility of forest roads is an important factor for ongoing harvesting and transporting activities the whole year around. Only proper constructed and well-maintained forest road networks enable cost efficient production of sustainable produced timber. Once the limit of moisture content within the construction layers reaches a certain level, forest road´s bearing capacity will not withstand the requirements of heavy traffic anymore and the surface layer or even the subgrade could fail. Exactly here, a smart trafficability prediction model could support the management of timber supply and prevent from unnecessary costs due to overloading weak and moist forest roads.

The aim of this study is to develop a smart model for predicting bearing capacity of forest roads. To determine the needed modelling parameters a measurements approach is suggested and applied in the field. This should enable to study the influence of harsh weather conditions on bearing capacity and trafficability whole year around.

2. Material and methods

The setup includes a meteorological weather station and three mounted soil moisture sensors in the forest road. The field trial is located 35 km north of Ybbs/Donau in Lower Austria (48°22'N, 15°02'E) within the geological formation of Weinsberg Granit. The road section is relatively flat and surrounded by young natural regeneration but more or less open to all directions.

The meteorological weather station is sensing rainfall, wind speed and direction, relative humidity with air temperature and solar radiation. An additional sensor is capturing snow height. All compiled data is transferred to the Institute of Forest Engineering` server once daily via GSM data communication. The power is supplied via a solar panel.

Three installed Hydra Probes (soil moisture sensors) coming from Stevens Water Monitoring Systems are recording data on temperature, conductivity, salinity, dielectric permittivity and moisture. Regarding calibration of the sensors according to the investigated soil type, the sensor could either use preconfigured calibration functions from the manufacturer or own developed functions based on the analysed material onsite. For this field trial, the sensor is preconfigured for sand and a calibration curve was developed in the lab using material from the site parallel to field trial. The Hydra Probes are installed alongside the carriageway by bringing in the sensor from the side into the road in depths of 21 cm, 43 cm and 62 cm respectively measured to the top edge of each sensor. All sensors run through a function check before installation respectively with air and natural drinking water. Starting at the bottom with the first sensor after installation the excavated material was filled back in compacted layers again.

Additionally the construction material from the site is analysed according to the standard ÖNORM EN ISO 17892 (4). Compared to standardized grading curves for forest road construction material suggested by RLW 1975 or based on the ideal curve from Fuller and Thompson (1907) this material show high proportion for clay and silt.

Monitoring road’s bearing capacity is done with the Light Falling Weight Deflectometer (LFWD)TerraTest 3000 GPS every week and after every rainfall. To avoid measurements at the same point a measurement grid was applied for each data set. Data set includes bearing capacity along both driving lanes as a data pair.

3. First results

In 2018, a heavy rainfall lasting from July 21st 13:00 until July 22nd 10:00 with a total precipitation of 85.7 mm reduced road´s bearing capacity already at July 21st in the evening below the threshold and reached a the lowest value with 34 MN/m² on July 22nd at 17:00. Bearing capacity started to recover again in the evening of July 23rd and reached already after 4 days 84.5 MN/m² (Figure 1).

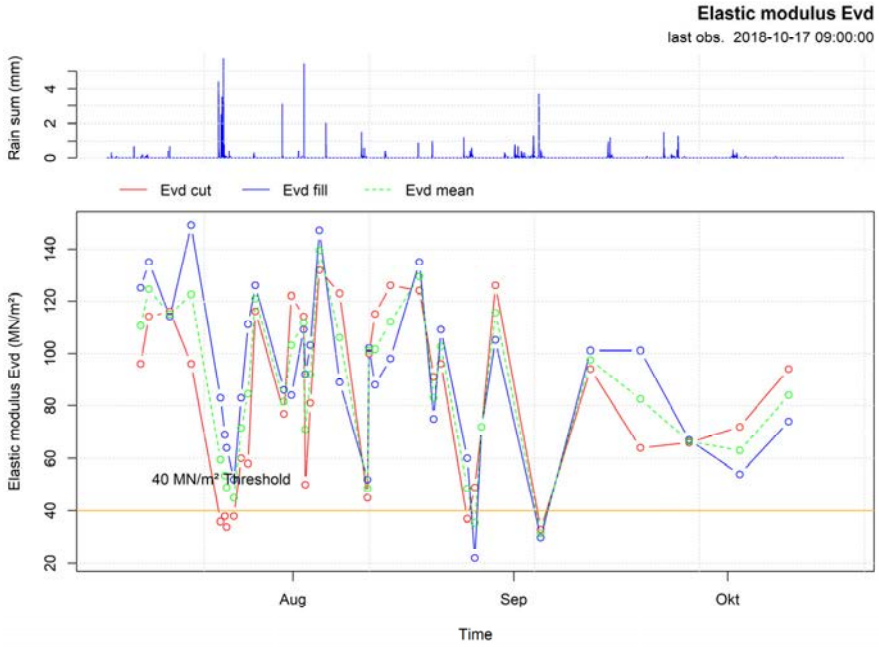


Figure 1. Recorded rainfall, elastic modulus on both lanes including the mean and threshold of 40 MN/m² plotted over time after Fritz (2018)

Acknowledgements

This publication is a part of the EU-funded project "Knowledge and Technologies for Effective Wood Procurement". The project and research presented here has received funding from the Bio Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No. 720757.

References

Fritz, M., 2019. Wassergehalt im Forststraßenkörper und dessen Auswirkungen auf die Tragfähigkeit. Master thesis, Institute of Forest Engineering, University of Natural Resources and Life Sciences, Vienna.

Fuller, W. and Thomson, S. (1907) The Laws of Proportioning Concrete. Transactions of the American Society of Civil Engineers, LIX, 67-143.

ÖNORM EN ISO 17892-4: 2017 05 01 Geotechnische Erkundung und Untersuchung - Laborversuche an Bodenproben - Teil 4: Bestimmung der Korngrößenverteilung (ISO 17892-4:2016)

Richtlinien für den ländlichen Wegebau (RLW 1975), Deutscher Verband für Wasserwirtschaft und Kulturbau. Arbeitsgruppe Ländliche Wege. Heft 103. Parey [in Komm.], 1982.

FORMEC 2019 – Exceeding the Vision: Forest Mechanization of the Future
6-9 October, 2019 - Sopron, Hungary

AN INNOVATIVE TIMBER FELLING SYSTEM BASED ON JAPAN'S TRADITIONAL TECHNIQUE

Yuko SHIRAI and Yuki MATSUO
Keio University
Graduate School of Media and Governance
Shonan Fujisawa Campus
5322 Endo, Fujisawa, Kanagawa, 252-0882, Japan
sry@keio.jp

Abstract: In an effort to revitalize Japan's forestry by technological development, the authors have so far developed and proposed two innovative timber harvesting systems with mobility in forest land. Both systems embody unique ideas from mechanics and informatics perspectives. One of the two systems is a portable tree-felling machine with a removable and interchangeable chainsaw. The other system is a tree-felling manipulator which performs the three-hinge tree felling method (*"Mitsuhimo-giri"* in Japanese), Japan's traditional timber felling technique. It is equipped with a drill and an end mill which was newly developed by the authors as a cutter. The machine targets trees of larger diameters. This paper reports the latter machine (Manipulator II). This R&D project will be presented at FORMEC 2019.

Keywords: Tree-felling operation, Manipulator, Japan's traditional timber felling technique, Three-hinge tree felling method (*"Mitsuhimo-giri"*)

1. Introduction

This paper reports an innovative timber harvesting system based on Japan's traditional tree felling technique called a three-cord felling method ("*Mitsuhimo-giri*" in Japanese). In an effort to seek a solution that would best address the current situation of Japan's forestry, we studied the method which has been used to cut trees for the emperor's shrine ceremonies since 1300 years ago. The sacred nature of the rituals requires the method to secure utmost safety to prevent any death or injury. This is the reason why the method was adopted for the manipulator proposed herein.

The manipulator we developed targets trees of 500 mm in diameter. The system consists of a machine (a manipulator) and a software program which operates the machine. The machine has a spindle block and an end mill with a drill, a new cutting tool we developed. Three prototypes have been developed (Manipulators I, II and III) as a result of our mechanization efforts and improvements to ensure safety of tree felling operations. We will present Manipulator II at this conference.

2. Japan's Forestry and Traditional Tree Felling Method

2.1 Industrial accidents

The forests in Japan have steep slopes, complicated terrains and soft ground, with high temperatures and humidity. The large and heavy machines used in Europe and the US cannot necessarily perform well in the forests in Japan. Serious accidents involving death and injuries occur in Japan's forestry industry. In

2010, there were 2,363 accidents and 59 deaths. The number of accidents has never been smaller than 1,500 cases per year. (Figure 1). In particular, tree felling operations cause many fatal accidents (Figure 2). There were 121 deaths from 2014 to 2016, of which 69% occurred during tree felling operation. There is an urgent need to address the problem. The manipulator we have developed concentrates on the work of felling trees with the aim of making the operation safe.

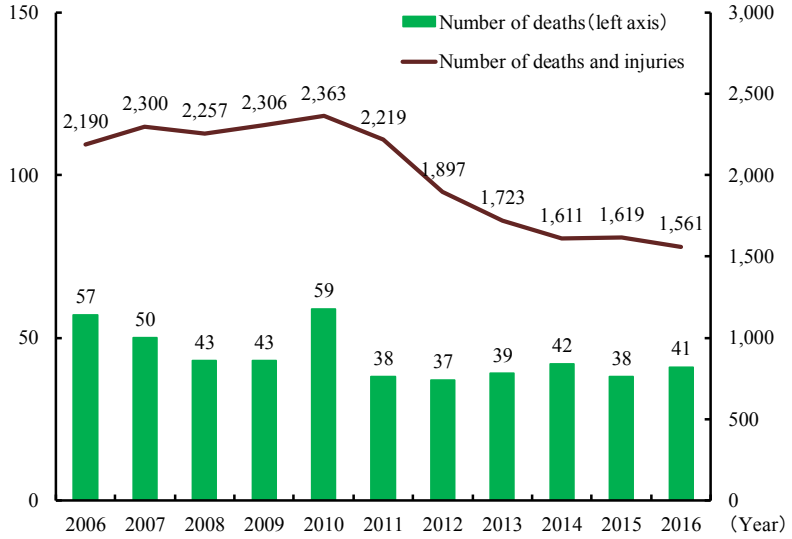


Figure 1: Industrial accidents in Japan

Source: Ministry of Agriculture, Forestry, and Fisheries (2018) "Heisei 29 Nendo Shinrin Ringyo Hakusho," [FY 2017 White Paper on Forests and Forestry].
Ministry of Health, Labour and Welfare "Rodosha shisho-byo hokoku" "Shibo saigai hokoku" [Statistics on industrial accidents].

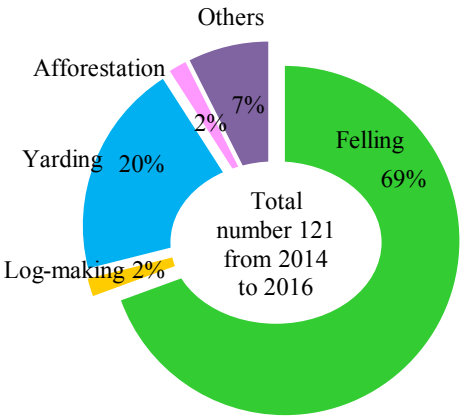


Figure 2: Deaths in forestry operations

Source: Ministry of Agriculture, Forestry, and Fisheries (2018) "Heisei 29 Nendo Shinrin Ringyo Hakusho," [FY 2017 White Paper on Forests and Forestry].
Forestry Agency "Rinyacho keiei-ka shirabe" [Study by Forestry Manamegent Improvement Division, Forestry Agency].

2.2 Three-hinge tree felling method ("*Mitsuhimo-giri*")

The authors have been focusing on the three-hinge tree felling method ("*Mitsuhimo-giri*" in Japanese). The method is one of Japanese traditional techniques, which started over 1300 years ago to cut sacred trees to build the first Grand Shrines of Ise (*"Ise-Jingu"* in Japanese) in the 7th Century. These shrines have since been rebuilt every 20 years. The three-cord tree felling method is used to cut trees for that purpose because it is very safe and provides stability. Fatal accidents or severe injuries hardly occur. Due to the sacred nature of the rituals, any bodily accident is especially abhorred.

As shown in Figure 3, this method first chips off the entire gray area,leaving the three hinges shown in white. The tree is supported by these 3 hinges to provide stability to the tree and safety to fellers. The side hinges and the back hinge are then cut off and the tree begins to fall. The tree topples in the direction of the red arrow (Figures 3,4 and 5). With this method, virtually any giant tree can be cut down safely.

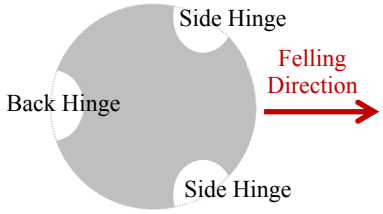


Figure 3: Cross-section of three-hinge tree felling method

The white areas indicate hinge positions.
The gray area is all chipped off.



Figure 4: Picture of three-hinge tree felling method

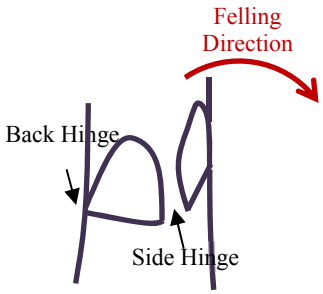


Figure 5: Longitudinal section of three-hinge tree felling method

2.3 Undercut and backcut method (*"Ukekuchi-Oikuchi-giri"*)

The undercut and backcut method (*"Ukekuchi-Oikuchi-giri"* in Japanese) is common throughout the world. This method uses a chainsaw to first cut horizontally and diagonally on the felling side to form a wedge-shaped space. The opposite side is then cut, and a wedge is driven into the backcut space. The tree topples on the undercut side.

Using the undercut and backcut method, we have developed a "portable" tree-felling machine with a removable and interchangeable chainsaw. The machine is light, small and portable. A single worker can carry it in steep mountains.

3. Innovative tree felling system

3.1 Principles for mechanization

The objective of this R&D was to ensure safety of tree felling operations. To achieve this objective, we first aimed to achieve the most important "movements that must be done by a machine" with minimal form and mechanism. No environmental condition or target is the same and differences are great. If specifications are rigidly set and designed, therefore, any machine may become unusable in practice, and the specifications may have to be changed.

For the R&D purposes, the following principles for mechanization were established via survey and experimentation on site:

- Recognize the body forms, postures and movements of the fellers traditionally handed down from generation to generation.
- Design a minimal mechanical device with refined “form” and “mechanism” of hardware.
- Design a mechanical device that creates simple motions that can handle all patterns of work in all kinds of environment.

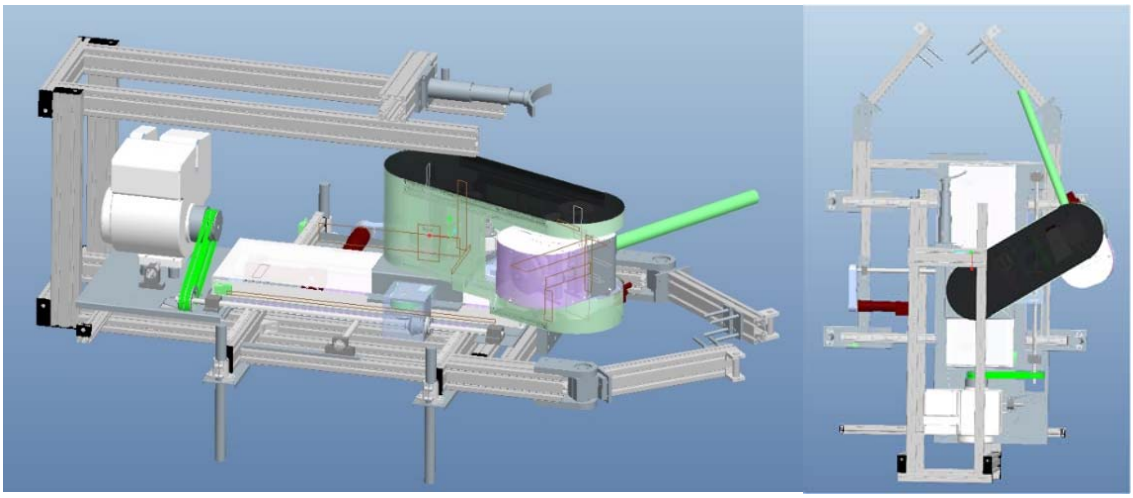
3.2 Tree-felling Manipulator Ⅱ

The authors have developed a new special blade that has functions of a drill and an end mill to replace and reproduce the work of *yoki* (Japanese style axe) used in the ceremony of three-cord tree felling (“*Mitsuhimo-giri*”). Manipulators I and II have two and four blades in the end mill, and Manipulator III has three blades. The blade length that was the same as the sawing diameter in I and II was reduced to one half in III. Main difference between II and III is in blade length and cutting orbit.

Manipulator II consists of a base and a robot arm. The base moves in a 2-axis linear motion and the robot arm moves in 2-axis rotation. The rotative power of the blade is continuously provided by an engine regardless of the posture of the arm. By the 4-axis movement, the manipulator performs the three-cord tree felling method (“*Mitsuhimo-giri*”). A video of the manipulators will be shown at FORMEC 2019.

The new tree-felling machine Manipulator II signifies a middle way between the traditional equipment (chainsaws) and the forestry machinery (harvesters and feller bunchers). It is small enough to be loaded on a pickup truck. And it fells trees of larger diameters.

In Figure 6, the left white block is an engine. The white square block in the middle is the base having a 2-axis linear motion. And the right cylinder is a robot arm. Inside the cylinder is another robot arm, shown in purple in the drawing. The blade is attached to the purple robot arm.



(Left CAD) Figure 6: Perspective drawing of Manipulator II
(Right CAD) Figure 7: Top view drawing of Manipulator II

4. Verification test

Figure 8 is an experiment photo of manipulator II. Figure 9 is an experiment photo of manipulator III. With Manipulator II experiment at a forestry site, we were able to verify that the direction of our development was correct. Tree-felling operation was also demonstrated with Manipulator III. The experiments successfully demonstrated safety, precision and effectiveness of Manipulator III. Since then, improvements have been made to increase the stiffness of the manipulator.



Figure 8: Experiment photo of manipulator II



Figure 9: Experiment photo of manipulator III

5. References

Ministry of Agriculture, Forestry, and Fisheries (2018) "Heisei 29 Nendo Shinrin Ringyo Hakusho," [FY 2017 White Paper on Forests and Forestry].

Sakamaki T. (1988) "Nokoshitai Mitsuhimo Kiri (Mitsuhimo Kiri Method that Should be Conserved)," Hirakawa Kogyosha.

Funato K. (1977) "Rimokon chainsaw kaihatsu he no ayumi (Course of the development of remote controlled chainsaw)," Ringyo Gijutsu, 424, 13–16.

Shirai Y. and Sugano S. (2010) "Hopes for robotics advancing forest industry," Journal of the Robotics Society of Japan, 28 (1), 43–48.

Shirai Y. and Sugano S. (2009) "A note about practical use of robots," Journal of the Robotics Society of Japan, 27 (6), 634–639.

Shirai Y. (2009) "Shinrin no Hokai (Collapse of Forest)," Shinchosha.

Shirai Y. (2018) "Feasibility studies on the portable tree-felling manipulator "TATSUMI" -Evaluation of the positioning, fixation, and ease of conveyance-," Journal of the Japan Forest Engineering Society, Vol.33, No.3, pp.157-168.

Shirai Y. and Iizuka R. (2015) "Portable tree felling manipulator "TATSUMI," Transactions of the Japan Society of Mechanical Engineers, 81 (831), 15-00169.

Shirai Y. and Matsuo Y. (2017) "Tree felling manipulator with drill bit-fitted end mill," Journal of the Japan Forest Engineering Society, Vol.32, No.2, pp.59-69.

Shirai Y. (2017) "A revolutionary technical development to revitalize Japanese forestry -A proposal for a portable tree felling manipulator to address specific properties of Japanese forestry-," Synthesiology (AIST: National Institute of Advanced Industrial Science and Technology), Vol.9, No.4, pp.234-251.

Shirai Y., Matsuo Y., Iizuka R., Endo H., Horiba K. and Sugano S. (Filing day March 26, 2013) "Jumoku no batto sochi (Tree felling device)," Patent application No. 2013-63308.

Shirai Y., Iizuka R., Matsuo Y., Endo H. and Sugano S. (Filing day March 26, 2013) "Jumoku no batto system, jumoku joho kenshutsu sochi oyobi sono program (Tree felling system, tree information detection device, and their program)," Patent application No. 2013-63309.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

APPLICATION OF MODERN TECHNOLOGY FOR TREE GROWTH MONITORING

Narongdet Detkong*, Nopparat Kaakkurivaara and Roongreang Poolsiri
Department of Forest Engineering, Faculty of Forestry
Kasetsart University, Bangkok, Thailand 10900
*Narongdet.de@ku.th

Abstract: *Aim of the study is track growth of trees using by Internet of Things (IoT) with growth monitoring tool to create a real-time monitoring system. This study try to find ways to reduce need of manpower and human error effects during forest inventory. The prototype system works by monitoring movement of a slider resistor sensor as the tree grows. Collected data is automatically sent to the user without the need for worker to collect information from the stand. Study of diameter at breast height (DBH), was measured among the automated dendrometer prototype with other popular tools such as diameter tape, diameter steel tape, Vernier Caliper and manual band dendrometers. It is found that tree growth data collected by all equipment are not significantly different, when tree growth data obtained from the prototype tool seems Tobe valid and comparable to other tools. The investment for developing a single prototype is round 154 EUR. When consider the entire rotation period of 30 years, the operational cost of where the prototype is 3,716 EUR. Although operational cost of prototype is pretty much higher than ordinary tools, but the prototype may reduce human error and provide real-time monitoring capability which is useful for plantation management in the long run. The recommendation for further studies should concern about cost reduction and investment feasibility as trend of electronic devices cost will decrease.*

Keywords: Tree growth, Dendrometer, Internet of things, Sensor

1. Introduction

Nowadays tree growth measurement can be done by many ways, from the use of simple tools to complex devices. Some devices have been developed to electronically read and collect data for maximum convenience. However, accuracy of such data depends on skills and expertise of the individual user. If the user is proficient, result will be more accurate than result obtained by an inexperienced user, indicating human impact on accuracy. This study aims to develop a prototype for real-time, unmanned tree growth measurement to avoid such human error by integration of Internet of Things technology. The availability of data from the prototype. In the future, it will be able to be used as data for decisions forest plantation management. By analyzed the appropriate time or use the information to create an alert system for the most duration trees cutting. To manage forests efficiently.

2. Method

This study examines operation of the prototype when used on Teak (*Tectona grandis Linn.f.*). Sampled Teak of three different sizes (small, medium and large sizes) are selected (Figure 1). Study area is divided into two locations as follows:

1) Lab experiment in the Faculty of Forestry, Kasetsart University, Bangkok.

2) Field experiment in Thong Pha Phum plantation, Kanchanaburi Province.



Figure 1 (A) Experimental plot aged between 1–10 years (small size), (B) Experimental plot aged between 10-30 years (medium size) and (C) Experimental plot aged over 30 years (large size)

Development of prototype tree growth monitoring device

According to design, the prototype consists of 3 main parts: 1) a 60mm sensor unit encased in a waterproof and corrosion-resistant aluminum box (Figure 2) if the tree grows up to 60 mm the scale must be reset and recalibrated before further use, 2) control unit which takes data from the sensor and transmit to the gateway (Ketcham, n.d.) which is selected by PVC to protect the component against water. The control unit consists of battery, control unit that control data recording interval (hourly, daily, weekly, monthly etc.) (Figure 3) and 3) gateway receives data from the sensor through the control unit, then transmit the data to the server for display. This unit consists of battery, and internet module (Figure 4). Details of all parts are shown in Table 1.

Principle of the prototype tree growth monitoring device is following, when tree grows, a cord around the tree stretches and make movement in the sensor unit, then the sensor unit records the length it moves (considered as tree growth) before transmitting the data to the control unit, which turning it recorded data and send it to the gateway for display on the program or application (Figure 5).

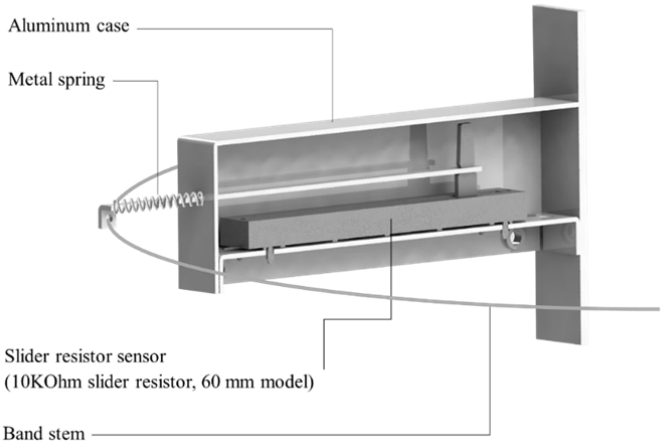


Figure 2 3D model of the Sensor unit

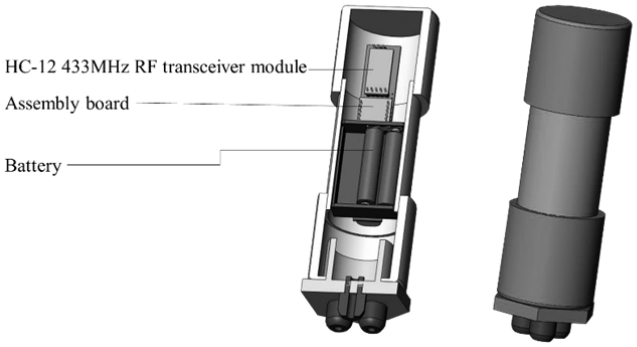


Figure 3 3D model of the Control unit

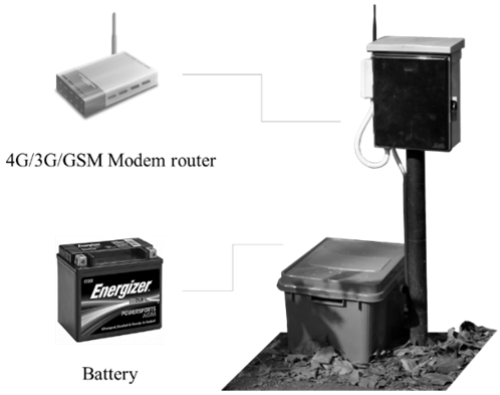


Figure 4 Gateway

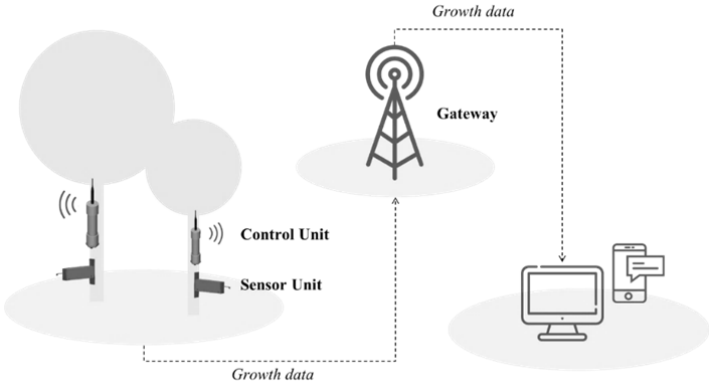


Figure 5 Working principle of prototype tree growth monitoring device

Data analysis

Study of tree growth by using the prototype tree growth monitoring device and other equipment to measure diameter growth at the height of 1.30 meter once a month for six months in total. Relationship between tree growths data obtained from different equipment is analyzed and compared with data from the prototype device. Data variance for each factor is determined by using ANOVA and statistical software.

3. Results and Discussion

Study of tree growth using the prototype and other equipment.

On-site experiment in Thong Pha Phum plantation showed problems in data transmission, probably due to signal instability, because lab experiment did not revealed the same problem. Also, equipment installed on-site were at risk of loss or damage from external elements such as wildfires, animals or humans. The solution is to use strong encasing material that should blend in well with the surrounding environment.

It is found that tree diameter (DBH) as measured by various equipment did not show any statistically significant difference therefore the prototype can be used in place of other equipment. Some excretions were observed prototypes show defects as shown in Figure 6 and their collected data were noticeably inconsistent with other devices. Such inconsistency may be attributed to signal interference or external disturbance to the sensor strip (by human or animal for example). The studied data also only covered 6 months of growth (January – June 2019), which was during dry season, when the tree did not grow much. Data collection therefore should be continue until rainy season, when the tree is expected to grow. Damp also can affect the equipment, in concurrence with a study by Mäkinen *et al*. (2008), which found that during fall and winter the Norwegian Pine [*Picea abies (L.*) Karst.] and Scottish Pine (*Pinus sylvestris L.*) had very low growth rate according to result from the equipment, while trunk radius growth dramatically accelerates during spring which is the most preferable time for tree growth measurement.

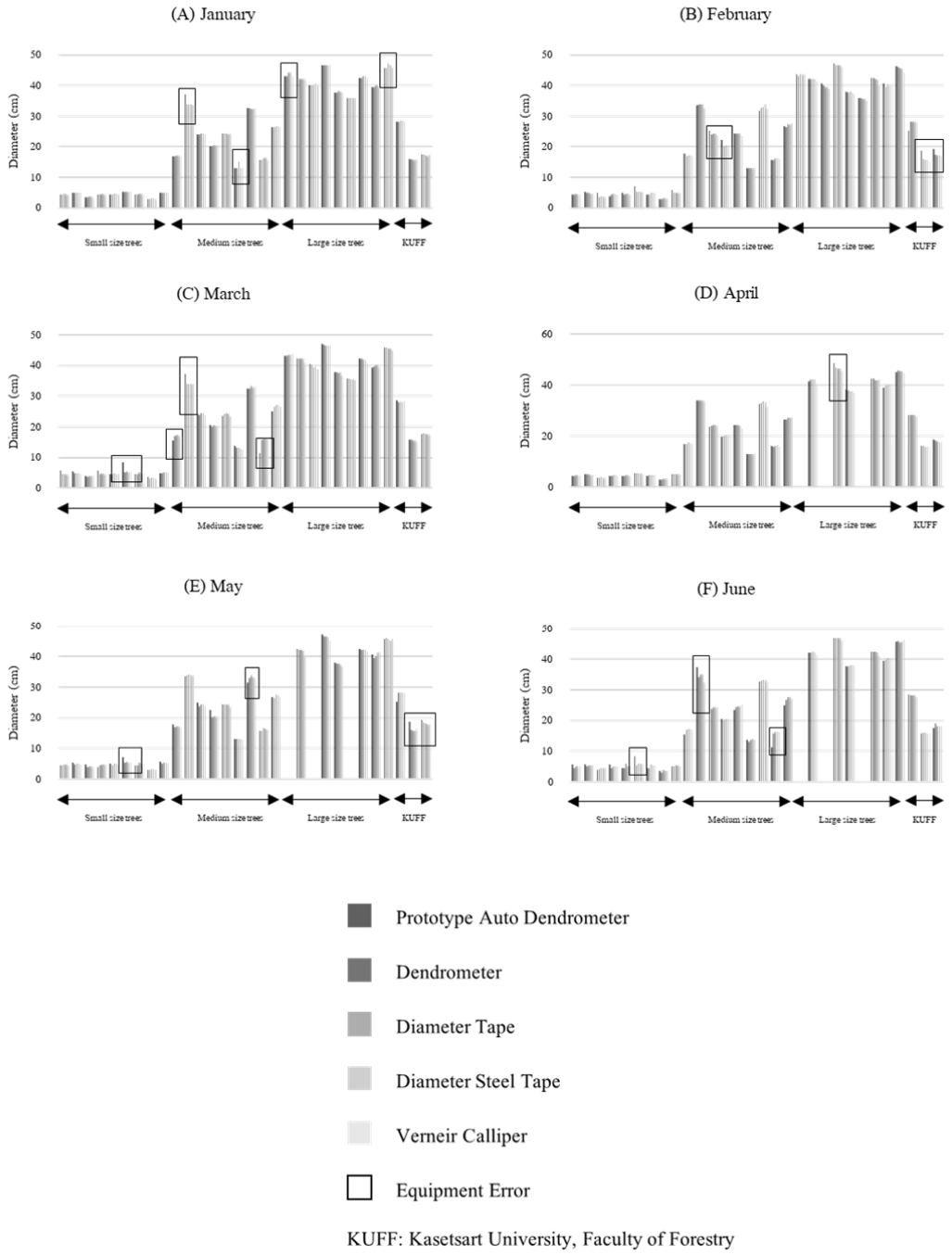


Figure 6 Tree growth data obtained from various devices (A) January 2019, (B) February 2019, (C) March 2019, (D) April 2019, (E) May 2019 and (F) June 2019

Table 1 Details of Automated-dendrometer Prototype

Part	Internal equipment	Unit	Unit price (baht)	Service time	Units within 30 years	Cost (baht)	Total cost
Sensor Unit	1. 10KOhm slider resistor, 60 mm model	1	340	7	4	1,457	**1,987**
	2. Aluminum case	1	230	30	1	230	
	3. Metal Spring	1	10	1	30	300	
Control Unit	1. 3V3 ATMEGA328 PROMINI MCU	1	130	5	6	780	**16,301**
	2. HC-12 433MHz RF transceiver module with antenna	1	210	5	6	1,260	
	4. Assembly board and fixed RTC power-down runtime	1	2,200	7	4	9,429	
	5. LR03 AAA Battery	3	12	0	361	4,337	
	6. CR2032 Li Battery	1	15	2	15	225	
	7. PVC Body	1	135	15	2	270	
Gateway	1. Stand and water proof metal box	1	4,000	15	2	8,000	**77,214**
	2. 12V 85 Ahr Battery	1	2,500	2	15	37,500	
	3. 4G/3G/GSM Modem router	1	3,500	5	6	21,000	
	4. Raspberry Pi B+ Mini PC with HC-12 433MHz transceiver module with antenna	1	2,500	7	4	10,714	
Total			**15,782**				**95,502**

4. Conclusions

The study found that tree growth data gathered by the prototype did not deviate from data gathered. From other tools, but unit cost was excessively high. In the future, if price of electronic parts drops further, adoption of such device for forest survey might be possible. Also, in the future the device should be further developed and refined to create commercial value for adoption by Teak plantation or any other plantations. Such device must be made for portability, cheap price and ease of use. The entire system should be made into a compact unit device that could be conveniently used anywhere and cooperation with other sectors and integration of knowledge from other fields might be necessary. In addition, a warning or alert system should be added in case of abnormal tree growth to allow quick examination. Forest management operations could be added to determine which tree should be harvested at a certain time. Successful development would be very conducive for effective forest management.

5. Acknowledgments

This research was supported, under the strengthening and developing new researcher plan, in conformance with the research and innovation of graduate study strategy of the national research council of Thailand (NRCT) as of the fiscal year 2019.

6. References

Anemaet, E. and A., Beth (2013), “Dendrometer bands made easy : Using modified cable ties to measure incremental growth of trees,” Applications in Plant Sciences, 1(9).

Forest Industry Organization. (n.d.). “Forest plantation survey of the Forest Industry Organization,” Forest Industry Organization, Bangkok.

Ketcham, M. (n.d.). Internet of Things (IoT). Available Source: http://203.155.220.230/bmainfo/data_DDS/document/internet-of-things.pdf, August 20 2017.

Mäkinen, H., W., Jeong, N. Pekka, S., Uwe and J., Risto (2008) “Seasonal Dynamics of Wood Formation: a Comparison Between Pinning, Microcoring and Dendrometer Measurements,” Springer-Verlag 127, 235-245.

FORMEC 2019 – Exceeding the Vision: Forest Mechanization of the Future
6-9 October, 2019 - Sopron, Hungary

NATURAL LANGUAGE PROCESSING AND IDENTIFYING CHARACTERISTICS OF JAPAN'S REGIONAL FORESTS, FORESTRY AND POLICIES

Ryotaro OKADA and Yuko SHIRAI
Keio University
Shonan Fujisawa Campus
5322 Endo, Fujisawa, Kanagawa, 252-0882, Japan
s17188ro@sfc.keio.ac.jp

Abstract:

This paper proposes utilization of natural language processing (NLP) and text mining technology in analyzing Japan's "Regional Forest Plans" and related documents to identify the characteristics of the forests, forestry practices, policies, issues and problems of each region, and discusses quantification and visualization of the results of such analyses for comparison and evaluation purposes. Particularly focused on are broadleaf trees.

After World War II, the Japanese government vigorously promoted expansive conifer afforestation. As a result, the main domestic supply is composed of softwood, and, contrary to the global trend, the growing stock has been accruing every year. This abundant resource from the man-made forests is not being harvested and utilized while Japan's import of wood products has been increasing, pushing down the self-supply ratio.

As to broadleaf trees, Japan's domestic supply of hardwoods has been unable to meet its demand therefor. But no clear plan is in place to increase the production of hardwoods in the future. Nor are the current situation and issues clearly understood.

It is therefore recommended to plant broadleaf trees, attend to them and increase the supply of hardwoods for the revitalization of Japan's forestry. What should be avoided in doing so is the uniform approach of the post-WWII afforestation that required the plantation of conifers only throughout Japan. Broadleaf trees vary a great deal from region to region. Any plan to cultivate the species and produce and supply hardwoods in a sustainable manner must take into consideration various differences of each region. To that end, it is important to establish a system that allows quantitative comparison and evaluation of the forests and the forestry of the regions.

In Japan, numerous documents are available that refer qualitatively to forests, forestry and associated issues and problems and forestry policies. This paper proposes utilization of NPL and text mining technology as a new method of analyzing those documents. Our presentation at this Conference will discuss the results of the analyses of the documents, and focusing on hardwoods, the identified qualitative characteristics of Japan's regional forests and forestry, and the derived results of quantitative comparison and evaluation.

Keywords: Natural Language Processing, Regional Forest Plans, Broadleaf Trees

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

THE EFFICACY OF *CHONDROSTEREUM PURPUREUM* IN THE SPROUT CONTROL IN MECHANIZED PRE-COMMERCIAL THINNINGS

Tiina Laine[1*], Leena Hamberg[2], Veli-Matti Saarinen[1], Timo Saksa[1]
[1] Natural Resources Institute Finland (Luke)
Natural resources
Juntintie 154, FI-77600 Suonenjoki, Finland
[2] Natural Resources Institute Finland (Luke)
Bioeconomy and environment
Latokartanonkaari 9, FI-00790 Helsinki, Finland
[*] Corresponding author
tiina.laine@luke.fi

Abstract: *Efficacy of young stand management can be improved by preventing sprouting and minimizing the number of repeated cuttings. Mechanized pre-commercial thinning combined with a white-rot fungal treatment resulted higher mortality compared to the control (cutting only). However, mortalities were lower than in previous studies.*

Keywords: biological control, mechanization, silviculture, vegetation management, fungal treatment

1. Introduction

Vigorous regrowth of deciduous stump sprouts after pre-commercial thinning (PCT) causes a need of later PCT in order to ensure better growing conditions for more valuable coniferous trees. Efficiency of young stand management can be improved by preventing sprouting and minimizing the number of repeated cuttings (Johansson, 2008; Uotila 2017). As the use of chemical herbicides in young stand management is restricted, the use of white-rot fungus (*Chondrostereum purpureum* (Pers. Ex Fr.) Pouzar) as a biocontrol agent has been studied. Results have been promising but there have been difficulties in motor-manual applications with a brush saw in practice due to weight of the inoculum and required additional time (Wall, 1990; Roy et al., 2010; Vartiamäki, 2009; Hamberg et al., 2015). Mechanized PCT combined with the *C. purpureum* treatment could solve the problem as machines would easily carry the load of the inoculum.

2. Material and methods

The efficacy of mechanized PCT done by Usewood Tehojätkä and Mense together with the fungal treatment (spreading an inoculum of *C. purpureum* as biocontrol agent on freshly cut stumps) was studied for three years in two separate studies (Figure 1). Efficacy was defined as increased stump mortality, decreased number of sprouts in a stump, and shorter length of sprouts compared to the control (cutting only). *C. purpureum* can utilize the woody material of birch (*Betula* sp.) better than that of the many other species, and therefore the results concerning birch stumps are presented here.



Figure 1. Tehojätkä (left) and Mense (right) in operation. Pictures: Veli-Matti Saarinen and Usewood Ltd.

3. Results

In the first study, the fungal treatment done by Tehojätkä was more effective compared to the control (cutting only) in terms of higher stump mortality (Figure 2) and the lower number of sprouts but it did not have as clear effect on the maximum height of stump sprouts. In the second study, mortality was also higher for the fungal treatment done by Tehojätkä and Mense compared to control (cutting only) (Figure 2), but there were no differences in the number of sprouts. Three growing seasons after the PCT, stump mortality for Tehojätkä was 34% and 42% for Mense. Stump mortality on the control stands (cutting only) was ca. 12%. Higher stand density (cut stumps and saplings) and larger stumps were associated with higher stump mortality. Also, timing of the treatment affected efficacy: stump mortality was lower in treatments performed later on in the growing season than in treatments performed earlier in the growing season.

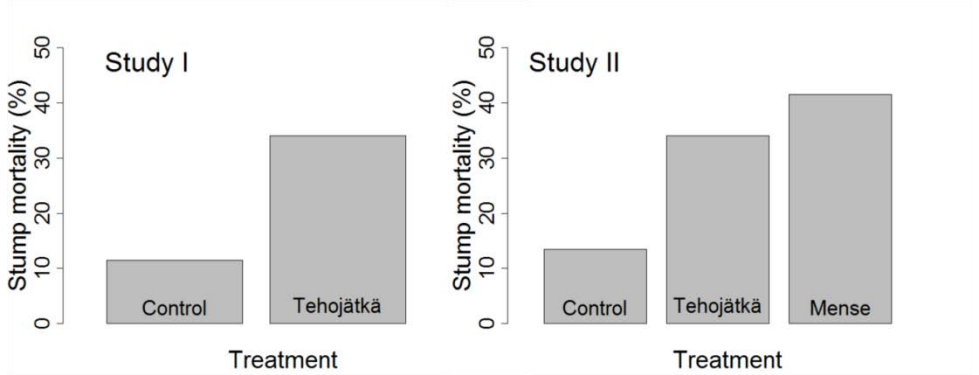


Figure 2. The effects of the control and the fungal treatments done by Tehojätkä and Mense on mortality of birch stumps three growing seasons after pre-commercial thinning in two different studies. Figures have been drawn based on the predicted values of the generalized linear mixed models.

3. Discussion

The fungal treatment was more effective compared to the control in terms of higher stump mortality. However, mortalities obtained in these two studies were notably lower compared to previous studies (i.e. Hamberg et al., 2015) which indicate that the accuracy of the spreading mechanisms was not satisfactory. We conclude that it is possible to decrease stump sprouting with the fully mechanized fungal treatment but implementation into practice needs more testing in order to increase efficacy.

Acknowledgements

This work was supported by the EU, through the EFFORTE (Efficient forestry by precision planning and management for sustainable environment and cost competitive bio-based industry) project (Grant agreement number: 720712 — EFFORTE — H2020-BBI-PPP-2015-02/H2020-BBI-PPP-2015-2-1).

Results are based on studies:

- Laine T., Hamberg L., Saarinen V.-M., Saksa T. 2019. The efficacy of *Chondrostereum purpureum* against sprouting of deciduous species after mechanized pre-commercial thinning. Silva Fennica vol. 53 no. 3 article id 10195. 8 p.

- Laine T., Hamberg L., Saarinen V.-M., Saksa T. 2019. The efficacy of *Chondrostereum purpureum* in sprout control of birch during mechanized pre-commercial thinning. Accepted for publication in BioControl.

References

Hamberg L., Vartiamäki H., Hantula J. (2015). Breeding Increases the Efficacy of Chondrostereum purpureum in the Sprout Control of Birch. PLoS ONE. 10(2): e0117381. 20 p. DOI: 10.1371/journal.pone.0117381.

Johansson, T. (2008). Sprouting ability and biomass production of downy and silver birch stumps of different diameters. Biomass and Bioenergy. 32, 944–951. https://doi.org/10.1016/j.biombioe.2008.01.009.

Roy, V., Dubeau, D., Auger, I. (2010). Biological control of intolerant hardwood competition: Silvicultural efficacy of Chondrostereum purpureum and worker productivity in conifer plantations. Forest Ecology and Management. 259, 1571–1579. https://doi.org/10.1F016/j.foreco.2010.01.033.

Uotila K. (2017). Optimization of early cleaning and precommercial thinning methods in juvenile stand management of Norway spruce stands. Disserationes Forestales 231. 42 p. http://dx.doi.org/10.14214/df.231.

Vartiamäki, H. (2009). The efficacy and potential risks of controlling sprouting in Finnish birches (Betula spp.) with fungal decomposer Chondrostereum purpureum. Dissertationes Forestales 93. 31 p. https://doi.org/10.14214/df.93.

Wall, R.E. (1990). The Fungus Chondrostereum purpureum as a Silvicide to Control Stump Sprouting in Hardwoods. Northern Journal of Applied Forestry. 7(1), 17–19. https://doi.org/10.1093/njaf/7.1.17.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

LOGGING PLANNING VIA AERIAL FOREST SURVEY

Angkana Thongkam, Nopparat Kaakkurivaara and Payattipol Narangajavana
Department of Forest Engineering
Faculty of Forestry, Kasetsart University
50 Phahonyothin Road, Lat Yao Subdistrict, Chatuchak District, Bangkok, Thailand, 10900
angkana.tho@ku.th

Abstract: *Thinning is an essential operation for improving the growth of stand. However, Thinning operation may cause damage to neighboring trees in the area. Therefore, the carefully planning of the skidding trail may help in reducing the impact that may occur on the remaining trees. The purpose of this research is to plan the skidding trail via aerial photography techniques to extract marked trees from the plantation area to temporary logs landing. The study site will be carried out at KhaoKraYang Teak Plantation, Phitsanulok, Thailand. Data collection starting with the UAV survey to capture the area that needs to be logged in the near future. Multi-Criteria Decision Analysis— the analytic hierarchy process (AHP) was used to estimated importance value of each criterion which to weighting the factors on creating the land stability map. And Network Analysis technique was used to plan and design the skidding trail according to land stability. The result showed the total distance of skidding trail is 716.11 meters and density 468.04 meters per hectares. Most of the marked trees in the area can access by the skidding trail. In conclusion, the Spatial Decision Support System provides the best route to access marked trees and can avoid disturbing leave trees in the plantation area.*

Keywords: Skidding trail, Network Analysis, Logging planning, Aerial forest surveying, SDSS

1. Introduction

The Forest Industry Organization is the largest producer of teak for domestic use in Thailand, with teak planting rotation of 30 years and occasional thinning as appropriate to maintain the forest and promote growth of the remaining teak in the plot. Teak logging is normally done by the tree-length method which length of the tree affects the environment, the longer the tree, the more damage to the environment. It is highly likely that felling and skidding during thinning will damage the remaining trees. The result of the study from logging impact researchers all agreed that logging and skidding could damage the area and other remaining trees, for example felling of one tree might cause it to damage nearby trees (like breaking the shoot or branch). Remaining trees usually have wounds on the trunk and roots from skidding (Reisinger and Pope, 1991; Clatterbuck, 2006 and Tavankar et al.,2013). So, timber extraction from the plantation needs careful planning to find felling direction and suitable skidding trails to reduce damage to the remaining trees and the environment, and improve management efficiency.

Nowadays unmanned aerial vehicle (UAV) videography is used in forestry because of its flexibility, speed and ability to get to difficult areas which reduce risk of dangers and accidents that will happen to humans. Identification of a suitable skidding trails should start from aerial survey with a UAV to collect information, which will be analyzed for area stability map in the Geographic Information System (GIS). One popular analysis technique is Multi-Criteria Decision Analysis (MCDA) which is a Spatial Decision Support System (SDSS) with varied objective and decision criteria to find the best alternative based on spatial information available on GIS (Malczewski, 1999). Result from the spatial analysis will be used as a guideline for skidding trails planning. Generally, network analysis is used by marking the starting and ending points on the map, after which the system will automatically set the best and shortest trails.

Application of UAV and GIS in forestry such as Parsakhoo et al. (2017), along with network analysis to support decision-making process in planning of skidding trails to landing can promote logging management and planning, and reduce impact on the environment. Sterenczak and Moskalik (2015) studied the use of LIDAR-based digital geographic model and single tree segmentation data to determine the best skidding trails network.

The objectives of this study are to plan skidding trails before thinning and to evaluate efficiency of skidding plan which reflects logging quality. Result of this study will lead to new techniques for more effective logging planning that reduce the environmental impact caused by logging activities in Thailand.

2. Materials and Methods

2.1 Study Area

Compartment 2514 of Kaokrayang forest plantation with a size of 27 hectares, this is located on KangSopha Sub-District, Wangthong District, Phitsanulok Province, Norther of Thailand. This place belongs to the Forest Industry Organization of Phitsanulok Region. This has been operated by Forest Industry Organization which has built a forest plantation in the Kaokrayang National Sanctuary and Keg river forest with the total area of 2,420 hectares. This place is the office of Kaokrayang forest plantation which is at coordinates of 47Q E 0686239 N 1863226 (From the satellite system of UTM (WGS 1984)) the area of Kaokrayang forest plantation has the elevation from 200 m to 700 m above mean sea level. A forest plantation policy aims to achieve a sustainable forest management. In the study plot, there are 16 years-old teaks That was randomly planted to resemble natural conditions. Logging operation is done by the tree-length method. (Figure 1).

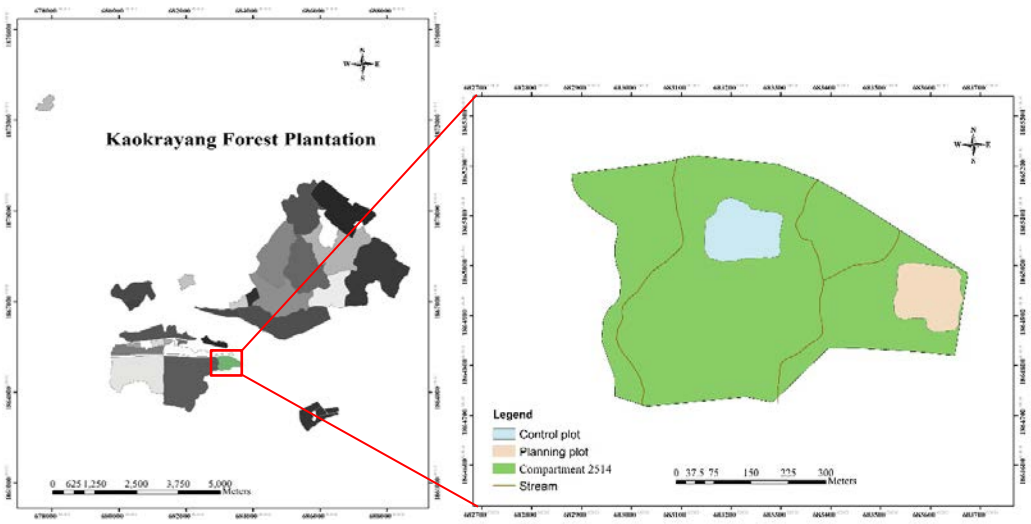


Figure 1 Location map of compartments 2514 in Kaokrayang forest plantation

2.2 Data Collection

There is a survey of the forest with an unmanned aerial vehicle and the taking of a photograph of a plot that will harvested in the future. Drone equipped with RBG camera will be taken the images before and after logging to create a Digital Elevation Model from Images. Two sample plots were determined on a study

area (one plot for controlled and another for planned the skidding trails). All trees position in experimental plots were marked with RTK GPS and tree sizes were measured. Soil compaction was collected with compaction tester (Skokagro soil penetrator) and soil sample were collected spread throughout the area in order to analyze soil properties in the laboratory.

2.3 Land Stability Map

In the studied area, skidding is normally done by tractor and thus the area must be able to support combined weight of the timber and tractor (Raza et al. 2008). Four maps are used in analysis: slope, distant from stream, soil type, and soil compaction. Slope map extracted from the digital terrain model which is generated by the drone photography. Slope is classified by skidding limitations. Slope between 0-15% is highly suitable for skidding as the tractor can easily navigate the area. Slope between 15-30% is moderately suitable for tractor but it may have to travel along the contour line. And slope greater than 30% is undesirable as the slope becomes too steep and assistant tool or changing of skidding method may be necessary (figure 2a). A distance from watercourse is made by aerial survey shows that land within 0-100 m from the water is low in stability, 100-200 m is moderate and over 200 m means high stability (figure 2b). The soil type map is obtained from the Land Development Department and additional field survey. The strength and stability of soil depend on its physical properties. Soil layers are stratified into codes. Code 1 which is RL soil group that has a lot of rocks. Soil in this group is sandy clay loam and considered highly stable. Code 2 consists of 35B and 35C soil groups that are ranged from sandy clay loam to loam and considered moderately stable. Code 3 is the 56C group that is sandy loam and has low stability (figure 2c). Soil compaction map is obtained by field survey using soil compaction tester. Soil layers are classified by kpa value, as 0-1000 kpa means low stability, 1000-2000 kpa moderate stability and over 2000 kpa high stability (Figure 2d).

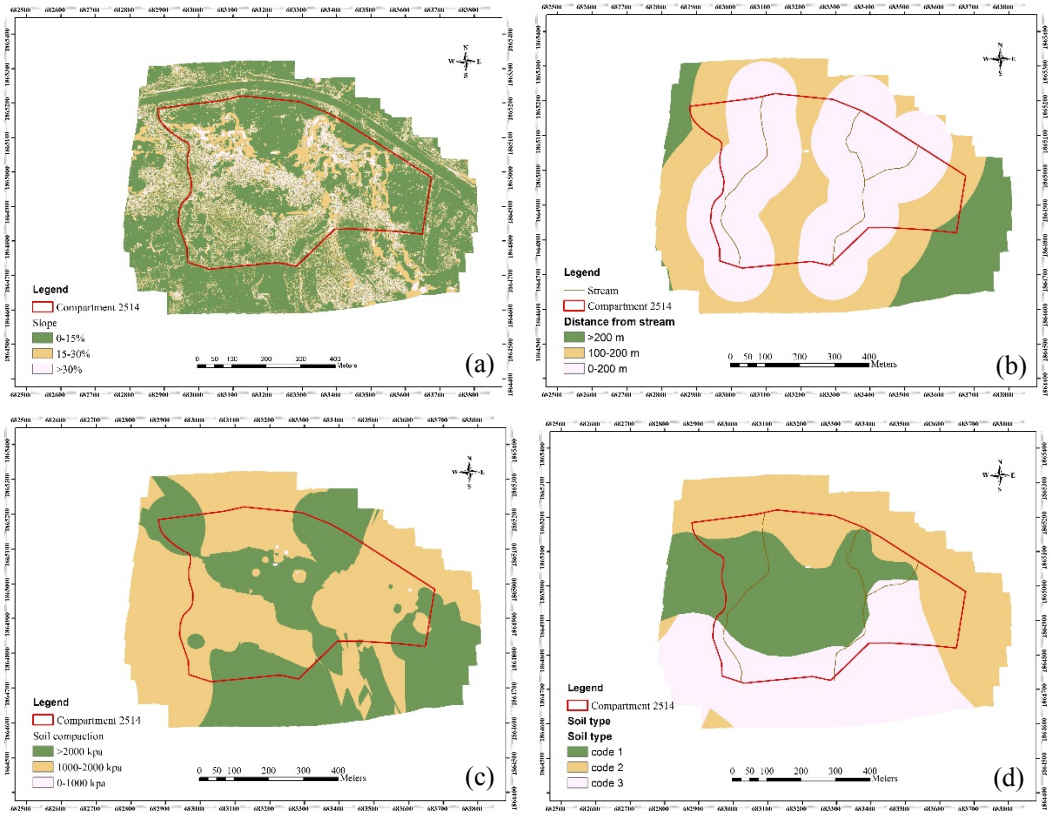


Figure 2 Slope map (a), Distance from stream map (b), (Soil compaction map (c), Soil type map (d)

This study examines land stability by MCDA—the analytic hierarchy process (AHP). Calculated importance value of criterions from pairwise comparison questionnaire. It was done by forest engineering experts (Table 1). Each questionnaire contained the questions about the importance of each factor influenced the stability for skid trail planning. Overlay process was done by using the raster calculator in the GIS to generated the stability map.

Table 1 Importance value of criteria influencing the land stability for modelling the land stability in an analytical hierarchy process

Criterion	Importance value	Class	Stability code	Stability class
slope	0.542	0-15%	1	High
		15-30%	2	Moderate
		> 30%	3	Low
Distance from stream	0.144	>200 meters	1	High
		100-200 meters	2	Moderate
		0-100 meters	3	Low
Soil type	0.144	Code 1	1	High
		Code 2	2	Moderate
		Code 3	3	Low
Soil compaction	0.170	>2000 kpa	1	High
		1000-2000 kpa	2	Moderate
		0-1000 kpa	3	Low

2.4 Skid Trails Design

The location of marked trees and standing trees are affected the skidding trails planning. It was started from placing 2 meters grid on the entire stability map. Then, temporary log landings are placed on highly stable areas nearby roads. Network analysis is used to determine the best trails with extraction point as the start node, and the access point as end nods. Barrier is created by using position of the standing trees (unmarked trees) with 1 meter buffer from the bark (Figure3). Service area of the skidding trails is determined by creating 5-meter and 10-meter buffers from the skidding trails.

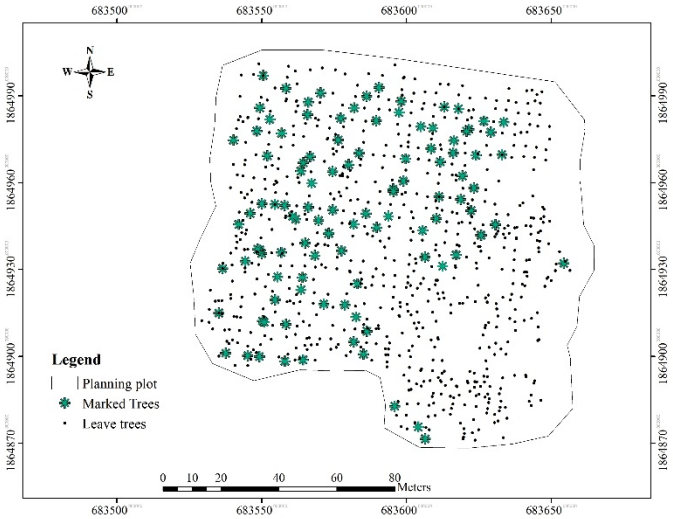


Figure 3 The location of marked trees and leave trees

3. Result

3.1 Weights of Effective Factors on Land Stability Map

Results showed that the criteria affecting the land stability were slope, distance from stream, soil type and soil compaction with the relative weights of 0.542, 0.144, 0.144 and 0.017, respectively. Stability values was increased by increasing a distance from the stream and soil compaction values. Moreover, Stability values decreased with increasing percentage of slope. The land stability zonation map was classified into three categories: high stability (code 1: 46.91%), moderate (code 2: 32.39%) and low stability (code 3: 20.69%). Concerning planning plot, the total area of experimental plot is 1.53 ha. Stability zonation is 64.93%, 25.23% and 9.84%, respectively (Figure 4).

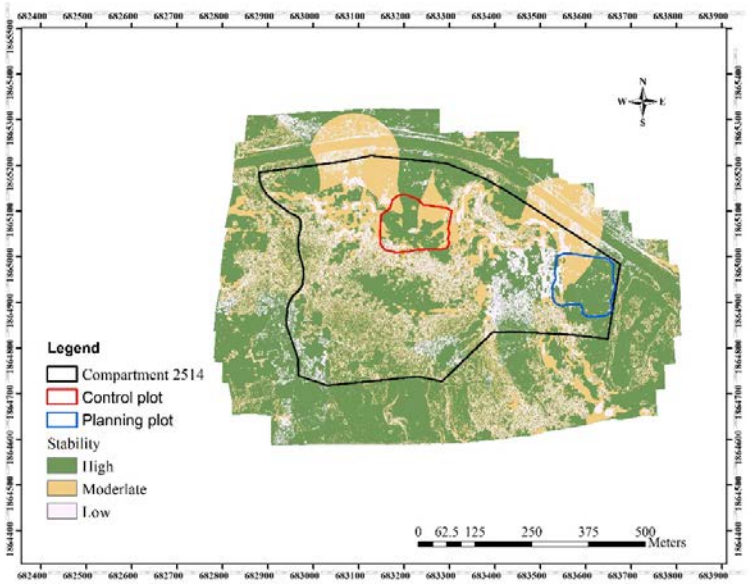


Figure 4 Land stability map of compartment 2514

3.2 Designed Skidding Trails According to Land Stability

The result of designed the skidding trail between all marked trees. The total length of the skidding trail is 716.11 meters. The distance of the skidding trail through the areas of high, medium and low stability is 429.30, 257.70 and 29.11 meters, respectively (Table 2). The density of the skidding trail is 468.04 square meters per hectares. More than 95% of the skidding trail passed through the areas with moderate to high stability (Figure 5).

Table 2 Technical parameters of designed skid trails

Stability level	Length of skidding trail		Area	Density
	(m)	(%)	(ha)	(m/ha^{-1})
High	429.30	59.95		
Moderate	257.70	35.98	1.53	468.04
Low	29.11	4.06		

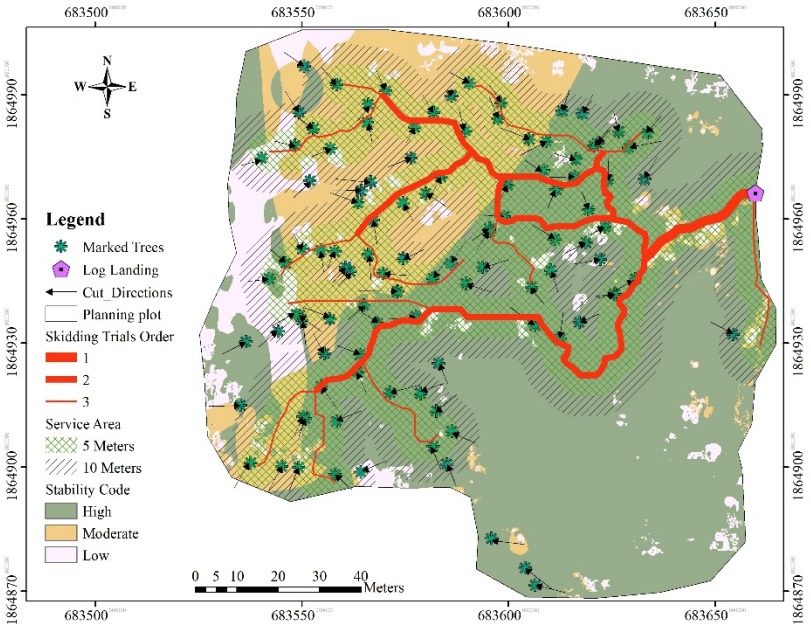


Figure 5 Distribution and service area of skid trails in compartment 2514

3.3 Service Area of Skidding Trails

The multiple ring of service area around any skid trail can be reached within 5 and 10 meters (Figure. 5). Most of the marked trees are located within 0-5 and 5–10 meters of service areas. In some cases, the marked trees are located far away from the service area of designed skid trails. These trees are called inaccessible (Table 3).

Table 3 Number of accessible marked trees in different service area categories

Service area (m)	Marked trees	
	number	(%)
0-5	101	75.70
5-10	20	18.69
Inaccessible	6	5.61

4. Discussion

The results of the designing of skidding trails showed that some of the marked trees located in an inaccessible area. Sometimes it is not worth the effort just to reach couple trees in an inaccessible area. However, it depends on the decision of the owner of the plantation. There is some information that should take into consideration while making a decision i.e. cost, traveling time and harvest volume in order to find the best solution. In case of skidding on the low stability skidding trails, the operation and working techniques must be intensively planned. The distance and density of skidding trail are relatively dense due to avoid damage that may occur on the standing trees. Since this experimental plot is first thinning, so there are still many trees left in the area. In this study, the felling direction was determined manually. Normally felling direction should have 0-45 degrees of angle from the skidding trail and be close to the skidding trail as possible. In the future, the automated selection of felling direction shall be considered.

5. Conclusion

The skidding trails design via aerial surveying and applying of decision support system demonstrated that the Network Analysis provided the best route from the marked trees to the log landing. The total distance of skidding trail was 716.11 meters and density were 468.04 meters per hectares. This study just a preliminary result on planning stage. Afterwards, the implementation will be carried out in the study site then logging impacts will be evaluated and compared between controlled plot and planned plot.

6. Acknowledgements

This research was supported by Kasetsart University Research Development Institute (KURDI) in research program: Applying precision forestry to teak plantation in northern Thailand.

7. References

Aggarwal, P. (2016) “The Importance of Management Information System (MIS) and Decision Support System (DSS) in Decision-Making Process” Imperial Journal of Interdisciplinary Research, 2(12), 243-246.

Agrawal, S., K.R. Subramanian and S. Kapoor. (2010) “Operations Research-Contemporary Role in Managerial Decision Making;” International Journal of Recent Research and Applied Studies, 3(2): 200-208.

Alter, S. (1980) “Decision support systems: current practice and continuing challenges,” Addison-Wesley Pub, Boston.

Banu, T.P., G.F. Borlea and C. Banu. (2016) “The Use of Drones in Forestry,” Journal of Environmental Science and Engineering B., 5: 557-562.

Cheung C. C., B. M. Yamauchi, C. V. Jones, M. B. Moseley, S. Singh, C. M. Geyer, B. P. Grocholsky and E. C. Cox. (2012) "Collaborative engagement for target identification and tracking," U.S. Patent US 8,244,469 B2.

Clatterbuck, W.K. (2006) "Logging damage to residual trees following commercial harvesting to different overstory retention levels in a mature hardwood stand in Tennessee," Proceedings of 13th Biennial Southern Silvicultural Research Conference. Department of Agriculture, Forest Service, Southern Research Station. Tennesse, 591-594.

Contreras, M.A., D.L. Parrott, and W. Chung. (2016) "Designing Skid-Trail Networks to Reduce Skidding Cost and Soil Disturbance for Ground-Based Timber Harvesting Operations," For. Sci., 62(1):48–58.

Dykstra, D.P. and R. Heinrich. (1996) "FAO Model Code of Forest Harvesting Practice" Food and Agriculture Organisation of the United Nations, Rome.

Edson, C., and M. G. Wing. (2011) "Airborne Light Detection and Ranging (Lidar) for Individual Tree Stem Location, Height, and Biomass Measurements," Remote Sensing, 3(11): 2494–2528.

Elias, G. Applegate, K. Kartawinata, Machfudh and A. Klassen. (2001) "Reduce impact logging guidelines for Indonesia," Center for International Forestry Research, Bogor.
Esri. (2012) "What is GIS?" Esri, USA.

Gunarathna, J.K. and R.S. Munasinghe. (2018). "Development of a Quad-rotor Fixed-wing Hybrid Unmanned Aerial Vehicle," In 2018 Moratuwa Engineering Research Conference (MERCon 2018). IEEE. Moratuwa, Sri Lanka, 72-77.

Japan Association of Remote Sensing. (1999) "Remote Sensing Notes," Available Source: http://wtlab.iis.u-tokyo.ac.jp/wataru/lecture/rsgis/rsnote/contents.htm, December 18, 2018.

Jeffrey, W.S. and P. Cary. (2001) "Kentucky Forest Practice Guidelines for Water Quality Management," College of Agriculture, University of Kentucky, Kentucky.

Malczewski, J. (1999) "GIS and Multicriteria Decision Analysis," John Wiley & Sons, New York.

Panagiotidis, D., A. Abdollahnejad, P. Surový and V. Chiteculo. (2017) "Determining tree height and crown diameter from high-resolution UAV imagery" International Journal of Remote Sensing, 38: 2392-2410.

Parsakhoo, A., M. Mostafa, S. Shataee and M. Lotfalian. (2017) "Decision support system to find a skid trail network for extracting marked trees" Journal of forest science, 63(2): 62–69.

Reisinger, T.W. and P.E. Pope. (1991) "Impact of timber harvesting on residual trees in a central hardwood forest in Indiana," Proceedings of 8th Central Hardwood Forest Conference. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Pennsylvania, 82-91.

Rubenstein, A. H. and C. J. Haberstroh. (1960) "Some theories of organization," Dorsey Press, Wisconsin.

Salles, M. (2006) "Decision making in SMEs and information requirements for competitive intelligence," Production Planning & Control, 17(3): 229-237.

Simon, H. A. (1960) "The new science of management decision," Harper & Brothers, New York.

Sterenczak, K. and T. Moskalik. (2014) "Use of LIDAR-based digital terrain model and single tree segmentation data for optimal forest skid trail network," iForest - Biogeosciences and Forestry, 8(5): 661-667.

Tavankar, F., B. Majnounian and A. Bonyad. (2013) Felling and skidding damage to residual trees following selection cutting in Caspian forests of Iran. Journal of forest science, 59(5): 196-203.

Winston, W.L. (2004) “Operation Research Application and Algorithms” 4th ed. Thomson Brooks/Cole, Canada.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

INCORPORATING STAND PROPERTIES AND BUCKING OBJECTIVES FOR BUCKING-TO-DEMAND HARVESTING

Jukka Malinen & Markus Mennala
University of Eastern Finland
School of Forest Sciences
P.O.Box 111, FI-80101 Joensuu FINLAND
jukka.malinen@uef.fi

Abstract: *Cut-to-length harvesting utilizing bucking-to-demand approach aims to maximize the fit between demanded and harvested log length-diameter distribution without compromising value recovery. Timber assortment specific price matrices define the values for each log length-diameter dimension, whereas demand matrices define the desirability of each dimension. However, as stands may be different in many respects, the same matrices may not be equally efficient for each stand.*
In the study, a fit between bucking objective parameters and stand and tree properties was investigated utilizing developed bucking-to-demand simulator and extensive stem data including harvester measured stems and estimated external quality affecting bucking. External quality estimations were based on stem quality database and non-parametric estimation. Stands were classified according average stem size, site fertility and proportion of defects affecting bucking.
Parameters defined and varied in bucking objectives included utilized range of lengths and diameters, type of pricing in price matrix, value differences within and between price matrices and adaptation percentages used in bucking-to-demand harvesting.
The study results can be used as a rule of thumb for constructing bucking-to-demand objectives for various product scenarios and stand characteristics.

Keywords: bucking, recovery, external quality

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

THINNING OPTIMIZATION IN BEECH POLE STANDS

Domen Arnič[1*], Jurij Diaci[2], Janez Krč[2]

[1]Department of Forest Technique and Economics.
Slovenian Forestry Institute
Večna pot 2, 1000 Ljubljana, Slovenia
domen.arnic@gozdis.si
[2]Department of Forestry and Renewable Forest Resources
University of Ljubljana, Biotechnical faculty
Večna pot 83, 1000 Ljubljana

Abstract: *Rationalization and optimization of forest operation is becoming increasingly important in the European forestry sector. In this study, three different thinning models in beech pole stands were developed using Visual Basic computer programming language. We assessed the impact of the number of candidates per hectare and the impact of thinning intensity on productive time.*

Firstly, we simulated different thinning configurations by altering the number of candidates, and the number and the dimensions of their competitors. Secondly, we calculated the main and auxiliary productive time of individual simulated configuration. Finally, we conducted a comparative analyzes to assess efficiency of thinnings.

In terms of costs, the results indicate that thinning model with less candidates per hectare are more efficient in comparison to high number of candidates per hectare. Moreover, the results shows that lower thinning intensity significantly increase thinning efficiency, while higher number of candidates per hectare decrease it. Both analyzed factors affect the ratio between the main productive and the auxiliary productive time.

Modeling has shown that thinning approaches with lower numbers of candidates (situational thinning) represent an alternative to classical tending (selective thinning) especially from economic and ergonomic perspective.

Keywords: Precommercial thinning, selective thinning, crop tree situational thinning, rationalization

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

LOG DETECTION BASED ON DEEP CONVOLUTIONAL NEURAL NETWORKS

Kengo Usui*, Masahiro Mozuna, Takumi Uemura, Masahiko Nakazawa
National Research and Development Agency Forest Research and Management Organization
Forestry and Forest Product Research Institute
Matsunosato 1, Tsukuba, Japan
kusui@ffpri.affrc.go.jp

Abstract: *Vision-based log detection techniques are useful for several operations, e.g., autonomous log loading and timber volume estimation. However, little techniques have been suggested that can detect log with robustness. As a recent development of deep convolutional neural networks, many object detection algorithms are proposed. In this paper, we apply these techniques to log detection and aimed to recognize log regions from color images by deep learning. We used object detection algorithm based on deep convolution neural networks. Training images were generated from these supervised images. In order to ensure robustness, data augmentation was processed. We used 2treatments: image processing and background swapping. As a result of training, the models had high precision and recall. In conclusion, it was suggested that it was useful to detect logs by deep convolutional neural networks.*
Keywords: autonomous forest machinery, deep learning, log loading, object detection

1. Introduction

Forest machine operation is complicated for not-well-trained operator, therefore operator proficiency could be bottleneck of performance and productivity (Westerberg and Shiriaev, 2013). Purfürst reported that performance of beginner operators was roughly doubled within the mean period of 8 months learning (Purfüerst, 2010). Thus, it is required to develop systems improving productivity or performance for beginners.

To solve this problem, it is suggested that operator support system by partly or fully automation. Previous researches focused on self-driving of automated or autonomous forwarder. On the other hands, log loading/unloading operations have not focused in previous studies. Therefore, it is necessary to develop underlying technology for autonomous log loading. Firstly, we focused on detecting log from forest environment. Since deep learning technology is widely used for object detection in robotics, we applied this technology to autonomous forest machinery. This study aims to develop log detection systems for operator-supporting systems of forest machinery by partly or fully autonomous.

2. Materials and Methods

2.1 Experiment

Experiment was conducted at forestry mechanization center (Numata city, Gunma Prefecture, Japan) on September 18 - 19, 2019. Stereo camera (Zed, Stereolabs) was set in front of grapple loader (CT500, Iwafuji). We recorded videos of log stacks. Videos were recorded 1280*720 pixels and 60 fps. Log stacks consisted of Sugi (*Cryptomeria japonica*), Hinoki (*Chamaecyparis obtusa*), and Momi (*Abies firma*) images. Log stacks including fresh logs and 3-years-old logs after cutting.

2.2 Detection Algorithm

We used deep convolution neural network-based object detection algorithm (Yolo v3)(Redmon and Farhadi, 2018). This algorithm detects regions containing log in the image.

It is important to ensure adequate amount of supervised data for deep convolutional neural networks. Lemley et al. indicated that not having enough quality labeled data will generate overfitting, which means that the network is highly biased to the data it has seen in the training set and, therefore will not be able to generalize the learned model to any other samples. (Lemley, Bazrafkan and Corcoran, 2017).

In order to ensure robustness, data augmentation was performed. Data augmentation is the process of supplementing a dataset with similar data that is created from the information in that dataset (Lemley, Bazrafkan and Corcoran, 2017). We used 2treatments: First, image processing, which was used in previous researches (Dodge and Karam, 2016; Shen *et al.*, 2016; Hussain *et al.*, 2017), by horizontal flip, gamma conversion, and gaussian filter were performed. Gamma conversion for 8bit depth RGB image is expressed by the following equation (1).

$$u_{ij} = 255\left(\frac{I_{ij}}{255}\right)^{\frac{1}{\gamma}} \tag{1}$$

where I_{ij} is brightness of pixel (i, j) in the input image, γ is a parameter in gamma conversion. γ in the gamma conversion was four levels: 0.5,0.8,1.2,1.5 from previous studies (Shen *et al.*, 2016).

The smoothing weight of gaussian filter $f(i, j)$ away from center coordinates (i, j) is expressed by the following equation (2).

$$f(i,j) = \frac{1}{2\pi\sigma^2} exp\left(-\frac{i^2 + j^2}{2\sigma^2}\right) \tag{2}$$

where σ is a standard deviation parameter of gaussian filter. σ in gaussian filter was varied from 1 to 9 step 1 (Dodge and Karam, 2016). The kernel was four times that of the one-sided σ. OpenCV 3.2.0 was used for each processing. As a result of this process, images extended to 28-fold.

Second, images composition by background swapping was also performed. The public domain images from Flickr composed to photographed log by polyethylene tarpaulin (Flickr, 2019). Images searched by 8 keywords (bazaar, desert, excavation, forest, landscape, lake, outdoor, vegetation) were composed 25 log images that were extracted from original images. Each keyword generated 400 composite images, in total 3200 images by this process. Example of generated images was shown in Figure 1.



Figure 1. Examples of input images (a) original, (b) gaussian filter and horizontal flip, (c) image composition of keyword" forest", and (d) image composition of keyword "lake"

As a result of data augmentation, we prepared 3088 images for no data augmentation, 86,464 images for data augmentation by image processing, and 176,064 images for data augmentation by the image processing and image composition. Training and treatments were performed with GPU (GTX1080Ti, NVIDIA).

2.2 Evaluation of trained model

Generally, precision and recall were used as evaluation of machine learning. Additionally, mean average precision (mAP), which used in PASCAL VOC style evaluation, and intersect of union (IoU) were also used as evaluation (Everingham *et al.*, 2010). These indices defined as follows.

$$Precision = \frac{TP}{TP \cup FP} \tag{3}$$

$$Recall = \frac{TP}{TP \cup FN} \tag{4}$$

$$AP = \frac{1}{N}\sum_{j=1}^{N} Precision_j \tag{5}$$

$$mAP = \frac{1}{M}\sum_{i=1}^{M} AP_i \tag{6}$$

$$IoU = \frac{TP}{TP \cup FP \cup FN} \tag{7}$$

where TP, TN, FP, FN is true positive, true negative, false positive, and false negative, respectively. AP is average precision. N is total number of correct labels that the model properly recognized at the time of the *j*, M is total number of images.

3. Results and Discussion

3.1 Result of Detection

Results of training, precision is 0.93-0.96, and recall is 0.44-0.95 (Table 1). An example of the detection results shown in Figure 2. mAP in no data augmentation, augmentation by image processing, augmentation by image processing and image composition were 0.53,0.81,0.91 respectively (Figure 3 (a)).

Table 1. Detection results of each treatment

	Precision	Recall	TP	FP	FN	IoU	mAP	Num. of images
No augmentation	0.93	0.44	125098	8786	159779	0.78	0.53	3088
Image processing	0.95	0.80	228326	11130	56551	0.81	0.81	86464
Image processing & composition	0.96	0.95	269867	10092	15010	0.82	0.91	176064



Figure 2. Example of detection

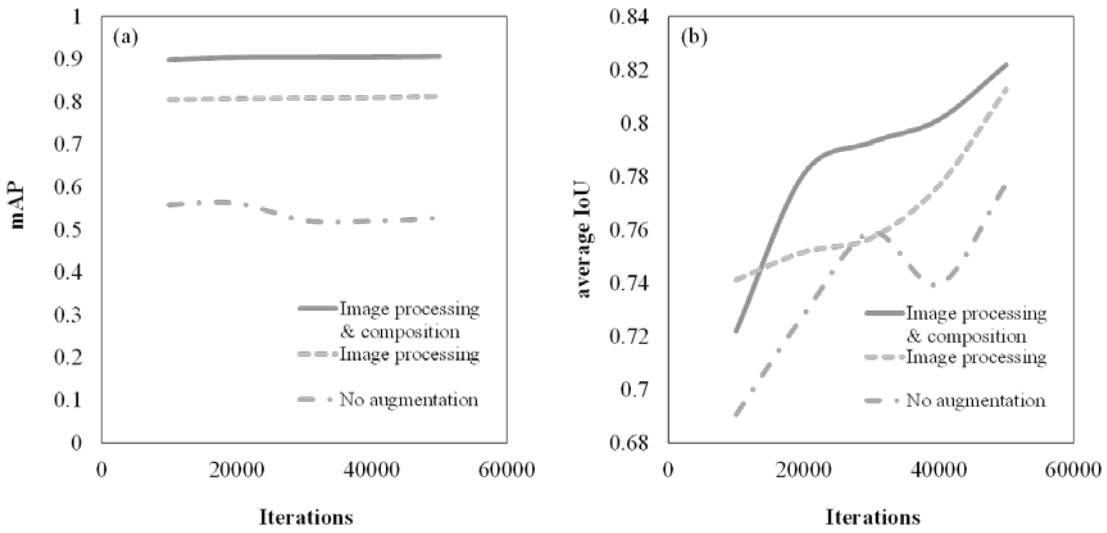


Figure 3. Changes of (a) mAP and (b) average IoU

IoU of each treatment were 0.78, 0.81,0.82, respectively (Figure 3(b)). It was suggested that each data augmentation could improve mAP and IoU. Further, the average time of detection of each treatment were 35.6, 46.8, 35.7 milliseconds, respectively. It was sufficient to detect log in real-time.

3.2 Trend of Detection

The higher ratio of the cut end surface of log stack in the detected region was, the lower accuracy of detection was. This trend means the image from horizontal to the grounds leads to decrease accuracy. It is considered that weighted models learned features of log bark. For precise detection, it was adequate to use an image obtained from the vertical direction or upwardly against visible butt bark surface.

Moreover, focusing on precision and recall in Table 1, significantly recall rose by performing extension number of training data. Low recall indicates large amounts of false negative, i.e. there are many missing logs in spite of there are logs actually.

4. Conclusion

It is confirmed to increase mAP and IoU by data augmentation. It was suggested that data augmentation contributes to improving accuracy of the detection region. In this study, we have generated images by not only image processing but also image composition using chroma key composition. It seemed to ensure the robustness from relatively small number of data by combination with image processing and image composition.

It considered it could measure log shape and volume in contactless by using this technology as pretreatment. This technology is a basis for smart forestry since it could extend range of sensing in ICT forest machinery.

5. Acknowledgements

This research was supported by grants from the Project of the Bio-oriented Technology Research Advancement Institution, NARO (the special scheme project on advanced research and development for next-generation technology).

6. References

Dodge, S. and Karam, L. (2016) "Understanding how image quality affects deep neural networks," 2016 8th International Conference on Quality of Multimedia Experience, QoMEX 2016, Lisbon. 1–6.

Everingham, M. et al. (2010) "The pascal visual object classes (VOC) challenge," International Journal of Computer Vision, 88(2), 303–338.

Flickr (2019). Available at: https://www.flickr.com/ (Accessed: 26 August 2019).

Hussain, Z. et al. (2017) "Differential Data Augmentation Techniques for Medical Imaging Classification Tasks," AMIA Annual Symposium proceedings 2017, Washington. 979–984.

Lemley, J., Bazrafkan, S. and Corcoran, P. (2017) "Smart Augmentation Learning an Optimal Data Augmentation Strategy," IEEE Access, 5, 5858–5869.

Purfüerst, F. T. (2010) "Learning Curves of Harvester Operators", Croatian Journal of Forest Engineering, 31(2), 89–97.

Redmon, J. and Farhadi, A. (2018) "YOLOv3: An Incremental Improvement", arXiv. Available at: https://arxiv.org/abs/1804.02767.

Shen, X. et al. (2016) "Automatic portrait segmentation for image stylization", Computer Graphics Forum, 35(2), 93–102.

Westerberg, S. and Shiriaev, A. (2013) "Virtual Environment-Based Teleoperation of Forestry Machines: Designing Future Interaction Methods," Journal of Human-Robot Interaction, 2(3), 84–110.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

BEST PRACTICE HARVESTING PROCEDURES TO MEET NATURE PROTECTION REQUIREMENTS IN GERMANY

Ute Seeling, Hans-Ulrich Dietz
Kuratorium fur Waldarbeit und Forsttechnik, Gross-Umstadt, Germany
kopetzky@kwf-online.de

Abstract: *Sylviculture strategies, increasingly focusing on the location, shifts in tree species selection caused by climate change and nature conservation objectives (Natura 2000, national parks, nature reserves, etc.) lead in the medium to long term to radical changes in forest compositions. In the future logging will take place on areas characterized by a higher proportion of hardwood, increased stem diameters and higher deadwood volumes. Additionally forests will be determined by a mosaic-like change of protected areas (e.g. small areas around habitat trees or large areas adjacent to old and deadwood islands), areas that fall under certain usage requirements and areas in which regulated sustainable forestry can be conducted. Border line effects in the transition zone of the areas and a changed forest infrastructure (wider distances between strip roads) increase complexity in deciding on suitable harvesting measures. In addition, there will probably be less timber volume per area in the future and the variety of assortments will also change, not least with regard to a shift in the ratio of saw logs to energy logs. These changes lead to a new situation not only for motor manual wood harvest, but also for the entire harvesting process and subsequent wood logistics chain. In order to overcome these challenges, wood harvesting processes must be developed and tested to meet the increasingly demanding conditions. In a first step of the project "BestHarvest", which was launched for this purpose, such wood harvesting methods are collected via interviews with harvest operation planners and other experts. These methods are then evaluated and modified in workshops if necessary in order to best comply with the aspects of "site protection", "occupational safety", "cost-effectiveness" and "ergonomics". In further steps, the modified wood harvesting processes will be tested in practical applications and evaluated again for the four aspects. As a result of the project, a selection of best practice procedures is expected to meet the various existing forest stand situations and nature conservation requirements. Time studies during the practical tests also provide better planning certainty in calculating the time and cost of the different procedures.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

UNLOCKING THE POTENTIAL OF HARVESTER ON BOARD COMPUTER DATA IN THE SOUTH AFRICAN FORESTRY VALUE CHAIN

Marius Terblanche, Pierre Ackerman*, Simon Ackerman
Department of Forestry and Wood Science
Faculty of Agri Science
Stellenbosch University
Private Bag X1, Matieland, 7602, South Africa

packer@sun.ac.za

Abstract:

South Africa is experiencing a rapid shift from semi-mechanized to fully mechanized cut-to-length harvesting operations. As a result, there is a marked increase of harvesters in the country, most of which are StanForD protocol compliant. This facilitates the collection of detailed tree and operational data. For various reasons, this data output is not being fully utilized by machine owners. From calibration of the on-board computing systems (OBC) it should be possible to accurately measure DBH and under bark volume, however this process is currently not fully understood and utilized in the South African plantation forestry context.
The objective of this study is to develop and apply a suitable bark deduction method for *Pinus patula* for South African conditions on the Ponsse Opti control system running on purpose built Ponsse harvesters. The StanForD protocol has preset functions to deduct bark volume and determine under-bark tree and log volumes, but these seem to not be adequate for South African conditions or plantation tree species.
This was accomplished through the modelling of historical *P. patula* bark thickness data from the Mpumalanga Highveld region to obtain the necessary bark thickness estimates for the two methods of bark deduction to be assessed that was available on the Ponsse Opti OBC system. Three trials were run: T1 (status quo no bark deduction function), T2 (length based (LB) bark deduction method) and T3 (diameter-class length based (DLB) bark deduction method). The two bark deduction methods were implemented successfully, and the harvester`s under bark diameter measurements compared with manual under bark diameter measurements which was derived through the novel application of photogrammetry technology. Results showed that if no bark deduction method is used the harvester overestimates stem volume by 13.68% and 14.59% for the length based and diameter-length based deduction methods respectively. Furthermore, the nature of *P. patula* bark being extremely thick on the base of the stem means this overestimation is even greater for but logs. The harvester overestimated the log volume of the first plywood log cut by 20.81% for Trial one, where through the implementation of a bark deduction method the volume estimation was improved to an underestimation of only 1.59% and 0.18% for trial two and three respectively. The results of this study shows that by not implementing bark deduction methods harvester`s log volume estimations are grossly overestimated and the usefulness of the harvester`s data for value chain management lost. This study is a first for South Africa.

Keywords: Bark thickness deduction, Harvester head calibration, Measurement accuracy, Volume estimation, StanForD, *Pinus patula*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

ESTIMATION OF FOREST ROAD NETWORK MAINTENANCE COST CONSIDERING COLLAPSE RISK: AN APPLICATION IN THE JAPAN MOUNTAINOUS REGION

Masaru Watanabe*, Masashi Saito, Hiroaki Shirasawa, Tatsuhito Ueki
Shinshu University Graduate School, Ina, Japan;
Minami Minowamura 8304 Nagano, Japan
18as411b@shinshu-u.ac.jp

Abstract: In Japan, predicting forest road maintenance cost requires essential considerations of the condition of road conditions due to the complexity of the geography of the terrain. With an aim to accurately predict the cost of maintaining forest roads that have collapsed, we constructed a generalized linear model designed to use recovery cost as a response variable and forest road feature values as predictor variables. With this model and an Akaike information criterion, the features and recovery unit cost of any forest road feature generally had the same relationship as did the features and the risk of collapse. We confirmed that trend from these results; however, all models show a low determining factor. Further work will be needed to convert geographic values into forest road features and a prediction method.

Keywords: Forest road, Recovery cost, Geomorphic quantities, Cost prediction

1. Introduction

Japan's land and climate conditions make its forest road network susceptible to damage by collapse caused by rainfall. Therefore, most forest roads, especially those under permanent use, require investment for maintenance cost in case they collapse. To develop forest road networks systematically, it is necessary to predict forest road maintenance costs due to collapse.

In Japan, the conditions of different forest road installations vary greatly due especially to the complexity of the country's terrain and geology. These conditions affect forest road maintenance cost. Therefore, considering the installation conditions for each road is an essential aspect of predicting the latter. However, no method has been previously established for predicting forest road maintenance cost based on installation conditions. As a result, it is uncertain exactly how much it will cost to maintain each forest road. The current method for forest road maintenance cost does not depend on installation conditions; instead, the average of past actual values or a uniform ratio is used to predict maintenance cost.

Considering maintenance costs expended to repair collapses (hereafter called "recovery cost"), we expect that the recovery cost for a certain road is considerably affected by its collapse risk. Recently in Japan, knowledge about the relationship between forest road installation conditions and its collapse risk have been accumulated. No study has yet analyzed the relationship between recovery cost and collapse risk or installation conditions extensively and comprehensively.

The aim of this study is to provide a predictive model of forest road recovery cost considering the collapse risk of each road. Here we report the results of constructing a model using recovery cost as a response variable and forest road feature values as predictor variables.

2. Research site and Methods

2.1 Research site

The target forest roads for the analysis were all located in the Nagano prefecture in Japan（Figure 1）. In this prefecture, data that are necessary for the analysis were well maintained.

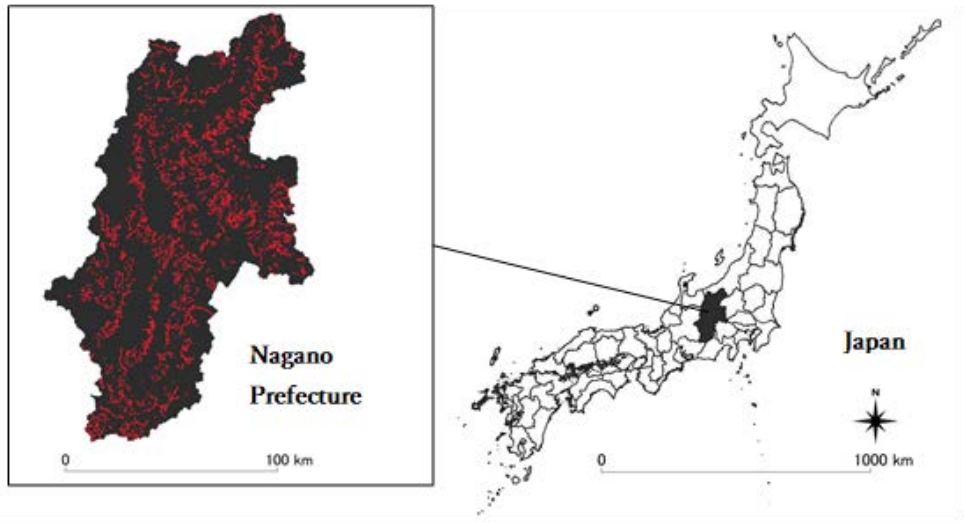


Figure 1 Research cite
Red lines indicate all forest roads in Nagano Prefecture

We used "forest road registry data", an administrative database of forest road management history, for forest road recovery cost data. In Japan, forest roads are public property and the government is required to record all data on forest road management. Recently, owing to computerization of these administrative data, a large amount of maintenance cost data can be obtained with relatively low effort. We obtained data on 1504 forest roads out of 1895 forest roads, which have been computerized from now on.

We used a digital elevation model (DEM) obtained from LiDAR to represent the topography of our study area. We resampled the original mesh size of 1 m to 5 m. We used a digitized geological map with a scale of 1:50000, saved as a shapefile, to represent regional geological and geographic data. We also used a shapefile to represent forest roads. We analyzed 1111 forest roads.

2.2 Tabulation of recovery cost

We tabulated 4 of the items recorded in the forest road registry; type of operation, operation year, operation cost, and operation extension. The type of operation was divided into seven groups; construction, disaster recovery, improvement, pavement, traffic safety, removal, and incorporation. Incorporation means a forest road incorporate part or entire of another for administrative convenience.

For this study, we defined disaster recovery cost as the recovery cost. For administrative reasons, disaster recovery is only applicable against collapse accompanied with damage to forest road facilities (such as slope structure, banks, and culverts). Therefore, the disaster cost does not include expenses due to recovery from collapse arising in slope without facilities. The reason why we could not include such expenses in the recovery cost is that this kind

of recovery work is defined as an improvement, and we could not differentiate them from the other improvement categories such as widening and work on longitudinal slope.

We converted the total recovery cost for each road into recovery cost per meter per year (hereinafter "recover unit cost (yen/(m year)"). Note that 1€≒120yen. Although the recovery unit cost could be converted more simply by dividing total recovery cost by the product of total extension and total duration, this study incorporated the extent and duration of each construction section on calculating the recovery unit cost using formula (1).

$$\frac{T}{\sum_{i=1}^{n}(d_i \times t_i)} \quad (1)$$

T: the total recovery cost (yen)
d_i: extension of i-th construction section
t_i: duration of i-th construction section

In addition, to convert recovery cost into present values we applied the construction cost deflator released by Ministry of Land, Infrastructure, Transport and Tourism. The deflator was relevant to the period 1951–2017. For that reason, 72 roads where disaster recovery had been done before 1950 were removed from consideration.

2.3 Acquisition of forest road features

It has been commonly known suggested by previous knowledge that a road section is likely to collapse under the following conditions:

- gradient is 30 degree and over (Yoshimura, Akahane and Kanzaki, 1995)
- having intersection of road and fault or boundary of geological
- deployed alongside a fault or boundary of geological
- passing corner geomorphic-like zero-order basin (Shirasawa et.al, 2018)
- having large cumulative flow (Iuchi, Oka and Teramoto, 2016)
- having high slope height (Kondou and Kamiya,1995)

Based on the above, we acquired the forest road features shown in Table 1. We accounted for each geomorphic quantity by making a raster of each one and associating these with each section of the road, which we divided into 5 m segments. After obtaining geomorphic quantities at each section, these were converted into values for each road unit; the mean, standard deviation, and ratio of sections with values above the thresholds.

Table 1 Forest road features

Each 5 m segment	each road	Abbreviation	unit
Gradient	Mean	Gm	degrees
	Standard deviation	Gs	degrees
	Rate of segment that is greater than or equal to 30 degrees	Gr	%
Average curvature	Standard deviation	Hs	rad/m
	Rate of segment that is less than 0	Hr	rad/m
Dissection height	Mean	DISm	m

	Rate of segment that is greater than or equal to 3.5 m	DISr	%
Dissection rate	Mean	R	m
Cumulative flow	Mean	Am	Cell number
	Rate of segment that is greater than or equal to 2000 m²	Ar	%
Zero-order basin	Rate of segment that is determined as a zero-order basin (gradient ≧ 30 degrees and average curvature < 0 and dissection height ≧ 3.5 m)	Zr	%
Geological crosses	Per meter	ISG	number/m
Distance from geological boundary	Mean	DistGm	m
Fault crosses	Per meter	ISF	number/m
Distance from fault	Mean	DistFm	m
-	Standard	Standard	1, 2, 3

Besides road features, there are several other features related to collapse risk: traffic volume, installation interval, and so forth. Since these features are hard to obtain extensively, we did not include them in this study. Finally, we constructed a generalized linear model (GLM) to predict recovery unit cost as a function of the values of forest road features.

3. Results and discussion

3.1 Distribution of recovery unit cost

Figure 2 shows the distribution of the recovery unit cost. The cost for about 40% of the 1111 analysis target roads is 0 yen/m year. As explained above, this distribution will be biased considerably by the fact that disaster recovery tabulated on this study did not include all collapses occurring on forest roads. Moreover, 98 roads were not included in this distribution, despite having experienced collapse, because of the difficulty of calculating present recovery unit cost due to the restriction imposed by the deflator and omission. Twenty-five percent of roads had a recovery unit cost between 0-100 yen/m year. Hence distribution of recovery unit cost biased tendency toward 0 to 100 yen/m year. About 96% of road recovery unit costs were less than 1000 yen/m year. The average recovery unit cost was 181 yen/m year. The median was 29 yen/m year. The standard deviation was 383 yen/m year.

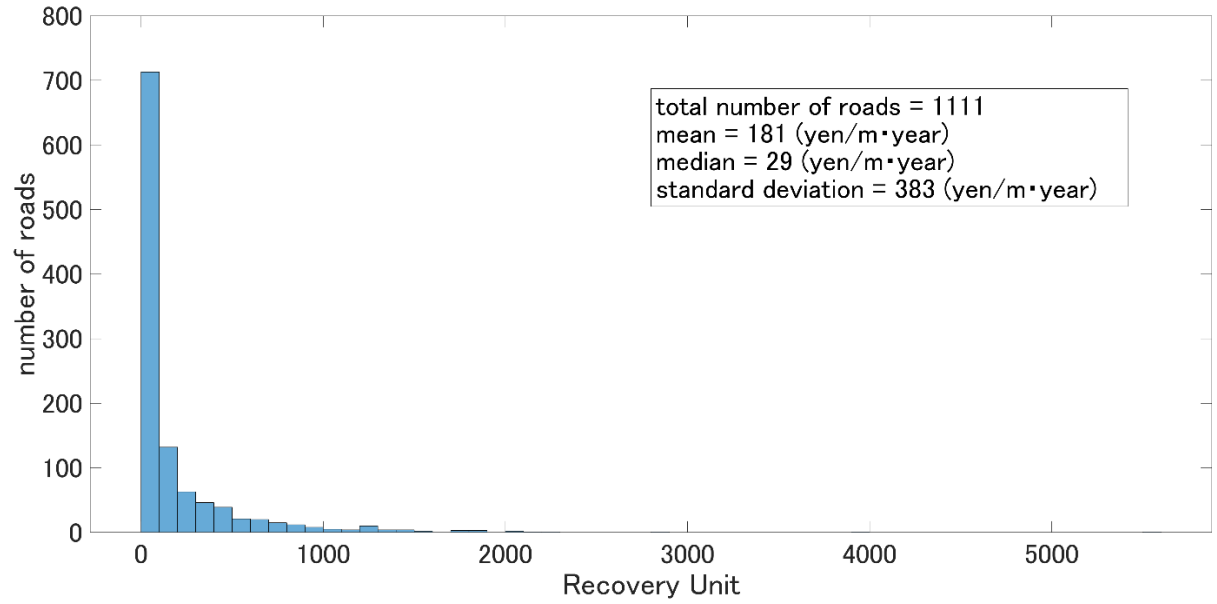


Figure 2 Distribution of recovery unit cost

3 .2 Feature selection

Figure 3 shows recovery unit costs for each standard. Black circles indicate the average and the horizon line in the box indicates the median for each standard. The p-value, as a result of one-factor ANOVA, was 0.02. We see that recovery unit cost differed from each standard. We assume the reason is that the higher standard a forest road is, the higher its slope height because of the necessity of securing width. Also, the higher standard a forest road is, the more likely it is to use facilities that are the target of disaster recovery efforts.

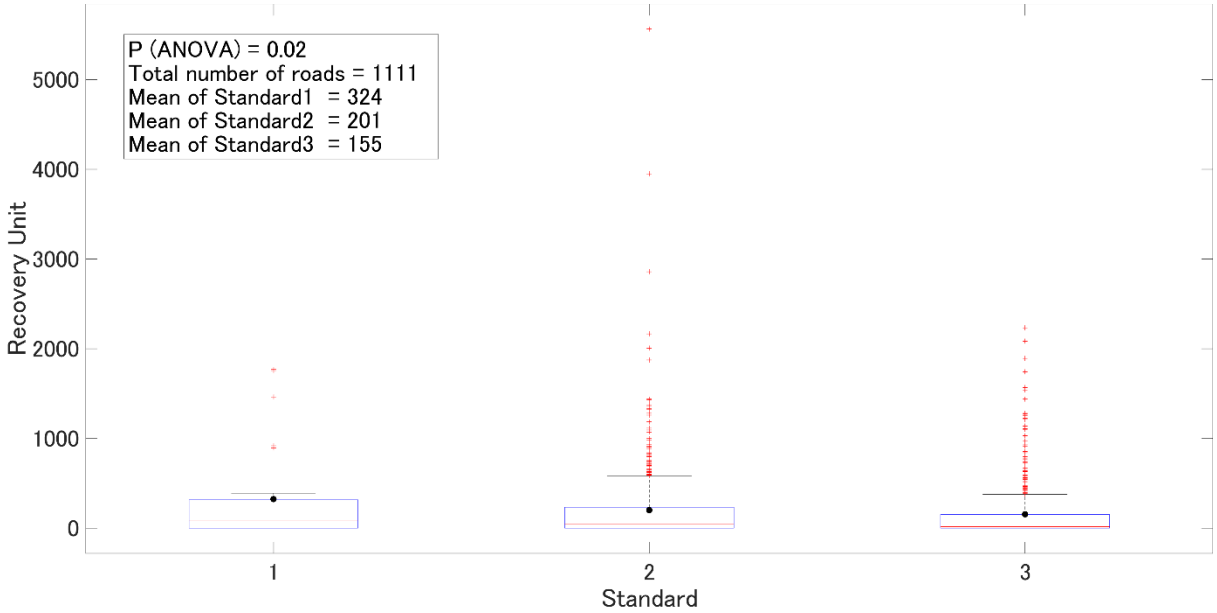


Figure 3 recovery unit cost for each standard

To reducing redundant features, we checked the relationship between forest road features and recovery unit cost (Figure 4) and between features. Within features, pairs of Gm-Gr and Rm-Hr showed high correlation coefficients. Therefore, we removed one of them, which had a lower correlation coefficient with recovery unit cost. Moreover, between features coming from the same geomorphic quantities, we removed the one with a lower correlation coefficient with recovery unit cost. Consequently, we used eight features as predictor variables: DISm, Zr, Hs, Gm, DistGm, DistFm, Am, and Standard.

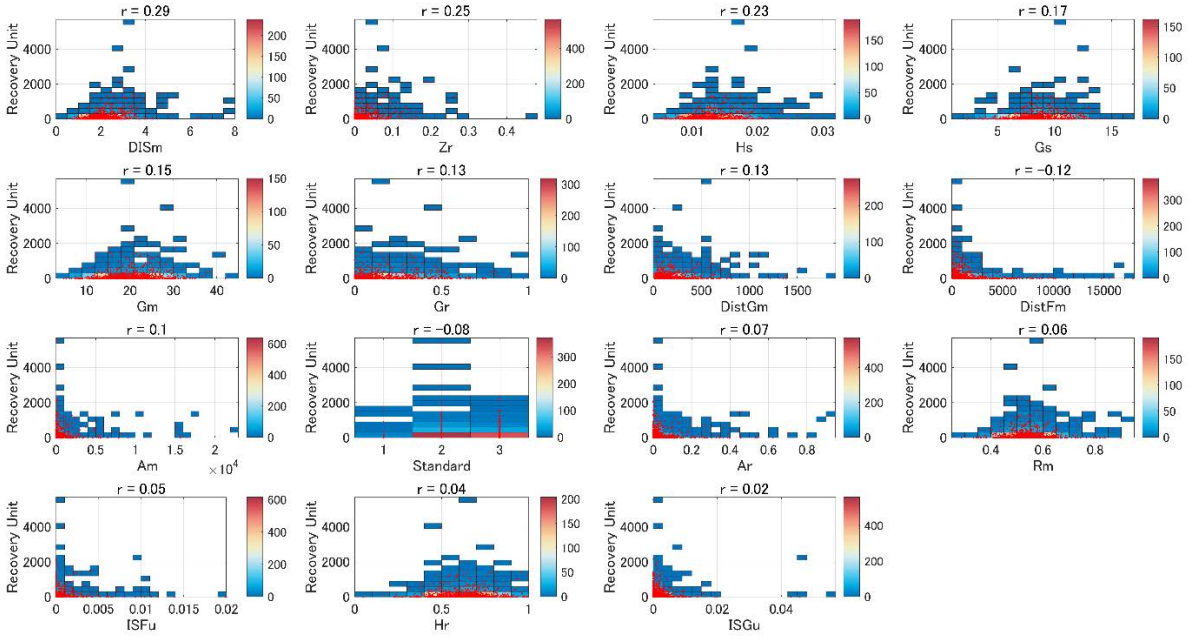


Figure 4 The relationship between forest road features and recovery unit cost

3.3 GLM

Considering practicability of prediction model, the number of predictor variables was up to three and interaction was not studied. On constructing the GLM, the normal distribution was specified as the distribution, and the log function was specified as the link function. Figures 5 to 7 show models including a constant term and one to three predictor variables that were top eight in terms of the Akaike information criterion. The R^2 value in each figure means determining factor with adjusted degrees of freedom.

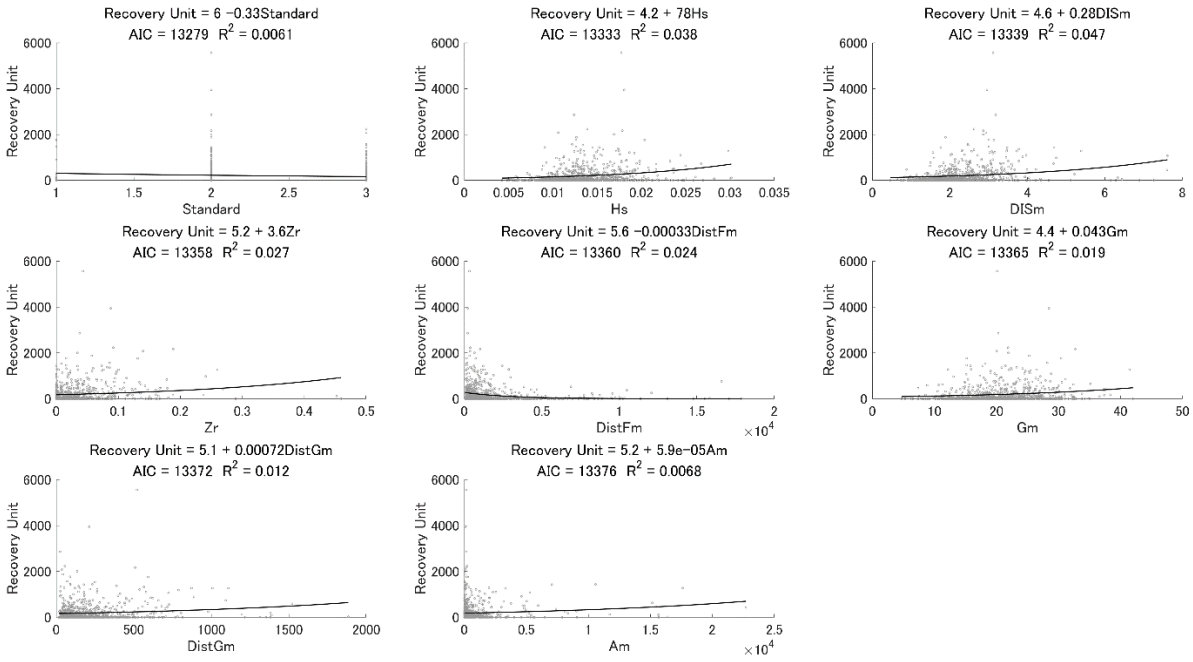


Figure 5 Models depended constant term and one predictor variable

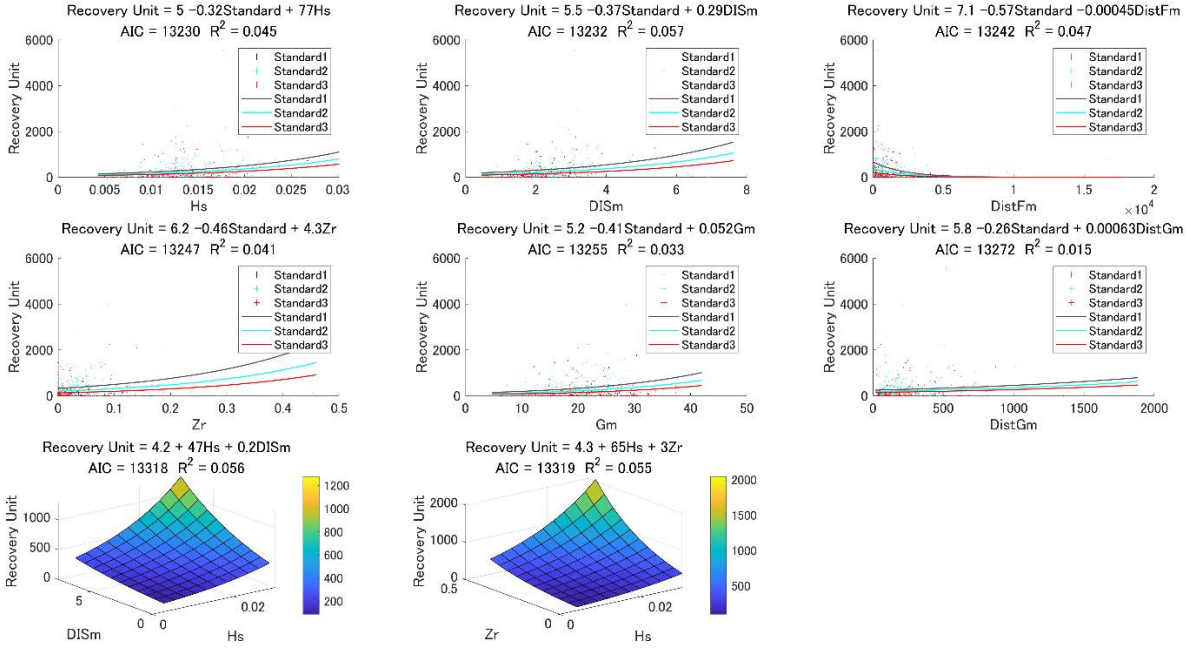


Figure 6 Models depended constant term and two predictor variables

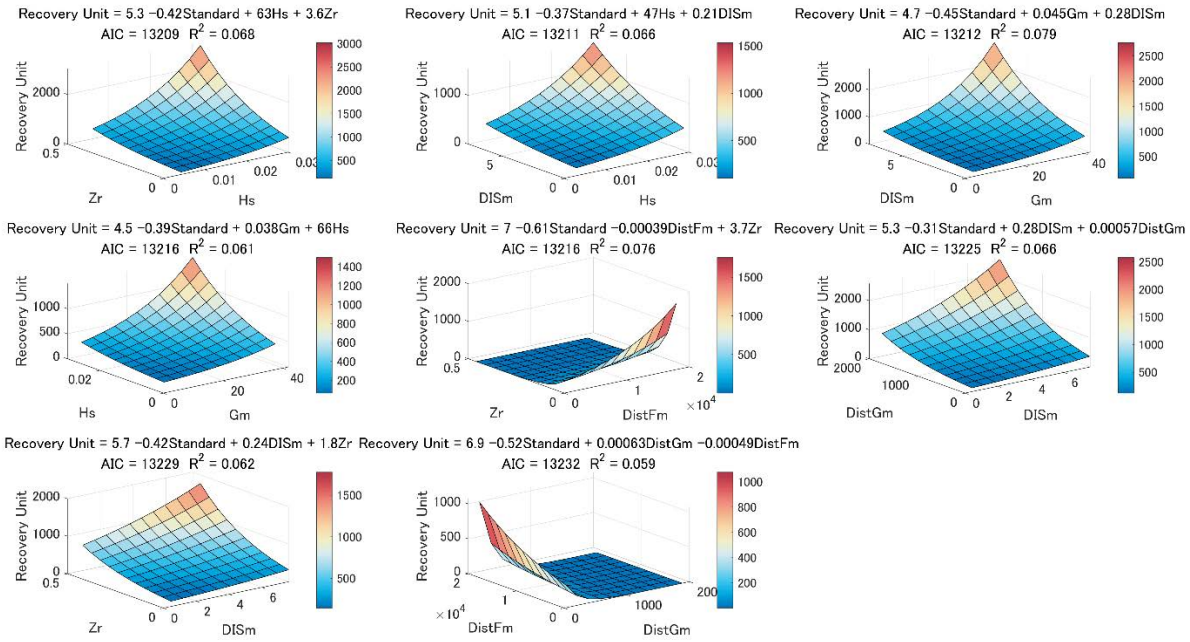


Figure 7　Models depended constant term and two predictor variables

Since all model include Standard as predictor value，these figures display prediction on condition Standard＝2

In any model, Standard, DISm, and Hs were especially selected as valid predictor variables. Except for DistGm, any forest road feature generally showed the same relationship between features and recovery unit cost (for instance the higher the dissection height is, the higher the recovery unit cost is) with relationship between features and collapse risk (for instance the higher the dissection height is, the higher the collapse risk is).

While we confirmed that trend from these results, all models show low determining factors. We recommend further study to convert geomorphic quantities into forest road features and improve the prediction method itself.

Acknowledgements

This work was supported by Ministry of Agriculture, Forestry and Fisheries Contract research 16783181.

References

Hiroaki Shirasawa, Masashi Saitou, Kenichirou Toda, Yasuyuki Tada, and Daimaru Hiromu. (2018), "Shallow landslide hazard assessment using high-resolution DEM for application on road alignment design,". J. Jpn. For. Eng. Soc. 33(2): 123–31.

Keiichi Kondou，Nobuhiro Kamiya. (1995), “ The analysis on the factors of forest road disasters in　the area of

Southern Akaishi Mountains,”. J. Jpn. For. Eng. Soc. 10（3）： 205～212.

Yoshihit Iuchi, Masaru Oka and Yukiyoshi Teramoto. (2016), “The presen tconditions and factor analysis of the forest road institution disaster in Amami Oshima,”. J. Jpn. For. Eng, Soc. 31 (1)：45～54.

Tetsuhiko Yoshimura, Gen Akanahane and Kouichi Kanzaki. (1995), “The evaluation of potential slope failure of forest roads using the fuzzy theory”. J. Jpn. For. Eng. Soc. (3)； 195～204.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

OAK LACE BUG IN EASTERN SLAVONIA (CROATIA), INTEGRATED FOREST PROTECTION IN FSC CERTIFIED FORESTS AND PRECAUTIONS IN OAK TIMBER PRODUCTION

Milivoj Franjević, Antonija Kolar, Andreja Đuka, Boris Hrašovec
Faculty of Forestry, University of Zagreb, Zagreb, Croatia
milivoj.franjevic@sumfak.hr

Abstract: *In FSC certified oak stands of Eastern Slavonia oak timber production is compromised by series of negative biotic and abiotic factors. Rapid spread and high population level of invasive alien species oak lace bug Corythucha arcuata (Heteroptera, Tingidae) in Croatia form 2013. onward is one of factors that contributes to concerns by forest operatives and forest protection specialists alike. Many questions arrived with new pest: what are the pathways for spread of this pest and an assessment of how well adults overwinter, do the infested trees suffer from tree mortality, reduced growth and/or reduced acorn production/germination? Are the effects more of an aesthetic issue with trees turning brown earlier than usual with relatively little impact on tree growth, or are impacts only detectable over longer periods of time? Is there any evidence that oak trees or stands of oak trees infested with C. arcuata are more susceptible to other pests and pathogens? For better understanding and developing of strategies for integrated pest management of C. arcuata from summer of 2017 until 2019 series of oak lace bug suppression tests were conducted including areal treatment, terrestrial spraying, tree infusion with insecticides, oak seed tests in nurseries and cardboard ring application on overwintering adults. During this trials only FSC certified insecticides were used and they were applied in experimental purposes. Nevertheless experimental aerial oak lace bug suppression showed weak results because oak lace bug was resistant to insecticide certified for application. Injectioning with insecticides is promising in some objects as oak seed orchards although in first season of testing with mixed results. Oak seed tests did not show established pattern between C. arcuata infested seed locations and control locations. Overall poor seed quality had greater impact on seed germination and it is unclear if oak lace bug influences seed germination, growth and quality. C. arcuata suppression of overwintering adults showed good results in oak seed orchards because of bark structure and proximity of branches but not in old stands were protection is marginal.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

THE EFFECT OF TREE PLANTATION-MANAGING TECHNOLOGIES ON BIODIVERSITY

Nóra Szigeti - Imre Czupy - Andrea Vágvölgyi
Institute of Forest- and Environmental Techniques
University of Sopron
Bajcsy-Zs. Street 4, H-9400 Sopron, Hungary
szigeti.nora@uni-sopron.hu

Abstract: *Forest plantations provide opportunity to produce a huge amount of biomass for industrial or energetic purposes. These plantations differ from natural forest in their regular planting network, the used propagating material, and while their cropping technology is almost fully mechanized. Certain operations can repeat for years, or many times a year. As an effect of these features, their wildlife community differs from natural forests too. Some them are important for game management and nature conservation too, offering an ecological corridor for many insect, bird and small mammal species. However, resource fluctuations and disturbance, and the combination of these factors has a synergistic effect on plant invasion. Depending on the rotation, the planted tree species and the structure of the plantation, these biomes can offer nutrition, hiding and living opportunities for several species, which are adapted to agricultural environment.*

Keywords: dendromass, tree plantation, managing technologies, biodiversity

1. Introduction

Agricultural tree plantations can have a positive impact on farming and quality of life in different ways. These impacts, according to Moreno et al. (2016), Vityi and Marosvölgyi (2014) and Westaway et al. (2016) are:
- carbon sequestration,
- water and soil protection,
- preserving biodiversity
- landscape diversity that also influences recreational opportunities
- creating a specific microclimate through windbreaking effect
- proving shade and protection for farm and wild animals
- broadening the income potential of farming
- ensuring the maintenance of farming in unfavorable conditions and protected areas
- habitat expansion of the natural enemies of pests and pathogens,
- beekeeping significance.

On the tree plantations a huge amount of dendromass can be achieved in a short time for energy or industrial purposes.

The aim of this study is to review the effects of tree plantations on biodiversity and the parameters that influence it.
Tree plantations are created for different purposes, the most commons of which are (but are not limited to):

- biotechnical engineering systems to reduce environmental or human impact (eg erosion, pollution or odor control);
-urban plantations due to their favorable microclimatic effects;
-roadside plantations to optically facilitate driving, accident prevention and snow blowing;
-soil protection plantations in damaged areas;
- or for industrial, energy purposes.
Different functions are not always clearly distinguished: a road or farm plantation can serve both climatic and accident prevention purposes, and the wood of a soil protection plantation can be utilized for industrial and energy purposes (Kiss-Szigeti, 2012).
Naturally, the reason for implementing a tree plantation strongly influences its appearance, characteristics, such as the size and shape, structure, age, management, so they cannot be analyzed uniformlyin terms of biodiversity. This study presents the characteristics of the fauna of the short rotation, energy and industrial tree plantations and the factors influencing it.

2. Types and characteristics of energetic purpose tree plantations

The energy plantations are classified according to the new Hungarian law:
- rolling energy plantation: there are kept up to 20 years, intended for energy recovery (Figure 1.);
- copping energy plantation: there are at most 5 years of rotation, intended for energy recovery;
- woody industrial plantation: for the production of wood raw material. (135/2017 (VI. 9.) Decree)



Figure 1. 7 years old rolling poplar energy plantation (Vágvölgyi et al., 2016)

The nature protecting relevance of energy plantations and industrial plantations is justified by the fact that the extraction of this type of wood demand would put enormous pressure on the remaining semi-natural forests. In developing countries, there is a growing need to preserve the natural forest environment, which can often only be achieved by eliminating (severely reducing) logging. Therefore, the satisfaction of the wood demand can be achieved by implementing tree plantations (Vágvölgyi, 2013).

Regarding to biodiversity, the tree species composition and the structure of the plantation are also extremely important. The most commonly planted tree species are willow and poplar species and clones and acacia.

Table 1. List of permitted tree species of short rotation coppice in Hungary

135/2017 (VI. 9.) Decree
Poplar species / Populus spp./
Water willow / *Salix viminalis/*, White willow /Salix alba/
Black locust / *Robinia pseudoacacia/*
Common alder / *Alnus glutinosa/*
Common ash / *Fraxinus excelsior/*
Hungarian ash /Fraxinus angustifolia danubialis/
Red oak / *Quercus rubra/*
Walnut species /Juglans spp./
Norway maple / *Acer platanoides/*

The area of rolling energy plantation for energy or industrial purposes is thousands of hectares in Hungary, the area of short rotation coppices is area more than 4000 ha (Szalay, 2018). Figure 2. shows the area characteristics by year.

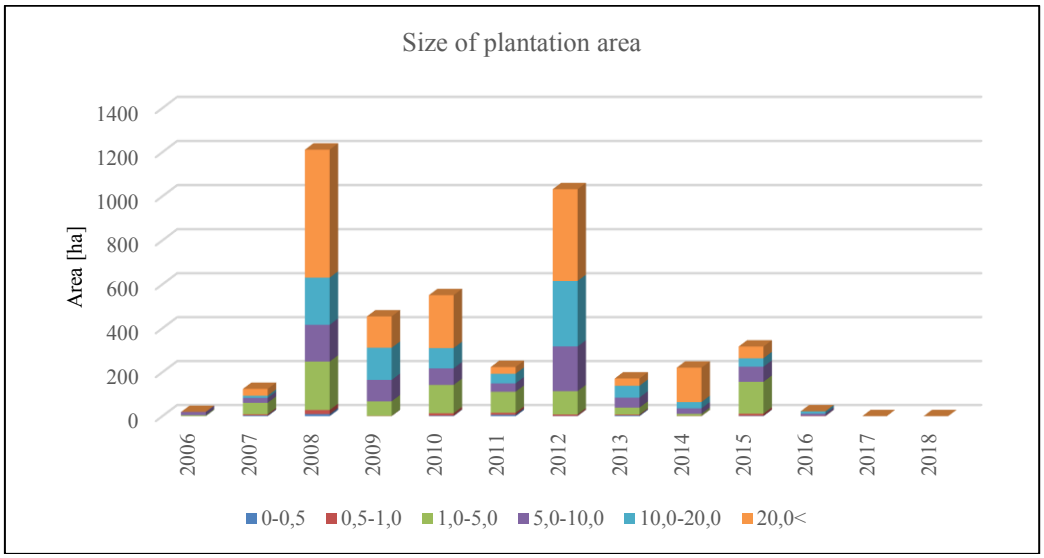


Figure 2. Area of established plantations [ha] depending on available support (Szalay et al., 2019)

Cultivation technologies of tree plantations may differ in several points from forest technologies. Figure 3. shows the ooperations and machines of energetic tree plantation technologies.

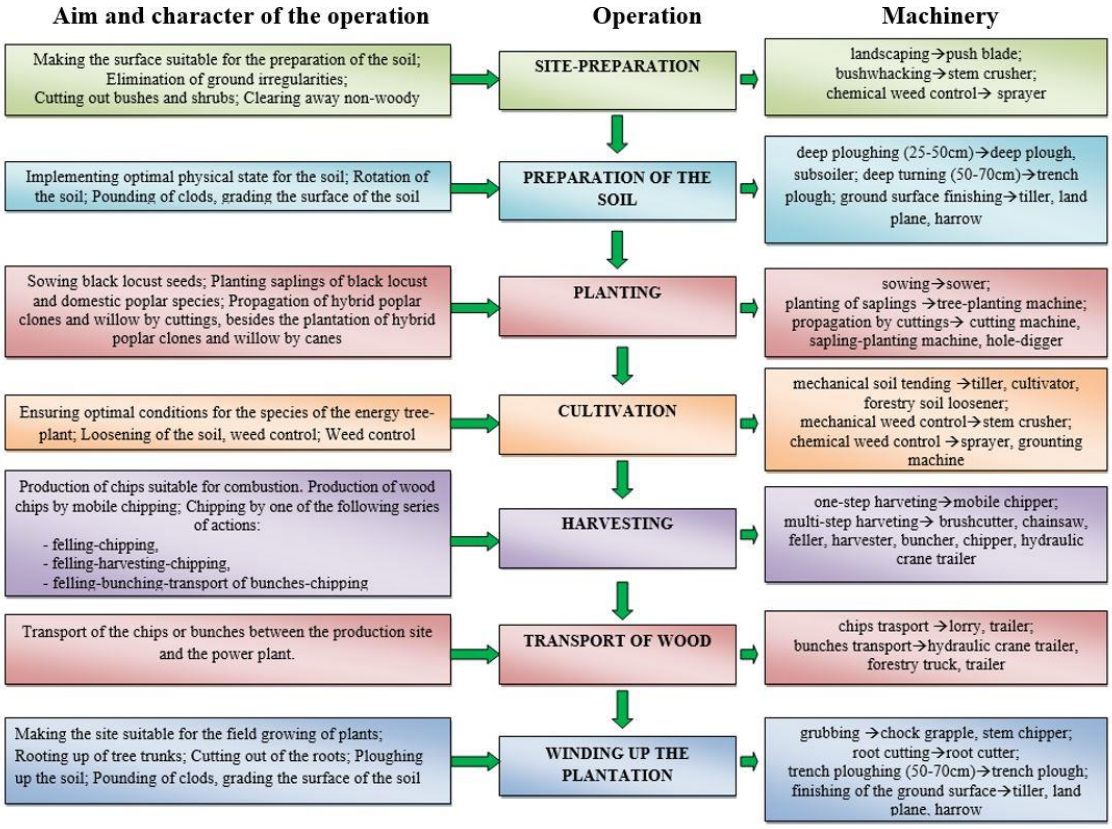


Figure 3. Operations and machines of energy tree plantation technologies (based on Czupy et al., 2012)

The size of the plantation determines the applicable technologies of management. On the small tree plantation (maximum 3-5 ha) manual planting and harvesting are profitable. With the growing size, need for bigger mechanization in the technology occur.
The rotation of tree plantations may differ: in case of plantations for energy purpose the rotation is maximum 5 years. This means, the plantation can be harvested in the age of 1 ,2, 3 years but the rotation time is maximum 5 years. In the case of rolling and woody industrial plantations the rotation period grows. The cultivation works are inevitable at least in the first two years of the plantations. In case of failing any management activities, weed competition can ruin the plantation.

3. Biodiversity in short rotation coppices

While natural ecosystems are self-regulating, high-stability systems under normal circumstances, that survive for decades and centuries, whereas the stability of man-sustained plant cultures is generally low Godó (2011). The perception of tree plantations in terms of their wildlife is very different in Hungarian and international literature, partly depending on the examined communities, and the ecosystem, they are compared with. If the plantation is located in an agricultural area, it is not worth comparing biodiversity with semi-natural habitats, but with intensively cultivated fields.
Biodiversity is one of the most fundamental aspects of evaluating and interpreting wildlife today. We try to cover the richness of life forms with this single expression (Mátyás, 2005).
The Convention on Biological Diversity defines: “Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems” (UN, 1992).

Diversity is increasingly and widely recognized, not only as a feature of association, but also as an intrinsic value, the preservation of which is a privileged task of nature conservation. Diversity plays a fundamental role in the formation and maintenance of the stability and complexity of ecosystems. Therefore, maintaining the diversity represented by the natural flora and fauna is vital for the survival of wildlife.

According to Mátyás (2005), tree plantations are worthless both in terms of maintaining species richness and habitat creation. For example, with regard to the vegetation of poplar plantations, forest species are usually not found in the understory layer due to the light conditions of the wide plantation network, regular tillage and short rotation. Frequently cultivated rows are dominated annual and biennial disturbance-tolerant species, while the less unraveled rows produce perennial, disturbance-tolerant ("weed") species. In case of failing agrotechnical interventions, also the perennials are colonizing.

According to Kölcsei (2015), European bioenergy plantations are considered to have a negative impact on the fauna in general, due to decreasing the area of animal distribution (habitat), the size of populations and the decline of species richness and increased invasion of alien species. The implementation of bioenergy plantations has a negative impact on 28% of species and a positive impact on 10%. These effects, of course, vary by animal species.

In contrast, Felton et al. (2016), based on observations in Sweden, found that the bird community of some industrial oak plantations is partially similar in composition and species richness (34 species) to protected oak forests (39 species). In addition, several endangered bird species (Dryocopus martius, Regulus regulus, Sturnus vulgaris, Emberiza citrinella) were observed during the survey. Although oak plantations cannot replace habitats provided by protected oak forests, these populations appear to provide conditions that are consistent with the diverse habitat and resource requirements of bird species, including species of high conservation value. According to them, industrial oak plantations have the potential to contribute positively to the conservation of biodiversity.

According to Liebhard (2009), especially in drier climate regions, they can contribute to the interconnection of living space systems as a green corridor. Thanks to their year-round mulching effect, they can provide shelter and provide nutrition opportunities for a part of wildlife. In particular, number of species and individuals of insects and birds can be increased in agricultural areas, with tree plantations. Similarly, a plantation on an agricultural area promotes the re-appearance of spiders. This effect is especially true if only part of the plantation area is harvested at one time, resulting in populations of different ages, and where wildlife is sheltered in undisturbed areas. A small water biotope adds further ecological value to the area. The positive effect on the edge of the plantation can be further enhanced by the creation of a less disturbed or untreated band with native species appropriate to the climatic and soil conditions. Many of these native tree species are favorable even for bees and pollinating organisms by extending the feeding and pollen collecting ability (Somogyi, 2014).

Verheyen et al. (2014) compared the flora and insect community of ten short rotation plantations with maize control areas. Significant differences were found in each plantation-cornfield comparison, both in terms of plant cover and species diversity in favor of plantations. In many cases the density of arthropods was almost double in the woody association than in the maize. In the case of functional groups, there were higher species numbers for each role. Predator communities of particular importance for plant protection appeared in the plantation with a better distribution and higher diversity of species. Overall, it has been found that tree plantations can significantly increase the diversity of plant and arthropod communities in an agricultural environment.

Müller et al. (2017) examined the relationship between the genetic diversity of planted willow species and the diversity of wildlife in plantations. According to the results of their experiments, by increasing the genetic diversity of willow, the species richness of arthropods, including herbivorous communities, increases significantly. Thus, a short rotation plantation of several varieties can contribute to the preservation of the diversity of the insect community.

Faragó (1997) found, that in Hungary, both weaving willow and short rotation coppice are considered to be acceptable habitats for small game. These plantations are implemented on nutrient-rich soils with favourable moisture conditions, and maintained for 10-15 (-20) years, which results habitats for long term. The vegetation structure is excellent for pheasants and hares. Harvesting is possible at any time from November to the end of February, extensively managed willow colonies provide protection and adequate nutrition for the small game almost throughout the year, and are almost undisturbed during the breeding period. Short rotation coppice rotations are treated with a 4-year rotation and, from the second year, provide an undisturbed hiding, resting and feeding area for wildlife, especially with permanent chemical-free technology.

Westaway et al. (2016), studying the utilization of biomass for agricultural production in the lowlands of northern Europe and its effects on (among other) biodiversity, found that hedges used for biomass-based fuel production have both positive and negative effects. on farm and landscape level. Even the smallest technological change is a significant factor in terms of biodiversity: the landscape relationships of the hedge, the density of the network, the density of the stem, the structure, etc. primarily influence the living community.
Similarly, according to Weih (2008), tree plantations can have both positive and negative effects on biodiversity, depending on location, management and land use prior to planting. In addition, many animal species use habitat systems, so their presence depends on the correct habitat combination. In this way, the diversity of land use in the landscape also strongly influences the diversity of plantation habitat.
According to Weih (2008), while compared to mixed coniferous forests, the diversity of flora is lower in young willow and poplar plantations, whereas it is larger in comparison with single-species treated pine forests.
The mammalian and bird communities of willow and poplar hybrid tree plantations are significantly more diverse than those of agricultural crops. These habitats are especially important for predator birds.
Of course, the cultivation of adjacent habitats is also decisive in the plantation's wildlife. A semi-natural forest facilitates the migration of plants, insects and birds, thus increasing the biodiversity of the plantation. Even a native tree or group of trees close to the plantation can provide temporary shelter for the wildlife while the plantation is under intensive management.
In larger plantations, the use of some plots in different years increases the structural and biological diversity. A similar goal is achieved by establishing many smaller plantations that are not harvested in the same year. In addition, these solutions also facilitate biological control of herbivorous insects, which is one of the cornerstones of plantation management.
Likewise, diversity of structure, and plant and animal communities, increases and the importance of weeds and diseases reduces when different species, varieties, or their combinations are placed in the blocks or rows. Finally, a few meters wide field left on the edges of tree plantations supports the settlement of various plant and animal species.
Overall, a well-designed, not too large, short-rotation tree plantation can increase biodiversity, number of species numbers and individuals, especially in intensive agricultural landscapes. On the other hand, such plantations should be avoided in the vicinity of wetlands or other, high nature value areas, as the value of such habitats is often due to their openness.
With these restrictions, implementing a tree plantation can be a good solution to supplement food production in agricultural landscapes and increase the variety of production.

4. Summary

Summarizing the above research results, we can see that the location of the plantation is of primary importance in assessing the impact of short rotation tree plantations on biodiversity. When replacing a natural forest or other high value association, intensive management resulting disturbance, and poor species and structural diversity have a severe negative effect on biodiversity.
There is a completely different perception of arable tree plantations, which can provide shelter and food primarily for bird and insect communities in monoculture systems.
If ecological regards are taken into consideration during implementation, great results and effort to conserve biodiversity can be achieved with little loss of space. A less intensively managed band with native tree species, a small water biotope, and wood harvesting shifted in time are beneficial not only for biodiversity but also for landscape. In addition, woody associations established in the agricultural area also have a beneficial effect on the microclimate, diversify the production, provide the region with additional income and employment opportunities, and promote a better distribution of income over time.

5. Acknowledgement

The described work was carried out as part of the „Sustainable Raw Material Management Thematic Network – RING 2017”, EFOP-3.6.2-16-2017-00010 project in the framework of the Széchenyi 2020 Program. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

6. References

Czupy, I., Vágvölgyi, A. and Horváth, B. (2012) “The Biomass Production and its Technical Backgorund in Hungary.” Proceedings of 45th International Simposium on Forestry Mechanization: "Forest Engineering: Concern, Knowledge and Accountability in Today's Environment". Dubrovnik; Cavtat, Horvátország. ISBN: 978-953-292-025-3. 1-9.

Faragó, S. (1997) Élőhelyfejlesztés az apróvad-gazdálkodásban: A fenntartható apróvad-gazdálkodás környezeti alapjai. Mezőgazda Kiadó, Budapest

Felton, A., Hedwall, P.O., Lindbladh, M., Nyberg T., Holmström, E., Wallin, I., Löf, M. and Brunet, J. (2016) “The biodiversity contribution of wood plantations: Contrasting the bird communities of Sweden’s protected and production oak forests.” Forest Ecology and Management Vol 365, 51-60. DOI: 10.1016/j.foreco.2016.01.030

Godó Z. (2011) Agro-ökológia. Digitális tankönyvtár.

Kiss-Szigeti, N. (2012) Mérnökbiológiai létesítmények környezetvédelmi alkalmazhatóságának vizsgálata. Varga G. (szerk.) Környezeti Kutatások 2008-2012. Nyugat-magyarországi Egyetem Kooperációs Kutatási Központ Nonprofit Kft.

Keserű, Zs. (2014) “Agroerdészet Magyarországon.” Erdészeti lapok CXLIX, 2, 49-50.

Kölcsei, T. (2015) Bioenergia-ültetvény és a biodiverzitás. Agroinform.hu

Mátyás, Cs. (2005) Erdészeti ökológia. Mezőgazda Kiadó, Bp.

Moreno, G., Berg, S., Burgess, PJ., Camilli, F., Crous-Duran, J., Franca, A., Hao, H., Hartel, T., Lind, T., Mirck, J., Palma, J., Pantera, A., Paula, J.A., Pisanelli, A., Rolo, V., Seddaiu, G., Thenail, C., Tsonkova, P., Upson, M., Valinger, E., Varga, A., Viaud, V. and Vityi, A. (2016) “Agroforestry systems of high natural and cultural value in Europe: constraints, challenges and proposal for the future.” 3rd European Agroforestry Conference Montpellier, France. Book of Abstracts 24-27.

Müller, M., Klein, A-M., Scherer-Lorenzen, M., Nock, C. A. and Staab, M. (2017) “Tree genetic diversity increases arthropod diversity in willow short rotation coppice.” Biomass and Bioenergy Vol. 108, 338-344. DOI: 10.1016/j.biombioe.2017.12.001

Pásztor, E. and Oborny, B. (2007): Ökológia. Nemzeti Tankönyvkiadó, Bp.

Szalay, D. (2018) “Energetikai célú dendromassza termesztés és hasznosítás lehetséges szerepe a lignocellulóz biohajtóanyag üzemem alapanyag ellátásában.” Doktori értekezés. Soproni Egyetem. Sopron, 151.

Szalay, D. Kertész, Sz., Vágvölgyi, A. (2019) “Changes in the legal and support background of woody energy plantations”. Analecta Technica Szegedinensia 13, 72-81. ISSN 2064-7964

Vágvölgyi, A. (2013): Fás szárú energetikai ültetvények helyzete Magyarországon napjainkig; Üzemeltetésük, hasznosításuk alternatívái. Doktori értekezés. Nyugat-magyarországi Egyetem, Sopron.

Vágvölgyi, A., Fehér, S., Horváth, B., Komán, Sz., Kovács, G., Szabó, L., Czupy, I., Grigorev, I., Grigoreva, O., Danilov, D., Kunickaja, O. and Krivash, E. (2016) Virascivanie I Ekspluatacia Lesnih Plantacij. Nyugat-magyarországi Egyetem könyvkiadó, Sopron, 132. ISBN: 9789633343029

Verheyen K., Buggenhout M., Vangansbeke P., Dobbelaere A. D., Verdonckt P. and Bonte D. (2014): “Potential of Short Rotation Coppice plantations to reinforce functional biodiversity in agricultural landscapes.” Biomass and Bioenergy. Vol 67, 435-442. DOI: 10.1016/j.biombioe.2014.05.021

Vityi, A., Marosvölgyi, B. (2014): Agroerdészet egykor és ma Agroforum 25, 10.

Weih, M. (2008) “Short rotation forestry (SRF) on agricultural land and its possibilities for sustainable energy supply.” Nordic Council of Ministers, Copenhagen. ISBN: 978-92-893-1695-8 (print)

Westaway S., Crossland EM., Chambers EM., Gerrard C., Smith J. (2016) “Does harvesting hedges for woodfuel conflict with their delivery of other ecosystem services?” 3rd European Agroforestry Conference Montpellier, France. Book of Abstracts 54-57.

UN 1992: Convention On Biological Diversity

135/2017. (VI.9.) Kormányrendelet a fás szárú ültetvényekről

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

TIMBER HARVESTS DUE TO BIOTIC AND ABIOTIC DAMAGE BY THE EXAMPLE OF EGERERDŐ PLC

Viktória Papp [1], László Babiczki [2], Szilárd Grédics [2], Dóra Szalay [1]
[1]Institute of Forest - and Environmental Techniques
Faculty of Forestry
University of Sopron
Bajcsi-Zs. Street. 4. 9400, Sopron, Hungary
papp.viktoria@uni-sopron.hu

Abstract: *As an indirect consequence of climate change, the rate of biotic and abiotic damage is also increasing across Europe. Drought, which is becoming more frequent and prolonged, causes the greatest damage in young seedlings. The unusual weather events of recent years have also left significant losses in mature tree stand. The area of Egererdő Plc. is placed in Hungary's largest forest covered mountainous landscape with three different facets of the Northern Mountains. This area belongs to the forest management area in Mátra, in the western part of Bükk and in the Heves-Borsod Hills. In the above-mentioned areas, ranging from forest steppe to beech-climate forest, they manage diverse forest stands. As regards the distribution of growing stock oak 36%, beech 29%, European-Turkey oak 17%, hornbeam 7%, pine and fir 7%, acacia 1%, other 3%. In the course of the research, data were collected and processed about the harvesting due to damage events in the territory of Egererdő Plc. for the last 15 years. It can be observed that in the last four or five years, as a result of ice damage and spring snowfalls, the beech(Fagus sylvatica) stock have suffered significant damage. The drought and the winter average temperature increases is also favorable to pests and insects. Significant wood mortality is also observed in pine and spurce trees due to both biotic and abiotic events. On the basis of emergency felling, beech, oak and pine trees suffered the most damage, and forced production significantly increased in the years following the abiotic damage. Ice, storm and wind damage coused harvest is a big challange for foresters, which require innovative mechanization solutions.*

Keywords: abiotic damage, emergency felling, beech, spurce, fir,

1. Introduction

The rate of biotic and abiotic forest damage increased worldwide in recent years. Rising average temperatures, lack of rain and shifts in time indirectly favor pests. According to the meteorological data, the number of havaria events has also increased significantly in recent years. New data show that extreme weather events have become more frequent over the past 36 years(EAESAC 2018) In addition to temperature and water availability, a wide range of other climate-related variables were associated with disturbance change, ranging from wind speed and atmospheric moisture content to snow pack and atmospheric CO_2 concentration(Seidl R. et al 2017). The increasing frequency and intensity of extreme weather, such as droughts, long periods of high temperature, strong winds, heavy rains, and floods, increase the susceptibility of trees to physical damage, disease, and pests(Sierota Z. et al 2019).

In addition, climate change can affect the developmental cycles of pathogenic organisms, which in turn may increase threats to trees (Jaworski, T.2013) (Hilszczański, J. 2014) Infestations of the European spruce bark beetle (*Ips typographus*), which is the most devastating biotic disturbance agent in forests of central Europe, are often triggered by storm damage. The understanding of spatio-temporal bark beetle dynamics at fine scales is still limited(Sedelman et al. 2014)

Firstly, local microclimate not only has influences on tree physiology and resistance, but also has direct effects on the prevalence of hazards. For example, high temperature and prolonged drought induce physiological stress in trees and at the same time are favourable to the development of pest insects and increase the frequency and severity of fires. Cool and wet conditions are often beneficial to fungal pathogens and of course more frequent strong winds increase the risk of damage.(Hervé Jactel et al. 2009) Disturbances such as storm damage and bark beetle infestations affect the development of forest ecosystems and are therefore key factors in forest dynamics and long-term succession (Ayres and Lombardero, 2000, Dale et al., 2001).

The frequency of droughts in Hungary has also increased over the last 50 years. In addition to the increasing trend, extreme droughts became increasingly common in the second half of the period. In close connection with this, the drought damage in our forests also increased significantly. Annually reported drought damage showed a very close, significant correlation with the annual values of the two drought indices examined (Pálfai's and Forestry Aridity Index). These correlations were exponential in both drought index(Hirka et al). Unlike before, drought damage has recently occurred not only in lowland young stands but also in older, indigenous tree stocks in the mountains. Drought plays a decisive role in the health status of Sessile oak(Quercus petraea) and beech(Fagus sylvatica)(Hirka et al 2018).

There are different ways to assess the forest damage.For example, GIS monitoring based on leaf color, examination of designated areas, or field sampling. Forest damage is a complex problem involving the interaction of exposures to acids and other air pollutants, forestry practices, and naturally occurring soil conditions.(Fund. ment of air pollution 2014)

In its annual reports, the ICP summarizes the state of Europe's forests, which also shows an increase in the proportion of damaged stocks. The transnational defoliation survey in 2017 was conducted on 5 496 plots in 26 countries. In total, 101 779 trees were assessed in the field for defoliation. The overall mean defoliation for all species was 21.7% in 2017; there was a slight increase in defoliation for both conifers and broadleaves in comparison with 2016. Broadleaved trees showed a higher mean defoliation than coniferous trees (22.7% vs. 20.7%). Among the main tree species and tree species groups, evergreen oaks and deciduous temperate oaks displayed the highest mean defoliation (28.1% and 23.9%, respectively). In 2017, damage cause assessments were carried out on 100 436 trees on 5 358 plots in 25 countries. On 47 948 trees (47.7%) at least one symptom of damage was found, and 595 trees (0.6%) were dead. (ICP 2017)

Insects were the predominant cause of damage and responsible for 26.9% of all recorded damage symptoms. Almost half of the symptoms caused by insects were attributed to defoliators (49.0%), the most frequent of all specified damage causes.Abiotic agents were the second major causal agent group responsible for 19.1% of all damage symptoms. Within this agent group, more than half ofthe symptoms (58.4%) were attributed to drought, while snow and ice caused 7.3%, wind 6.7%, and frost 5.0% of the symptoms.(ICP 2017)

Due to the various abiotic damage events, changes are also observed in logging . For example, Slovenia was hit by a major ice storm in late January 2014. Lasting ten days and coating vast swathes of the country in thick glaze ice, the extreme weather event left deep scars on Slovenian forests that remain painfully visible. Six million cubic metres of wood had to be felled as a direct consequence of the glaze ice, more than the typical annual nation-wide wood harvest, with an almost three million cubic metres more left to rot in forests.(Slovenian Forest Survive 2018)

Since 2012, the state of health of forests in Hungary continued deterioration observed. This process has intensified over the past two years: in 2018, less than 60% of the trees examined were classified as healthy or slightly damaged. In 2018, only 26.5% of all sample trees were asymptomatic, meaning that the number of healthy individuals decreased further in leaf loss compared to previous year. The proportion of endangered trees was 26.2%, that of moderately damaged individuals was 36.5%, and that of severely damaged trees was 8.8%. There was no significant change in the percentage of dead trees (2%).(Nébih 2019) In 2018, there was no significant change in trunk damage compared to last year: 63.4% of the sample trees were asymptomatic, 22.2% were endangered, 12.1% were moderately damaged and 2.2% was in a severely damaged category. When evaluating the data, it should be borne in mind that bark injuries are

more difficult to heal, last longer (unlike, for example, annual foliage renewal), so that cumulative damage data is reported year by year.(Nébih 2019)

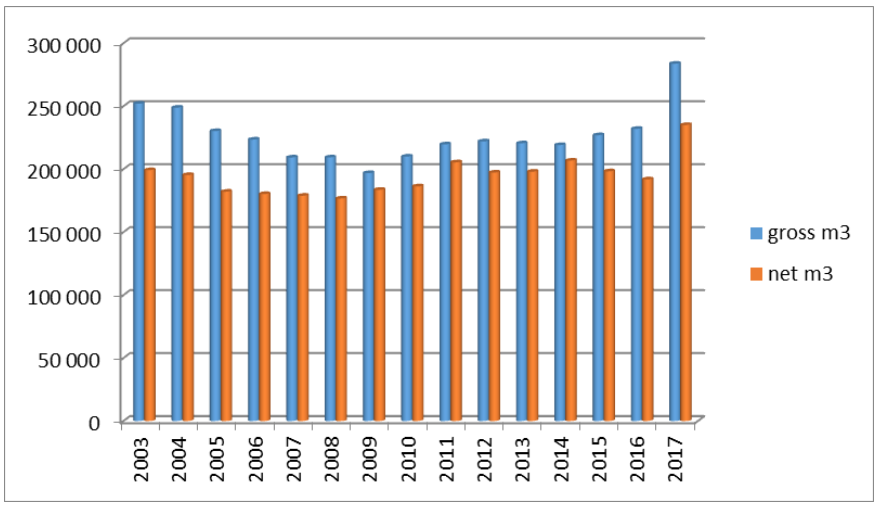
2. Methods

Data on forest damage events have been collected in the area of Egererdő Plc. for 15 years. In addition to the annual claim report, information was also collected on the evolution of yields by area and species. The data comes from field surveys and accurate logging of harvested timber. The main abiotic and biotic damages by tree species have been summarized and the annual and regional summary of the emergency felling has been made. The Forest Act provides for the reconstruction of the damaged forest areas. To reduce the damage, subject to the consent of the nature conservation authorities, fallen trees to be processed and cleaned the tourist routes due to the risk of accident. Major damage events have now been analyzed, including the ice, wind, tornadoe and storm damage in 2009 and 2014, which caused the biggest problem in the beech forest. Among the biotic damage, the bark beetle damage caused the most destruction in the spruce stands.

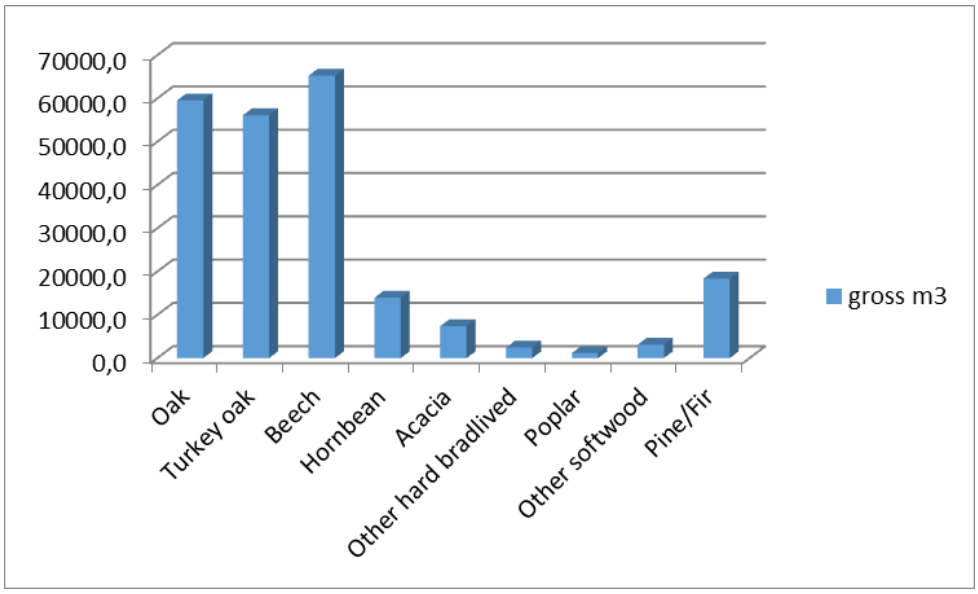


1. Figure Ice damage in 2014(Urban P. 2015)

In addition, the 15-year average gross and net yields for the main tree species have been determined, and later on this can be compared to the evolution of yields.

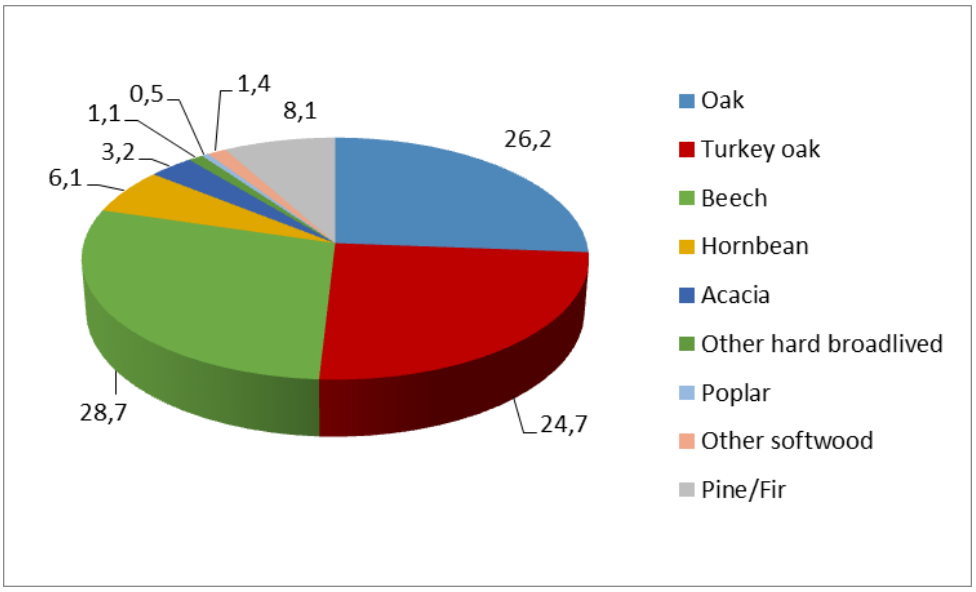


2. Figure A summary of 15 years of Total Logging(2003-2017)



3. Figure Average annually wood harvest in the last 15 years(2003-2017)

The largest areas are oak and beech, so it can be seen in the trends of the harvest that most of wood came from these species.



4. Figure Yields by tree species(%)(2003-2017)

3. Results

Of the damage occurring in forestry, this article deals only with damage to a larger area of major tree species. Significant amounts of health and emergency timber were harvested in the beech forest due to the storm damage in 2014 and the ice damage this year. As a result of the storm, logging continued in the following years, as shown in the following figure. Then in 2017, the snowfall in the spring caused problems reaching the already leaf covered forest.

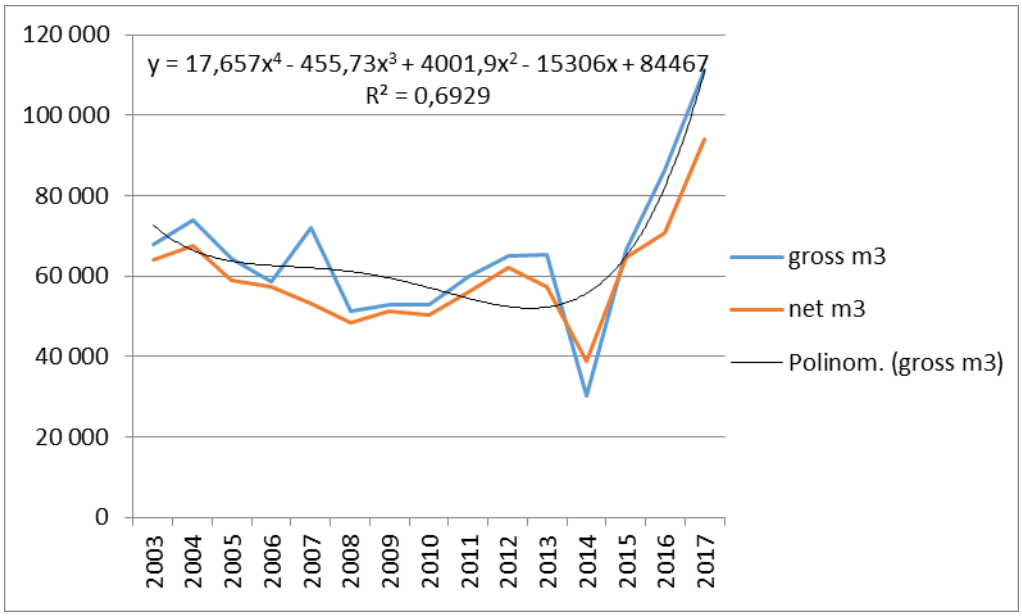


Figure 5. Beech(Fagus sylvatica) annual total harvest (2003-2017)

From 2014 onwards, health care logging will show outstanding values. As a result of storm, snow and ice damage, the average annual output of beech has nearly doubled.

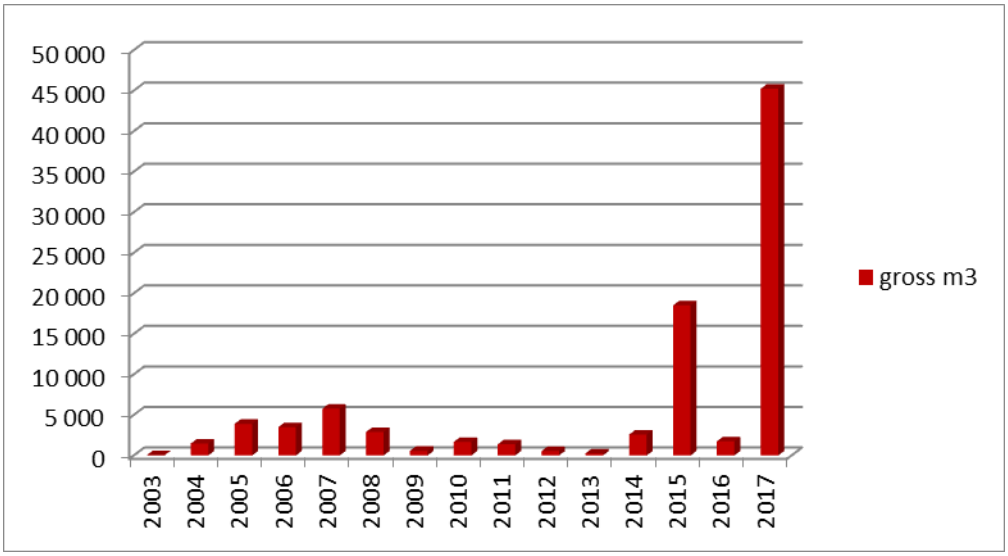


Figure 6. Beech(Fagus sylvatica) emergency felling

In the case of spurce and fir, the bark beetles weakens the trees. Average winter temperatures have also increased in recent years, making it easier for pests to overwinter. As a result, storms, wind and ice damage are more prominent on weakened stocks. The situation is exacerbated by the increase in summer and winter temperatures in recent years, as well as the extreme heat that often occurs in summer.

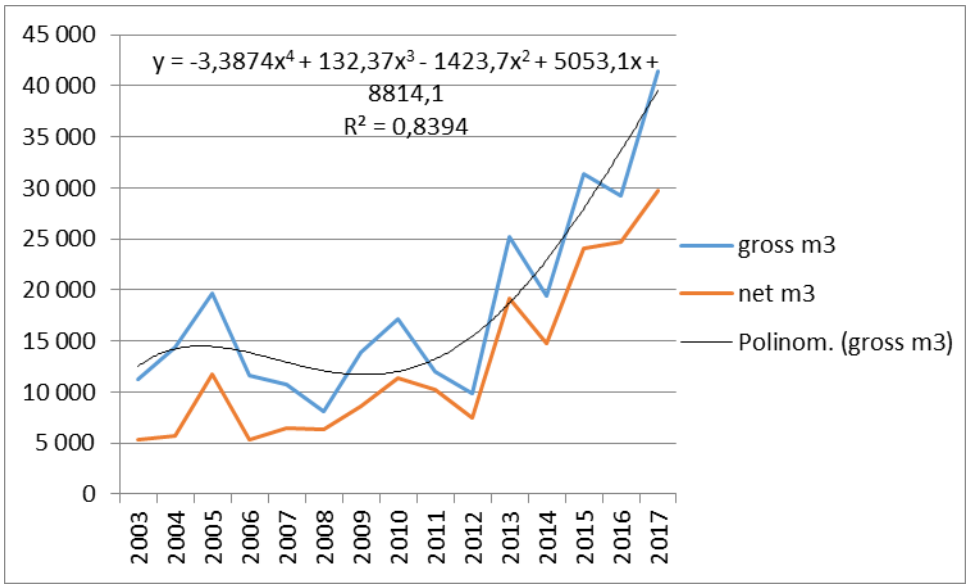


Figure 7. Total annual logging data of spurce and fir

The health and forced logging of pine trees was caused by storm, wind, and ice damage, and their combined effects. The following figures highlights the increase in forced and annual logging due to damage over the last 7-8 years.

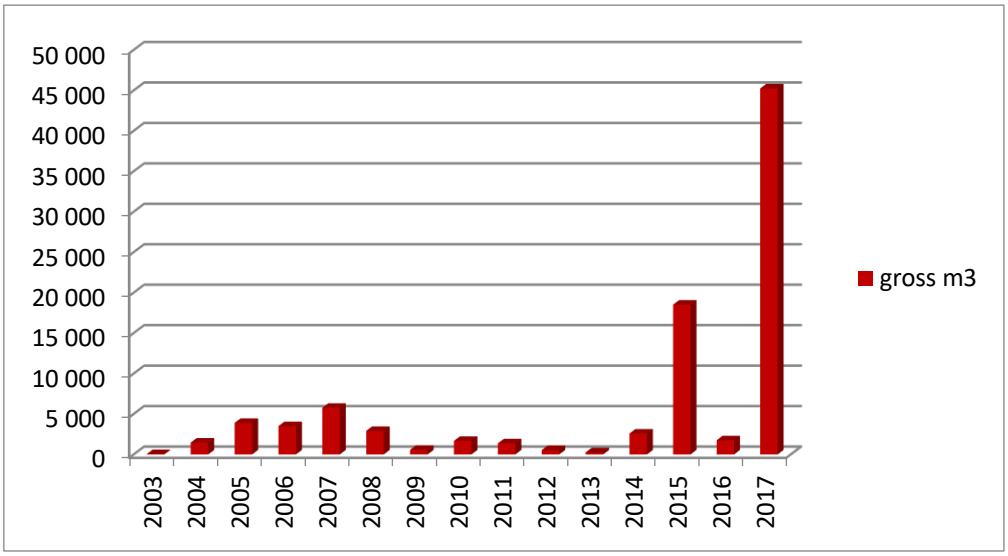


Figure 8. Spurce and fir emergency felling

4. Conclusions

Overall, similarly to European trends, biotic and abiotic damage and yields have increased significantly in the studied area over the last decade. In the case of beech forest, the greatest damage was caused by wind, storm, ice and snow. While in the conifers, the insects also weakens the tree stocks, making them less resistant to a storm or ice damage. Logging has also increased significantly over the past seven years due to meteorological damage, compared to previous years' average. If as an indirect consequence of climate change these events continue, it will affect the future trend of the yields. Consideration should be given to changing the species structure and promoting the plantation of climate-resistant tree species, which poses a major challenge for forestry.

5. Acknowledgements

The described work was carried out as part of the „Sustainable Raw Material Management Thematic Network – RING 2017", EFOP-3.6.2-16-2017-00010 project in the framework of the Széchenyi 2020 Program. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

6. References

Alexa Michel, Walter Seidling, and Anne-Katrin Prescher (editors) (2018): ICP Forest Report, Forest Condition in Europe (2018) Technical Report of ICP Forests Report under the UNECE Convention on Long-range Transboundary Air Pollution (Air Convention) - Available from: https://www.researchgate.net/publication/328956391_Forest_Condition_in_Europe_2018_Technical_Report_of_ICP_Forests_Report_under_the_UNECE_Convention_on_LongRange_Transboundary_Air_Pollution_Air_Convention

DaleV.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P.Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J.Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks, B.M.Wotton(2001): Climate change and forest disturbances,BioScience, 51 (2001), pp. 723-734

EAESAC- European Academic Science Advisory Council(2018): Extreme weather events in Europe - https://easac.eu/fileadmin/PDF_s/reports_statements/Extreme_Weather/EASAC_Statement_Extreme_Weather_Events_March_2018_FINAL.pdf

Fundamentals of air pollution (2014): https://www.sciencedirect.com/topics/earth-and-planetary-sciences/forest-damage

Hirka Anikó, Pödör Zoltán, Garamszegi Balázs, Csóka György (2018): A MAGYARORSZÁGI ERDEI ASZÁLYKÁROK FÉL ÉVSZÁZADOS TRENDJEI (1962-2011), Erdészettudományi közlemények, 8 vol, 11-25p.

Herve Jactell et al.(2009): The influences of forest stand management on abiotic and biotic risk of damage, Firest Science, vol 66. online at : INRA EDP Sciences

Hilszczański, J.(2014): Dynamika populacji owadów oraz ocena ich funkcji ekologicznych w ekosystemach leśnych w związku ze zmianami klimatycznymi [The dynamics of the insect populations and the assessment of their ecological functions in forest ecosystems in relation to climate change]. In *KLIMAT. Lasy i Drewno a Zmiany Klimatyczne: Zagrożenia i Szanse. Materiały Pierwszego Panelu Ekspertów w Ramach Prac nad Narodowym Programem Leśnym [CLIMATE. Forests and Wood and Climate Change: Threats and Opportunities. Materials of the First Panel of Experts as Part of Work on the National Forest Program]*; Rykowski, K., Ed.; Instytut Badawczy Leśnictwa: Sękocin Stary, Poland, 2014; pp. 174–188.

Jaworski, T.; Hilszczański, J.(2013): The effect of temperature and humidity changes on insects development and their impact on forest ecosystems in the context of expected climate change. *Leś. Pr. Bad./ For. Res. Pap. 74*, 345–355.

M.P. Ayres, M.J. Lombardero(2000): Assessing the consequences of global change for forest disturbance from herbivores and pathogens,Sci. Total Environ., 262 (2000), pp. 263-286

Nébih Erdészeti Igazgatóság (2019): Erdeink egészségi állapota, Országos jelentés, Hungary Forest Report, pp.12

Slovenian Forest Survive (2018): Annual Forest Report, Five Years After Ice Storm, Damage to Slovenian Forests Remains,

Seidr R. et al. : Rupert Seidl, Dominik Thom, Markus Kautz, Dario Martin-Benito, Mikko Peltoniemi, Giorgio Vacchiano, Jan Wild, Davide Ascoli, Michal Petr, Juha Honkaniemi, Manfred J. Lexer, Volodymyr Trotsiuk, Paola Mairota, Miroslav Svoboda, Marek Fabrika, Thomas A. Nagel & Christopher P. O. Reyer (2017) - Review Article, Forest disturbances under climate change *Nature Climate Change* volume7, pp.395–402

Stedelman et al (2014) Spatial interactions between storm damage and subsequent infestations by the European spruce bark beetle- Forest Ecology and Management Volume 318, 15 pp. 167-174

Sierota Z et al (2019) : Abiotic and Biotic Disturbances Affecting Forest Health in Poland over the past 30 Years: Impacts of Climate and Forest Management ,*Forests* 2019, *10*(1), 75*Review*

Urban P.(2015): Jégkárok az EGERERDÕ Zrt. által kezelt erdõkben- Ice damage in the area of Egererdő Plc., Erdészeti lapok, vol CL/1. , https://erdeszetilapok.oszk.hu/01799/pdf/EPA01192_erdeszeti_lapok_2015-01.pdf

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

DATENBASIS WALDARBEIT – PLANNING TOOL FOR AVERAGE TIME CONSUMPTION AND COSTS OF STANDARDISED FOREST WORKING PROCEDURES

Andrea Hauck[1], Dr. Markus Dög[2], und René Maxeiner[3]
[1]Kuratorium für Waldarbeit und Forsttechnik e.V., Spremberger Straße 1, 64823 Groß-Umstadt, andrea.hauck@kwf-online.de
[2]Georg-August-Universität Göttingen, Abt. Forstökonomie, Büsgenweg 3, 37077 Göttingen, mdoeg@gwdg.de
[3]Georg-August-Universität Göttingen, Abt. Arbeitswissenschaft und Verfahrenstechologie, Büsgenweg 4, 37077 Göttingen

Abstract: ***"Datenbasis Waldarbeit"*** *is a tool to define and classify data for planned time consumption and planned costs for specific forest operations i.e. timber harvesting, planting, and pre-commercial thinning. This database includes an online-form, which allows to directly transmit own information in order to continuously update the database.*

Keywords: planning times, planning costs, resource management, working procedures

1. Introduction

(Pre-) calculations in operational management in forest enterprises and companies associated with forestry are crucial to guarantee economic success and an efficient use of resources. Missing or no knowledge on time and resource consumption concerning existing and new operational methods make planning and coordinating forest management difficult. Therefore, a current database on actual time consumption and costs concerning main operational tasks is required.

This task was dedicated to the project „RePlan" (Optimising resource management in forestry through the use of qualified planning times and planning costs for standardised working procedures). Project partners were the KWF (Board of Trustees for Forest Work and Forest Technology) and the University of Göttingen (Burckhardt-Institute, Department of Forest Economics and Department of Forest Work Science and Engineering).

The goal of the project was to develop a method to track and update data and create a nationwide database with consumption times and costs to be used by all actors in forestry (forest owners, forest enterprises, forest consultants and forest entrepreneurs). A further project objective was to develop a method to continuously update this database by the KFW.

2. Project results

The prototype planning tool Datenbasis Waldarbeit was developed by the end of the project: It allows users to determine the time consumption and costs of standardized tasks in forestry (timber harvest, young timber thinning/tending and planting). The user itself is able to use specific parameters and replace predetermined data for personalized calculations.

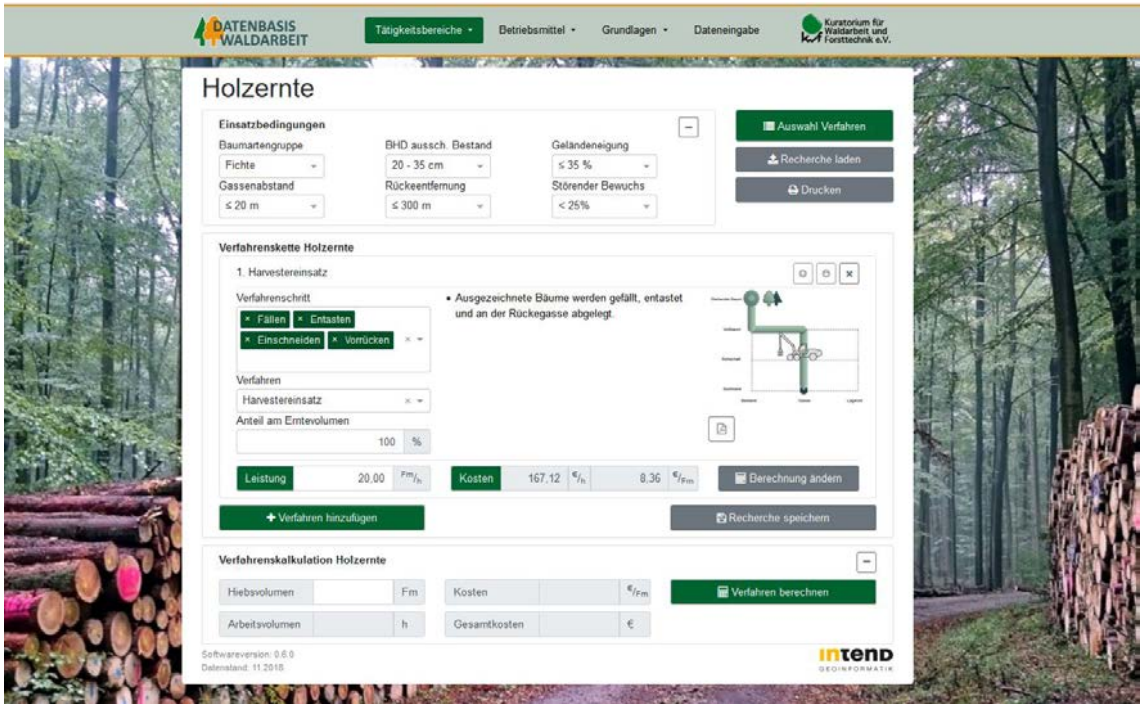


Figure 1: Example of a search in the field of timber harvesting in the research database

In addition, methods to determine or derive the time consumptions times were developed. With these methods the database can be kept up to date. At the same time cost calculation schemes were developed. These enable the user to derive cost rates that could be used in forest management planning.

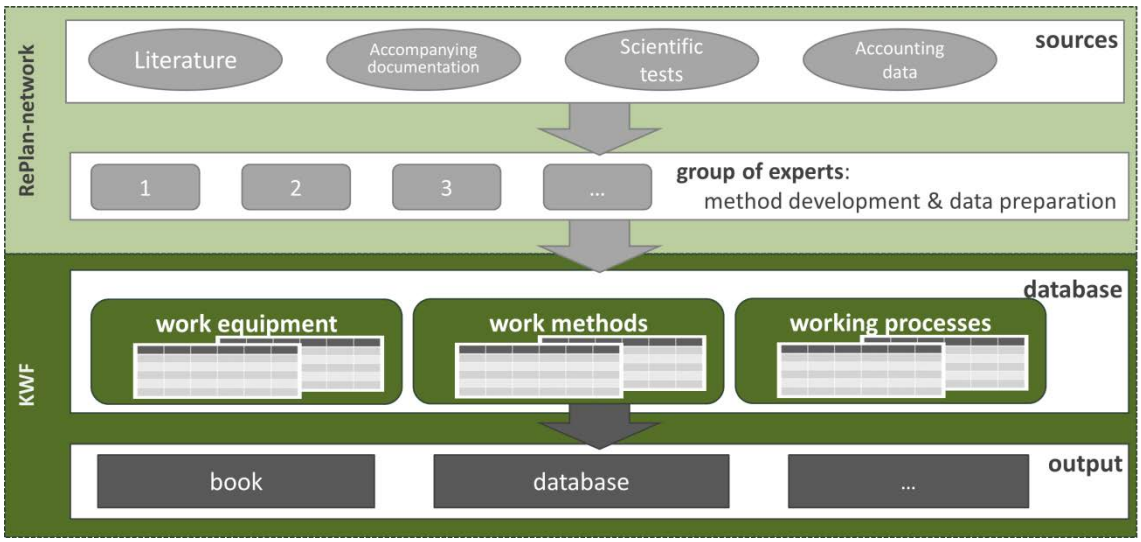


Figure 2: Sources and data storage

Standardized content and definitions are required to determine and compare times and costs of working processes. As part of the project, specific terms were harmonized and systematic structures regarding resources and processes were created. The glossary will contribute to harmonizing specific terms and definitions in forestry. The database can be accessed at http://dbwaldarbeit.kwf-online.de.

To update the values of the database, methods were analyzed, developed, evaluated and tested for future application. The Datenbasis Waldarbeit provides an online input tool where users can transfer information for the database directly to KWF. With the use of standardized work orders, a further contribution has been made to harmonize working procedures in forest management. With an additionally developed addendum, there is also the possibility to transfer actual implementation data from German forest practice, to continuously update the data base.

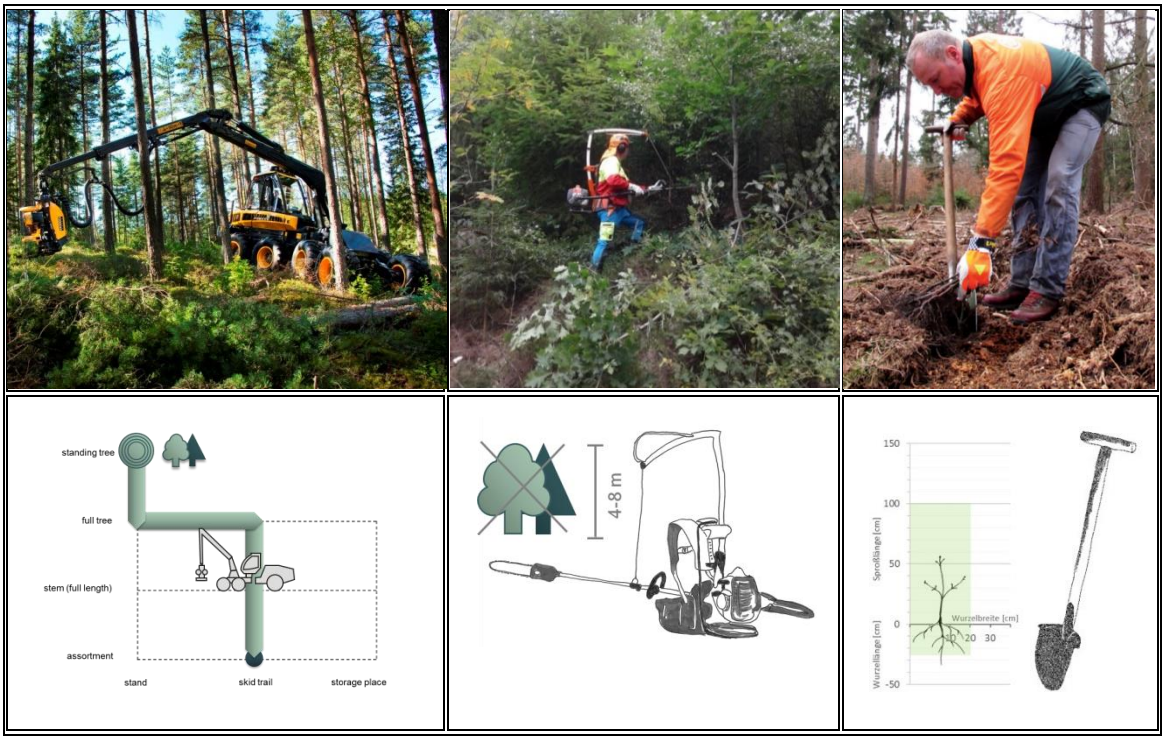


Figure 3: Graphic representation of working procedures

3. Summary

This tool is currently available as a prototype. Working processes are defined and performance data and related costs are compiled. Despite the specific stand conditions in individual enterprises, it is intended to ensure a high transferability of the results throughout Germany. In the future the „Datenbasis Waldarbeit“ will be maintained by the KWF.

4. References

Abschlussbericht 2019. Verbessertes Ressourcenmanagement in der Forstwirtschaft durch qualifizierte Planzeiten und Plankosten für standardisierte Arbeitsverfahren (RePlan) – not published yet

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

DEVELOPING AND EVALUATING LOGISTICS CHAINS WHEN USING DEBARKING PROCESSOR HEADS (DEBARKING HEADS II)

Andrea Hauck[1], Jochen Grünberger[1], Bernd Heinrich[1], Joachim B. Heppelmann[2,3], Ute Seeling[1], Stefan Wittkopf[2]

[1]Kuratorium für Waldarbeit und Forsttechnik e.V.
Spremberger Strasse 1, D-64823 Gross-Umstadt, Germany
andrea.hauck@kwf-online.de

[2]University of Applied Science Weihenstephan-Triesdorf
Hans-Carl-von-Carlowitz-Platz 3, D-85354 Freising, Germany.

[3]Department of Ecology and Ecosystem Management, Technical University of Munich,
Hans-Carl-von-Carlowitz-Platz 2, D-85354 Freising, Germany

Abstract: *Based on the experiences of modified debarking harvesting heads within the Debarking Head I project, , the presented study investigates the entire supply chain for debarked roundwood, right down to the wood industry. Technical, environmental and business analyses are carried out for a holistic working process assessment of the developed debarking system. The customer requirements and demands on debarked logs were determined as starting point for the assessment.*

Keywords: stand sustainability, debarking, debarking harvesting head, spruce bark beetle prevention, roundwood logistics

1. Introduction

Germany is one of the central European countries with a rather high forest density. With 11.4 million hectares, almost a third of the total area is covered by forest land. In order to conserve and improve the forest resources and diverse forest functions, modern forestry needs to respond to varying climate change conditions. The main challenges can be listed as:

- conservation of soil fertility (especially in stands with low nutrient supply);
- promotion of tree diversity in the forest stand;
- increased vulnerability of stressed trees to pests and infestations.



Figure 1: Debarking harvesting head in operation, debarking Scots pine (*Pinus sylvestris*)

With both silvicultural and technical treatments, modern forestry can influence the development of sensitive forest ecosystems. An example for utilization of new technical methods is the control of spreading spruce bark beetle infestations, by debarking infested logs during fully mechanized harvesting operations directly in the forest stand.

2. Project

Debarking Heads I

The Kuratorium für Waldarbeit und Forsttechnik e.V. (KWF) tested in close cooperation with the University of Applied Science Weihenstephan-Triesdorf (HSWT), debarking rollers and other modifications, originally designed for Eucalyptus harvesting heads, on commonly used harvesting heads to assess the possibility of adding debarking to fully mechanized cut to length operations, under Central European conditions for the first time (Abschlussbericht, 2018).

Summary of the main findings within the 'Debarking Head I' project**:**

- Debarking logs of Norway spruce (Picea abies) and Scots Pine (Pinus sylvestris) by applying modifications on conventional harvesting heads proved to be technically and financially feasible, providing sufficient debarking results during summer harvesting operations.
- Limitations of debarking results can be caused by diameters exceeding the operating optimum of the debarking harvesting head and associated carrier machine.
- The debarking head modifications can potentially be utilized to debark further tree species such as larch, douglas fir, beech, oak, birch and poplar.
- The length measurement stayed within the expected range and did not vary significantly in comparison to applications of conventional harvesting heads.

- It is possible to carry out conventional harvesting operations, while the debarking modifications are attached, without a major loss of economical efficiency, as the productivity decline is directly linked to the harvesting process modifications (multiple feed runs in full length through the debarking harvesting head).
- Investigations on the debarking result showed a significant correlation between vegetation season and the debarking percentage.
- Operating modified debarking harvesting heads within the winter season is not recommended so far. Although the bark can be removed from the trunk to a high share by increasing the feeding runs, the trunk itself is damaged accordingly during the process, questioning the further applicability of the timber and further decreasing the productivity.
- Within an associated study, it was proven that the depth of the debarking roll-penetration was significantly lower than for conventional rollers. On the contrary, due to the more aggressive setup of the delimbing knives, the damage on the wooden body was increased significantly (Labelle et al. 2018).

In conclusion, the modification of commonly used harvesting heads was a success and exceeded the expectations within the vegetation season. If similar debarking results shall be desired for winter harvesting operations in future, further developments and modifications will become necessary. At this stage, the system is highly recommended for all harvesting operations that shall include prompt debarking directly within the forest stand (e.g. spruce bark beetle treatments). To minimize occurring damages on the surrounding forest stand, it is also recommended to avoid applications of the debarking system in very dense stands and stands with advanced regeneration.

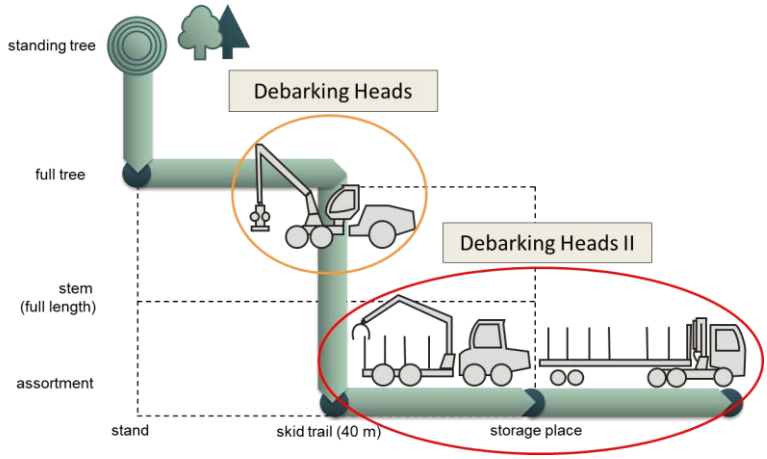


Figure 2: Schematic representation of the research extend within the 'Debarking Head' projects

Objectives within the 'Debarking Heads II' research project

Based on the results of “Debarking Head I”, the impact of debarked stems on transport, storage and processing is currently under investigation. Based on case studies, environmental and economic advantages and disadvantages, as well as the associated opportunities and risks, are considered and assessed in close cooperation with the wood-processing industry. In addition, further tests are carried out in order to evaluate the debarking process of spruce bark beetle infested logs and perform a holistic and final economic and ecological evaluation.

Preliminary results of the 'Debarking Head II' project

In the current spruce bark beetle infestation situation, the bark beetle control of standing and infested trees without the use of any insecticides has the highest priority. Therefore, the application of debarking

harvesting heads eradicates the spruce bark beetle breeding habitat and destroys the bark beetles in the larval and pupal stages reliably. After debarking, the infested logs pose no further threat towards the remaining forest stand and the removal logistic is relaxed considerably. The use of debarking harvesting heads is expected to be an effective tool to manage future spruce bark beetle infestations. Within the research project, debarking percentages of up to 90% were achieved within infested forest stands.



Figure 3: Engraving pattern of the spruce bark beetle (Ips typographus) within harvester-based removed bark

Another main focus of the 'Debarking Head II' project is set on the timber transport: Preliminary results show that the debarked logs should be stored and dried for a few days, when harvested within the vegetation season. A sufficient drying phase, reduces the slippery surface and hence eases the forwarding and stacking of debarked round wood assortments.

By debarking the logs, a mass reduction is achieved by removing the bark itself and enabling a faster drying rate. This can result in an additional net load of debarked roundwood per truck load, potentially decreasing the costs and the ecological footprint of timber transports. This effect is currently under investigation in a field trial in central Germany.





Figure 4: Forwarding and transporting debarked logs, within a field trial in central Germany

In addition to the benefits on spruce bark beetle operations and the logistic chain, did in-stand proved to be a reasonable solution to leave more nutrients within the forest stand. Depending on the nutritional element (nitrogen; phosphorus; calcium; magnesium and potassium) about 14 to 31 percent of the usually extracted nutrients are remaining in the forest ecosystem and can help to improve the soil fertility (Weis and Göttlein 2012).

Further did the 'Debarking Head I' project showed that customers and the wood processing industry acted carefully towards harvester-based debarking, despite the positive effects on nutrient sustainability. A major concern apart from the damages on the wooden surface was an expected loss in value due to negative storage effects on debarked roundwood (cracks, fungi, etc.).
However, if the wood is piled up in loose layers and can dry well, blue-stain fungi did not spread on the on the debarked logs. An extraordinary frequency of occurring cracks was also not observed during the field experiments.

3. Summary:

Based on the results of the 'Debarking Head I' project, the presented study assesses the entire value chain for debarked roundwood, until the first product within the wood processing industry. For a holistic assessment of the associated work processes, technical, environmental and business analyzes are carried out.

Debarked roundwood assortments provide many advantages such as the improved nutrient supply of the forest soil, potential savings in the logistics chain, positive effects within spruce bark beetle treatments and less ash and fine dust outtake within firing plants.

In Germany, over 30 modified harvester heads are currently applied in debarking harvesting operations and despite the potential of further improvements on the debarking harvesting head modifications, does the possibility to debark logs within the forest stand, offer both major economic and ecological advantages for future applications.



Figure 5: Debarked roundwood assortment (Norway spruce), summer 2019

4. References

Abschlussbericht 2018. Nährstoffentzüge bei Holzernte minimieren durch die Nutzung von entrindenden Harvesterfällköpfen (Debarking Head). Bundesministerium für Ernährung und Landwirtschaft. p. 100.

Heppelmann, J. B., Labelle, E. R., Wittkopf, S. Seeling, U. (2019). In-stand debarking with the use of modified harvesting heads: a potential solution for Key challenges in European forestry.
European Journal of Forest Research, p. 15.

Heppelmann, J. B., Labelle, E. R., & Wittkopf, S. (2019). Static and Sliding Frictions of Roundwood Exposed to Different Levels of Processing and Their Impact on Transportation Logistics. Forests, 10(7), 568

Labelle, E.R., Breinig, L. and Spinelli, R., 2019. Extent and severity of damages caused to spruce roundwood by harvesting heads in standard versus debarking configurations. European Journal of Forest Research, 138(1), pp.151-163.

Weis, W., Göttlein, A., 2012. Nährstoffnachhaltige Biomassenutzung. LWF aktuell (90): 44–47.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

FOREST WORK IN THE TROPICS IN THE FOCUS OF WORK SCIENCE[1]

Siegfried Lewark
Chair of Forest Work Science
Faculty of Environment and Natural Resources
University of Freiburg
Werthmannstraße 6, D-79085 Freiburg, Germany
siegfried.lewark@fobawi.uni-freiburg.de

Abstract: *What is special about work in tropical forests? There is forest work in plantation and natural forests, for retrieval of wood for industrial use, but also for NWFP, and for other traditional utilization. The working conditions differ from those of forest work in industrial countries, not only with respect to climate, state of mechanization and work organization. Most of the work is done in the informal economy and much by illegal logging.*
Research in Work Science is partly done in cooperative projects by institutions in tropical and industrialized countries. Number of researchers in tropical countries is quite limited, most educated in the traditions of forest work science in the industrialized countries, publications following research questions from these traditions. The potential of knowledge transfer is limited. There is a need for integrative research approaches, integrating research questions and methods oriented towards an inclusion of social and economic conditions.

Keywords: forest work, tropical forests, work science, work study, working conditions

1. Forest Utilization for Livelihood and Industry

Tropical forests are utilized in many different ways, for traditional products as well as for industrial raw material, thereby serving as resources for livelihood, providing forest products, employment and work. Natural conditions of the tropical forests of the world are different, so are the respective characteristic forests. Also the relationships between forests and people and its history are very specific. Tropical forests all are situated in developing countries, where economical, political and social conditions are different from those in industrialized countries.

Work in tropical forests is often associated with retrieving big logs of precious wood from the jungle, the tropical rain forests. Such exploitation, "timber mining", has been the common way of taking wood from tropical forests since the start of colonization. Wood, also Non-Timber-Forest-Products (NTFP), was taken from forests of all types, not confined to the rainforests.

Because of the destruction and degradation of tropical forests and the generally growing demand for wood the establishment of plantation forests is often seen as a solution, at least for producing more industrial wood. There are plantation forests in a big scale, but also of small scale, owned by farmers or communities. A great deal of wood, especially fuel wood, and NTFP are also provided from trees growing outside forests (FAO, 2016).

[1] This text is drawing from "Work in Tropical Forests", book under preparation (Lewark, 2019b).

2. Forest Work in Tropical Forests

2.1 Who does Forest Work?

More than one billion people are living in or near tropical forests (Chao, 2012), living in rural areas. But also many urban people depend on resources from the forests. They all work in the tropical forests for their livelihood. Most of those people belong to the poorest in the world. These people are living in tropical forests of all types as outlined above, from humid to dry forests and savannahs. But their work in traditional utilization in natural forests is easily ignored.

Large parts of these populations are indigenous to the regions, countries and forests in the etymological sense of the term, many of them are indigenous people according to their self-understanding and to definitions of the UN and ILO (2013).

The natural forests in all their stages of utilization, conservation or destruction also serve for employment, which the plantation forests and other land uses after conversion of the natural forests do as well. Employment will be the content of another text (Lewark, 2019a).

2.2 Decent Work and Sustainable Forest Management

Decent Work (DW) has been developed and propagated by ILO (2019) as a comprehensive concept, which may serve as a standard for judgement of a particular working situation, and at the same time as a goal of Forest Work Science. As the majority of those employed in the forest work are not in formal employment the demands of decent work are only meaningful for a small fraction of the forest dependent people, though this is still a large number. Decent work is considered an important component of one of the dimensions of SFM, the social sustainability.

Most of the work based on forest and tree products is outside the actual forestry business, but in traditional forest utilization. This work is rarely included in research and publications of Forest Work Science and Forest Sciences in general, but it is well known, that standards of decent work are generally not met.

These limitations have to be kept in mind when reading the elaborations about Forest Work Science below and the examples of studies quoted. In many subtropical forests working situations are similar, which is especially true for plantations forests. They will therefore be included in the observations here, though not all subtropical forests are situated in developing countries and may show principally different social and political conditions.

2.3 Which Forests?

The dramatic degree of destruction of the tropical forests, already done as well as ongoing, is well-known and deplored in the public and has been described and analyzed by scientists (Martin, 2015). Quite often forestry is blamed, while more detailed analyses show, that unsustainable industrial timber exploitation on pantropical scale is only one of the important causes today, though indeed the main responsible one for forest destruction in some regions.

The very wasteful way of exploitation refers to the damage to the remaining stands and the soils compacted by heavy machines. Foresters and forest scientists strive for Sustainable Forest Management (SFM) in natural forests, including the development and implementation of Reduced Impact Logging (RIL). But the success is very limited so far, we find SFM in natural forests to a limited degree. Estimations of 7% of the forests used for industrial wood production, of the estimated size of the natural Tropical Forest Estate (TFE) of 761 million hectares, are given e.g. by ITTO (Blaser et al., 2011). This is

opposed to official statements that often claim that SFM is applied, e.g. in Malaysia and Papua New Guinea (Bruenig, 2017).

Plantation forests are defined by the establishment through planting. The scientific and political stakeholders discuss, already for long time, but do not agree on any definition. According to the definition by FAO plantation forests in the tropics are considered forests, which is contested by some NGOs (Cossalter and Pye-Smith, 2003). Nearly 60 million hectares of plantation forests have been established in the tropics (FAO, 2016).

3. Forest Work Science

Work Science studies human work, this is called work study. Ergonomics literally has the same meaning as the term Work Science, but this meaning may be less obvious, to many readers, than the term Work Science. Forest work has sometimes named a 3-D job, attributed the properties dirty, difficult, dangerous (Poschen, 2019), indicating the many accidents, the work outdoors under hard and sordid conditions due to work objects and work site, and finally the extremely high workload and the high demand for specific skills. As a consequence one direction of forest work study is to an assessment of working conditions, which make up the hardships of forest work, everywhere and in particular in tropical forests. Another reason for the development of the discipline of Forest Work Science was coming from Taylorism, like in general Work Science, but even more so in Forest Work Science. But here the adoption of these principles posed special challenges and resulted in specific answers.

In contrast to the human centred orientation of Forest Work Science issues of forest work and operations in a broad number of other scientific disciplines and approaches are rather technology oriented (Figure 1). They have a range of different names, and there is obviously no standard or terminology consistent or underlying understanding.

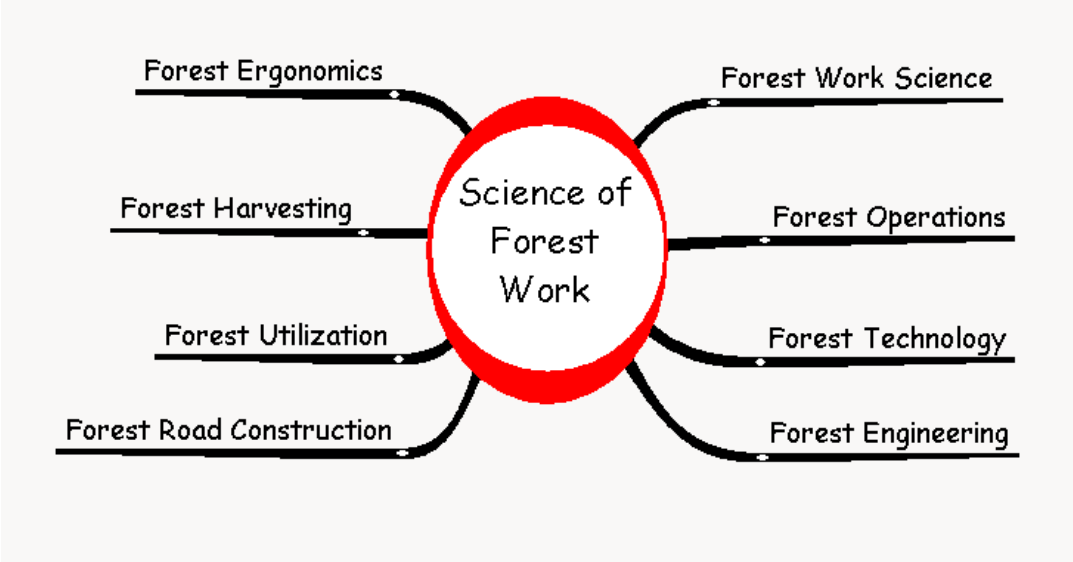


Figure 1: Forest Work as Object of Related Scientific Disciplines

A broad programmatic discussion for the discipline of Forest Operations Engineering and Management has been presented by Heinimann (2007). He looks back at the development of that discipline and the ruling paradigms over time and explicates present challenges and finally presents a vision for the near future. Many of his ideas apply to Forest Work Science in a similar way, even more so as many references he draws on certainly apply to the whole field of methods and conditions of forest operations.

4. Work Studies

Work study is based on many traditions with different concepts and terminology. Any assessment of workload and working conditions is only meaningful in relation to performance. A strong plea is made not to occupy the term work study for mere time study, but to use it in a broad sense and then to clarify, whether it is performance study, methods study or ergonomic study what is attempted and done.

4.1 Operations in Natural Forests

Dimensions of trees being taken from natural tropical forests often are big, posing high demands to operations of felling and conversion as well as transport of logs. Mechanization started with machines for opening up and transport, while mechanized tree felling is limited and mechanized tree conversion by harvesters is often done only at the landings (Castro et al., 2016). So felling and cross-cutting are still done mostly motor-manually, using big chainsaws.

SFM as well as unsustainable forest utilization and illegal logging are only possible with loggers, all is clearly based on forest work. Work tasks, work objects and the physical work environment may be similar to those in SFM, but other working conditions, resulting from the social and political environment and from work organization, are not. Therefore Forest Work Science deals primarily with the small part of work in SFM, that consists of harvesting and silvicultural operations.

Industrial wood was taken from the tropical forests throughout time since beginning of colonization, but initially only small areas of forest have been involved, with relatively little impact on the resource, till the 1950s. “Mechanized logging technologies developed in industrialized countries were introduced into the tropics quickly, and both the scale of operations and their intensity changed substantially.” (Dykstra, 2002) This mechanization obviously refers to machines used for opening up the forests and forest wood transport, and perhaps with respect to felling and processing using heavy chainsaws.

The conversion includes cutting off the crown and branches and cutting the stem to length, for some uses also debarking. The problem of handling and transport of big and heavy logs also early on led sometimes to conversion at the felling site, from felled trees to planks. Pit-sawing is still found, but for many years has been more and more replaced by chainsaw milling. Now the number of records published on conversion of felled trees by chainsaw milling is increasing, because the potential obviously has been underestimated and the extent of use and the perception is growing worldwide.

Pit-sawing was customary for long time, also in the forests of the temperate zones, which is nicely documented in popular older texts and photos. Even earlier beams have been hewn with axes, also of different types (Gayer and Fabricius, 1921), e.g. for converting smaller trees to railway sleepers. In the tropics this on-site conversion was the common way for retrieving precious wood, but today the demand of sawn wood of lower quality at local markets is met by wood from on-site conversion. Worldwide today it is done on one hand an important operation in small-scale forestry, with small quantities per operation, by farmers for self-supply and local markets. On the other hand there are in the tropics many small enterprises, which together produce considerable quantities of sawn wood. Obviously pit-sawing as well as on chainsaw milling are hard work, which includes the handling of the logs. A few work studies have been published (Rurangwa et al., 2011).

The analysis of FAO (2014) on informal employment is “restricted to less developed countries on the assumption that most employment [is] in the production of woodfuel”. There are no official statistics. Numbers of employed and beneficiaries have been calculated from estimates of production of forest products and estimates of labour productivity. This refers to use of woodfuels, including charcoal, and construction wood for local use. The number of people required amounts to 115.3 million Full Time Equivalents (FTE) for rural use, thereof 74.5 million FTE for firewood and 6.4 million FTE for charcoal. For urban use 18.3 million FTE have been estimated for firewood, 18.1 million FTE for charcoal production. As most of the people engaged in this are working part-time, a much higher number of people involved have been estimated: 882 million employed in this field, 95% of them part-time.

For an evaluation of the overall workload of those involved in work for traditional forest utilization we need information about the amount of time devoted to their different activities. This can be gained through an analysis of time allocation, which has been rather a domain of Anthropology than of Forest Work Science so far as an extensive bibliography shows (Behaviour observation, no year). Typically times included are during daylight or in the dark, before sunrise and after sunset, as many examples show. The categories used will naturally depend on the people studied and their occupations and include activities for getting and preparing food and collecting firewood. Great seasonal differences are found, which needs special attention of the data assessment. Data on forest related work have been collected by Colfer in an exemplary way in the 1970s, 1980s and 1990s in Kalimantan (Colfer, 2008).

4.2 Operations in Plantation Forests

Plantation forests in the tropics and subtropics are mostly high-yield short-rotation plantations using one species – a limited number of exotic softwood or hardwood species for industrial mass use, some others with native hardwood species. Establishing plantation forests starts with planting, before that site clearing and preparation may be done. Planting is preceded by nursery work. The last operation in a rotation will be the final harvest, in most cases by clear-cut, and the associated transport and stacking, whereupon a new generation will be started by site preparation and planting.

The processes and the amount of work are very much depending on the degree of mechanization. More and more work is done motor-manually, tree felling mostly with the use of chainsaws, also brush saws, and planting sometimes using hand-held power post-hole borers (ILO 1998). But there is still much manual work as well, using axe and saw. Also the logs are often still carried on the shoulders of the workers to the roadside, or skidding is done by humans or animals. The question of appropriate technology is an important one.

Mechanization is possible for most operations, e.g. harvesting using harvesters for felling and conversion, and forwarders for primary transport. This has been implemented to some degree in different countries, with Brazil as the leading country. Working conditions in mechanized harvesting and transport have been studied widely outside of tropical countries, for example in the research project Ergowood (Lewark, 2005), but as research questions, methods as well as results are widely transferable, they are not further considered here.

Sample work studies of manual planting and pruning in plantation forests are summarized in Table 1. Planting is often considered light work, which may be a justification of low pay, especially when done by women. Workload is primarily depending on organization, tools and environmental conditions. Work organization of planting *pines* in the Southeastern United States has been perfected to the extreme, resulting in highest work intensity. It is done with awkward work postures, workload is extremely high, in repetitive work with an enormous number of work elements of short duration, of 10 seconds or less per plant. The study by Granzow et al. (2018) gives evidence of the exposure to physical risks.

An explorative one-day study of manual pruning was made by Nutto et al. (2013). Six workers did first lift pruning of *eucalypts* with two different pruning shears and a motor-manual tool combining a classical time study with a stress and strain study. Pruning height was 3m, which requires an extension of the tools or a short ladder. Performance was highest with the electric shear, significantly lower with the manual shear and still lower with use of the handsaw. The heart rate, under consideration of the different physical capacity of the two workers, indicated very hard work with the hand tools and middle hard to hard work with the electric shear, exceeding the permanent work capacity.

These two samples have been selected for demonstration of work study approaches in plantation forests. Most of the studies published though, with similar research questions, on workload and performance under different working conditions or with different work methods have been done on tree harvesting operations.

Table 1: Sample work studies from planting and pruning in plantation forests

	Planting study (Granzow et al., 2018)	Pruning study (Nutto et al., 2013)
Study background		
Research question	Exposure to physical risks, performance	Impact of tools on workload and performance
Country, region	Coastal plain of Alabama, USA	Southern Brazil
Study set-up	Study in real work situation (one work day per study person)	Study in real work situation, experiment (each tool used 90min twice)
Operation details		
Studied operations	Planting, secondary tasks	First lift pruning, 3m, secondary tasks
Working objects	Seedlings in containers	Stand age:18 months; spacing 5.0x2.8m
Tree species	*Pinus spec.*	*Eucalyptus grandis*
Quality requirements	Soil firmed	Short stump, no bark wounding
Work site	Logged areas, no preparation	Slope (rolling, steep), hindrances
Time of assessment	Planting season: January-February	Pruning season: all year round
Working system		
Work method, task	Hand planting, 2200 plants per shift expected	Manual pruning from ground and step
Working tools	Dibble bar with T-style handle	Handsaw with extension (0.55+1.5kg), manual and electric shear; step (1600g)
Pers. prot. equipment		Hard hat, safety glasses, gloves
Working cycle, elements	Planting 76%; loading into bags, walking with load	Walking, first lift pruning, adjusting step, second lift pruning, stepping down, taking off the step; maintenance
Transport	2 bags, carried like backpacks, 500 seedlings	
Working persons		
Study groups	14 male seasonal workers, H-2B visa *2)*	2 male workers
Age, anthropometric data		45 years (77kg), 20 years (72kg)
Fitness	No history of MSDs in neck/shoulder or back regions	General complaint: stiffness, pain around lumbar parts
Employment, payment	Employed by reforestation contractor, hourly based payment	Employees of contractor
Familiarity with tasks	First season to 10 years of experience	
Work organization	Shift 8-10hrs, lunch break, working groups	8 hrs day shift (simulated), pause regime
Ergonomic assessments		
Parameters	Electromyography, movements	Heart rate
Body postures	Upper arm and trunk postures	7 postures (video camera), Looking upwards
Performance	N of seedlings per hour, times per work element	N of pruned trees per shift
Terrain conditions	Easy terrain, sometimes frozen, free of stones	
Influencing factors		Branches: n, diameter, wood hardness
Specific health risks		Risk by slippery step

5. Outlook

This short text is intended to introduce the broad scope of research on work in tropical forests. Many topics and issues are not covered, like issues of occupational diseases and accidents, working conditions in harvesting of NWFP, of wood and NWFP in agroforestry, or the impact of work under forests concessions in natural forests and the development of contractor work. Working conditions in informal employment will be the topic of another text (Lewark, 2019a).

With the outline of the scope of different work tasks in natural forests and plantations forests it is shown that actually most work is outside of forestry business. This certainly also deserves scientific attention, not only from Anthropology or Human Geography, but also from Forest Work Science. Table 1 gives examples of typical work studies with an ergonomic focus on work in tropical forests, done by professional though not necessarily trained forest workers. Most Work Science publications indeed are on work traditionally considered forest work, but work in tropical forests would imply much more than that.

6. References

Behavior observation (2019) Behavior Observation and Time Allocation Bibliography, http://qualquant.net/training/behavior05/Bib-behavior-time.pdf (Retrieved June 2017).

Blaser, J., Sarre, A., Poore, D. and Johnson, S. (2011) "Status of Tropical Forest Management 2011." ITTO Technical Series, 38. International Tropical Timber Organization: Yokohama,.

Bruenig, E. F. (2017) Conservation and Management of Tropical Rainforests: An Integrated Approach to Sustainability, 2nd edition. CABI: Wallingford, Boston, MA.

Castro, G.P., Nutto, L., Malinovski, J. R. and Malinovski, R. A. (2016) Machinery and Equipment in Harvesting. In: Pancel, L. and Köhl, M. (eds) Tropical Forestry Handbook. Springer: Berlin, Heidelberg, 2395-2443.

Chao, S. (2012) Forest Peoples: Numbers Across the World. Moreton-in-Marsh, UK

Cossalter, C. and Pye-Smith, C. (2003) Fast-wood Forestry: "Myths and Realities," Forest Perspectives, 1, CIFOR: Bogor, Indonesia

Dykstra, D.P. (2002) "Reduced Impact Logging: Concepts and Issues." In: Enters T (ed) Applying Reduced Impact Logging to Advance Sustainable Forest Management. Int. Conf. Proceedings, 2001, Kuching, Malaysia. FAO: Bangkok, Thailand, 23-39.

FAO (2016) Global Forest Resources Assessment 2015: How are the World's Forests Changing? Rome.

Gayer, K. and Fabricius, L. (1921) Die Forstbenutzung, 12. ed., Parey: Berlin.

Heinimann, H.R. (2007) "Forest Operations Engineering and Management – the Ways Behind and Ahead of a Scientific Discipline." Croatian Journal of Forest Engineering, 28,107-121.

ILO (1998) Safety and health in forestry work. ILO Code of Practice. Geneva.

ILO (2013): Understanding the Indigenous and Tribal People Convention, 1989 (No. 169). Handbook for ILO Tripartite Constituents. Geneva.

ILO (2019) Decent Work, www.ilo.org/global/topics/decent-work/lang--en/index.htm, (Retrieved August 2019).

Lewark, S. (ed.) (2005) “Scientific Reviews of Ergonomic Situation in Mechanized Forest Operations.” Uppsats, Institutionen för skogens produkter och marknader, 2. SLU: Uppsala.

Lewark, S. (2019a) “Informal Work in a New Book on Tropical Forestry”, This volume.

Lewark, S. (2019b) Work in Tropical Forests, Under Preparation.

Martin, C. (2015) On the Edge: The State and Fate of the World's Tropical Rainforests: a Report to the Club of Rome. Greystone Books: Vancouver, Berkeley.

Poschen, P. (2019) “Industries Based on Biological Resources: Forestry.” In: ILO, Encyclopaedia of Occupational Health and Safety. www.iloencyclopaedia.org/part-x-96841/forestry, (Retrieved August 2019).

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

DENDROMASS4EUROPE (D4E) - SECURING SUSTAINABLE DENDROMASS PRODUCTION WITH POPLAR PLANTATIONS IN EUROPEAN RURAL AREAS

Natascia Magagnotti, Raffaele Spinelli
CNR Ivalsa, Sesto Fiorentino (FI), Italy
magagnotti@ivalsa.cnr.it

Abstract: *D4EU is a large project launched within the scope of the Bio-Based Industry Joint Undertaking (BBI-JU), a public-private partnership supported by the European Union under Horizon 2020 initiative. BBI sponsors pre-industrial projects providing environmental and socio-economic benefits for European countries.*

D4EU aims at establishing sustainable, Short-Rotation Coppice (SRC)-based regional cropping systems for agricultural dendromass on marginal land that feed into bio-based value chains and create additional job opportunities in rural areas. For that purpose, 2,500 ha of short rotation poplar plantations will be planted on marginal or currently unused land in rural areas of the Slovak Republic. These plantations will provide the feedstock for the establishment of four new bio-based value chains based upon products from wood and bark from poplar trees. A functionally adapted lightweight board for furniture production is manufacturing by IKEA Industries (Slovakia). The new structure gives more stability to the boards, which will be lighter and consuming fewer resources. Poplar bark is processed by Pulpack (Poland) into eco-fungicidal moulded fibre parts to replace plastics in packaging. At the same time, Energochemica Trading (Slovakia) plans to incorporate the bark into bark-enriched wood-plastic composite and wood-plastic granulate.

The researchers of the National Council for Research (Italy), Ökoforestino Ltd. (Hungary), the Swedish University of Agricultural Sciences (Sweden) and Technische Universitaet Dresden support the industrial partners involved, with their expertise in the fields of agriculture, forestry and wood sciences. The Kompetenzzentrum Holz GmbH (Austria) and Daphne, Institute for Applied Ecology (Slovakia) are providing expertise on ecological questions of management. Stakeholders, especially the respective scientific and industrial communities, e.g. those of forest sciences, agricultural and forest policy, nature conservation and bio-based materials research will be informed and involved during the entire project for example via field demonstrations, publications and a project website as well as social media. The project started in June 2017 and has a duration of 5 years with a otal budget is 20.5 Million €. The project, coordinated by the Technical University of Dresden (Germany), gathers 9 partners from 5 European Countries.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

MULTI-FUNCTION MACHINE'S WORK QUALIFICATION

Katalin Szakálosné Dr. Mátyás - Ferenc János Sudár - Attila László Dr. Horváth
Institute of Forest- and Environmental Techniques
Faculty of Forestry
University of Sopron
Bajcsy-Zs. u. 4, H-9400 Sopron, Hungary
szakalosne.matyas.katali@uni-sopron.hu, ahorvath@uni-sopron.hu

Abstract: *Labor shortages make tree harvesting difficult nowdays. Therefore, there is a tendency that multi-function machines are spreading in Hungary.*
Thanks to technical and technological developments, the harvester-forwarder units can be used in broadleaf forest or thinning.
Systems have part in the forest management in Hungary. However, the question is whether the quality of work will change or this system could be careful.

Keywords: harvester, logging damage

1. Introduction

More and more harvesters and forwarders have been appearing in Hungary in the last years. Highly mechanized logging technologies are more often used, for example the CTL (Cut To Length) work system when felling, skidding, delimbing, assorting, chopping, bunching and reviewing are done with a harvester and skidding and forwarding are done with a forwarder.

The timbering working systems was compared with percentage indexing methods on points developed on a conceptual or experiental basis till now in terms of the tolerance. Ormos–Rumpf–Keresztes (1990) applied a method on points, Mihály (1993) prepared weight number assessment. Suwala (2000) drew up a percentage indexing method that averages the index of the tree harms and the harm index of the upper soil layer.

The damaging which can be caused by the harvesting, are not restricted to the stands of trees and the harms, which were caused in the soil. Gólya (2003) drew up an evaluative system, which takes the rest of the elements of the sylvan environment into consideration. Harvestings' comlex classification can be done with the thinning result control. This method includes the examination of the tolerance.

2. Material and Methodes

2.1 Questionnaire

A questionnaire was carried out to find out the factors influencing the quality of harvesters working. A questionnaire was compiled in order to get to know the circumstances influencing the work, so it was possible to get the opinion of the practitioners more widely. The first few questions required independent answers (job, age, place of work), which later could be used to group the answers or to filter out irrelevant ones. The influencing factors in the questionnaire had to be rated on a scale of 1-10 (1 is the weakest 10 is the strongest). In the last reply, further comments could be made.

Results in the answers are numbers from 1 to 10, so they can be easily averaged. Below the averages we calculated the standard deviation, so that the more shared questions become visible. The weighting of the influencing factors was averaged in the column direction. We averaged the answers in several directions, so we got the average value of each respondent, which is also suitable for filtering out the bad answers.

Field work was aided by the influencing factors identified in the questionnaire survey. A protocol form was created. It contained possible answers to the relevant aspects, so that the conditions of the exploration under investigation should be circled only during field trips and interviews. This form allows you to categorize all the extractions according to the same criteria, and it only takes a few minutes.

2.2 Field surveying

The field data captures happened in Leka, Schwarzenbach and Langeck. Some of these areas were 1-5 ha private forest. Allocation of ground plots was on Borostyánkő and Kőszeg mountains.
It is important to mention the 45,5 lm/ha (linear metre pro hectare) accessibility in the area of the examined forests, which is very high. To compare, in domestic forests this value ranges from 4 to 22 lm/ha, with an average of 7,2 lm/ha.

The reforestation occurs naturally, the regrowth can be found everywhere, in different age distribution and density. In order to protect the natural regeneration, it is important to keep the wild game at a tolerable level, which is achieved through intensive hunting. A short-tree working system was used with harvesters and forwarders.

Data measured in the plots:

- Skidding trails distances.
- Plots areas.
- Tree species, number of pieces, breast height diametres, tree heights.
- Stem hurts, hurts sizes, skidding trails deep.



Figure 1.: The tested harvesters and forwarders (Sudár, 2018)

3. Results

3.1 Factors affecting loggings

The questionnaire survey received 53 valid answers from Hungary (Figure 2.) and 9 from Austria and Germany (Figure 3.). 34 manual workers and 28 intellectual workers completed the questionnaires.

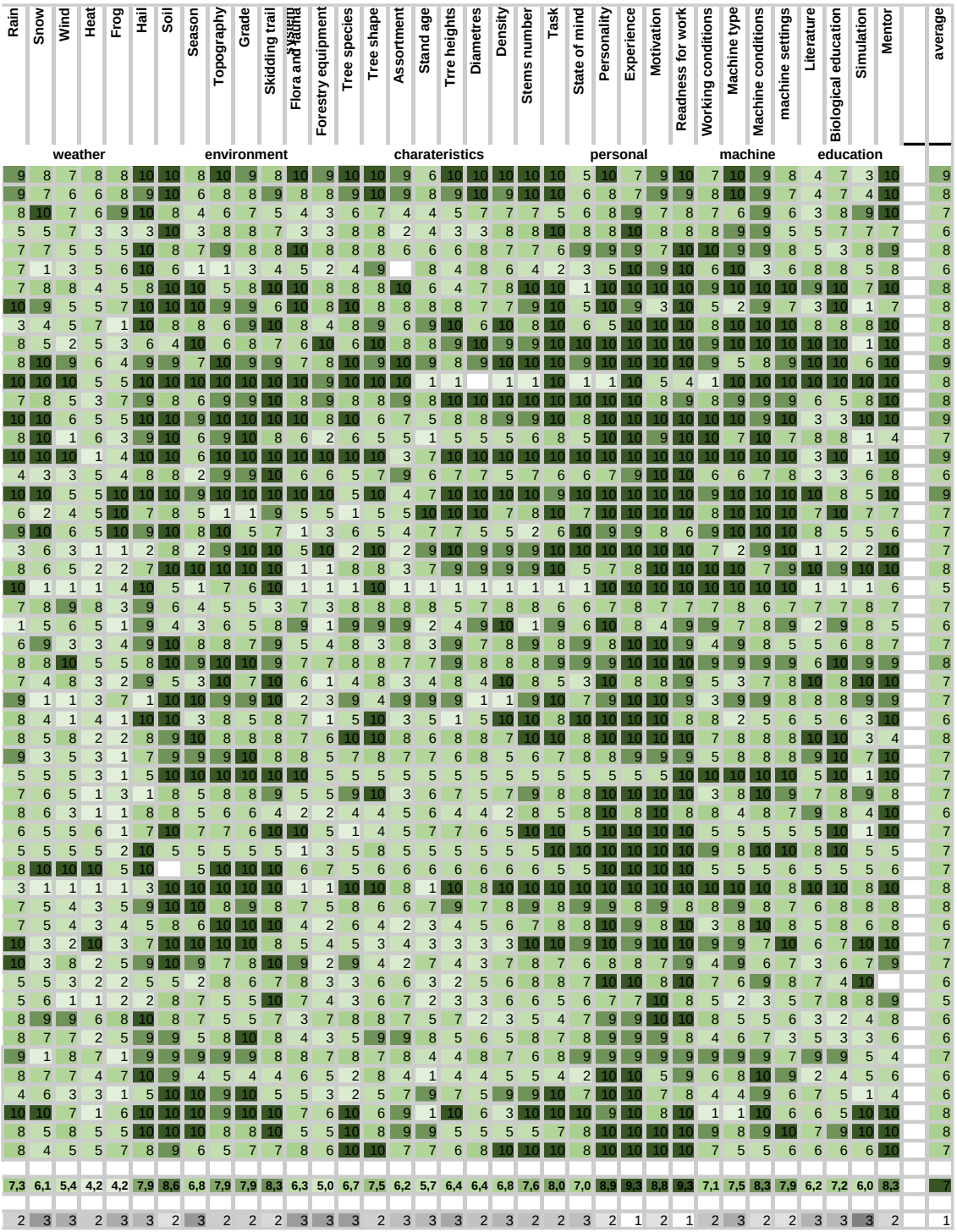


Figure 2.: The Hungarian answers

According to the Hungarian answers, two serious problems are clear: the low quality forestry skilled worker and the low pay of forestry enterprises.

Comparing the Hungarian and German-Austrian answers, there are differences. Overall, the mean of the Hungarian answers were 7,1 and the German-Austrian answers were 6,6 so the German-Austrian respondents generally replied more modestly. As regards environmental parametres, it is generally true that Hungarian respondents considered it more important. The biggest difference can be seen in the question of ice, tin, and hail, with Hungarian respondents saying it is 37% more important. The second major difference in the issue of education is the importance of the mentor, with 24% of Hungarian respondents thinking that the mentor's help is more important. The third big difference is the characteristics of the forest. For German-Austrian respondents, wildlife is more important, 22% thought that it was more important than Hungarian respondents. There was no significant difference between the tree species, the forest equipment, tree shape, assortments.

Rain	Snow	Wind	Heat	Frog	Hail	Soil	Season	Topography	Grade	Skidding trail system	Flora and fauna	Forestry/running equipment	Tree species	Tree shape	Assortment composition	Stand age	Tree heights	Diametres	Density	Stem number	Task	State of mind	Pesonality	Experience	Motivation	Readiness for work	Working conditions	Machine type	Machine condition	Machine settings	Literature	Simulation education	Mentor		average
3	1	8	2	5	3	10	10	10	10	10			3	10	10	4	9	8	9	10		10	8	8	7	8	9	9	9	9					7,6
9	6	1	1	8	1	10	10	8	3	1	10	2	1	9	7	10	10	10	10	2	10	10	10	4	10	10	7	6	10	1	4	5	5		6,5
4	3	4	1	6	8	10	4	5	4	2	7	7	4	6	3	3	7	6	4	8	8	7	7	7	4	8	2	7	6	6	3	6	4		5,3
5	3	2	2	3	5	10	6	7	7	10	10	6	5	9	5	8	8	4	3	8	9	3	5	9	9	6	5	8	8	6	3	1	5		6,0
3	8	2	5	1	4	10	10	7	8	8	8	9	10	6	7	8	6	6	1	4	7	9	10	7	9	8	8	10	10	10	7	4	10		7,1
8	6	9	9	6	8	8	4	6	8	8	10	8	8	7	9	8	6	3	3	7	7	6	8	10	10	1	9	6	8	7	9	5	1		6,9
6	1	7	1	2	2	8	10	5	3	7	4	2	8	9	7	7	7	4	6	10	5	8	10	7	8	7	2	4	5	6	3	9	10		5,9
7	5	3	5	1	2	7	10	7	7	10	10	5	10	7	7	10	10	7	1	10	10	7	7	10	10	10	1	1	5	1	2	2	5		6,2
10	6	1	3	3	3	5	10	8	10	10	8	8	8	8	8	10	10	10	10	10	10	5	5	5	5	5	5	10	5	5	5	5	5		6,9
8	4	7	5	3	5	10	7	9	9	9	9	3	9	9	8	8	9	9	9	9	8	9	9	9	9	9	9	9	9	9	9	6	10		8,0
6,3	4,3	4,4	3,4	3,8	4,1	8,8	8,1	7,2	6,9	7,5	8,4	5,6	6,6	8,0	7,1	7,6	8,2	6,7	5,6	7,8	8,2	7,4	7,9	7,6	8,1	7,2	5,7	7,0	7,5	6,0	5,0	4,8	6,1		6,6
2	2	3	3	2	2	2	3	2	3	3	2	3	3	1	2	2	2	3	4	3	2	2	2	2	2	3	3	3	2	3	3	2	3		1

Figure 3.: The German and Austrian answers

In the questionnaire, respondents provided more details besides environmental factors. According to the answers, the two most important circumstances are the person and the environment. Within a personal or machine management group, the experience, motivation and personality influence the quality of the work more. Within the environment group, the soil, skidding trail system, topography and sloping terrain are the most influential factors, according to respondents.

3.2 Logging damage

The basis of the research was the examination of 10 logging. Great emphasis has been placed on recording the circumstances so that the values obtained can serve as a basis for comparison.

An evaluation table (Figure 4.) was prepared for processing the data, which contains all the measured datas. The evaluation was always done with Microsoft Office Excel to facilitate usability. Each page has data for a plot and its evaluation, so it is easy to review and evaluate each plot in its own right. At the bottom of the page, sample data for each harvesting are summarized.

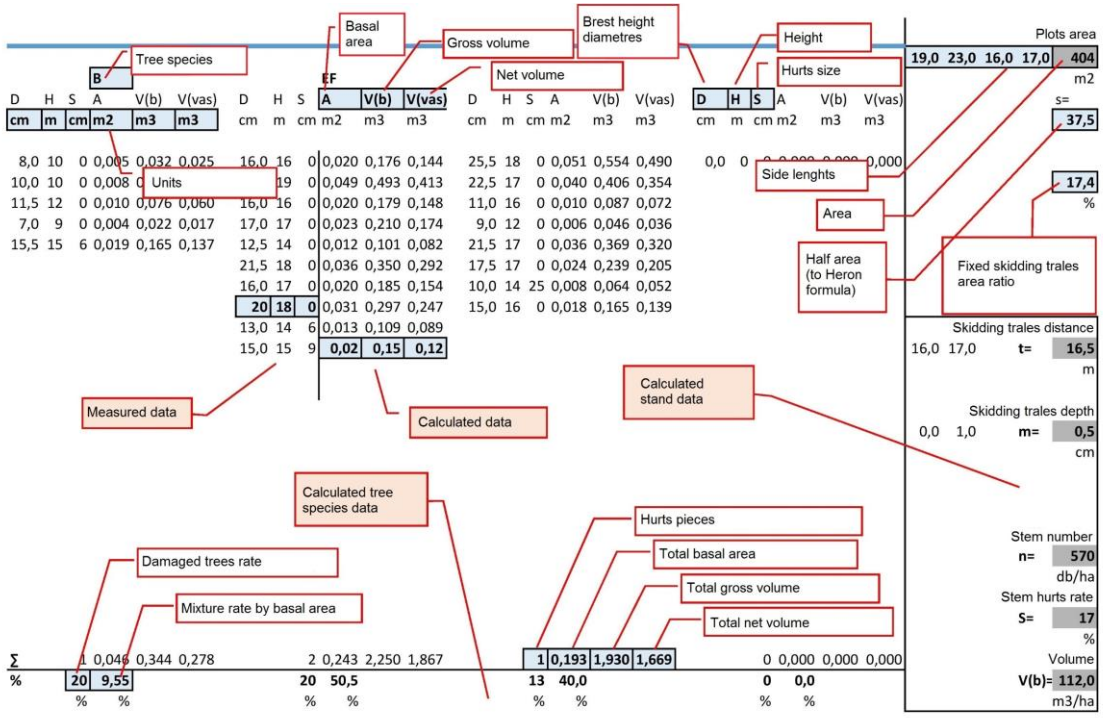


Figure 4.: The evaluation table

The results of the examination of the injuries of the remaining pieces of wood were in accordance with our expectations and the literature. The beech (7,8%), spruce (7,2%) and fir (7,5%) were damaged at a higher rate, while oak (2,7%), larch (3,3%) and Scotch pine (6,0%) were less damaged.

The average skidding trail distance was 16,2 m, the minimum was14,4 m, the maximum was 18,4 m. The average skidding trail width was 3-3,5 m. On average, 16,7% of the forest area is covered by skidding trail system.

The depth of the skidding trails was also measured, which shows that a depth of more than 1-2 cm was formed where the slope increases (above 20 °), and the soil carrying capacity or the branch carpet thick was not enough. Only 2 test areas had a critical proximity skidding trail (soil damage) of more than 10 cm. Thanks to the soil integrity, the root system did not suffer from any major numerical damage.

Thanks to the system of the skidding trail, there was enough space for the movement of the machines, so no stump damage occurred. After 30-40% thinning intensity, depending on the circumstances, the stem injury was 0-19%. The average rate of damaged trees was 8-9%.

4. Discussion

The final conclusion is that the highly mechanized logging work system in the studied forest areas does not cause much damage. Thanks to the well-chosen machines, well-established network and work order. The developed measuring systems are always well-suited for application and the logging can be compared with them.

5. Acknowledgements

The described work was carried out as part of the „Sustainable Raw Material Management Thematic Network – RING 2017", EFOP-3.6.2-16-2017-00010 project in the framework of the Széchenyi 2020 Program. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

6. References

Gólya, J. (2003) "Munkarendszerek környezeti elviselhetősége. Fakitermelési munkarendszerek gyérítésekben" Doctoral dissertation, Nyugat-Magyarországi Egyetem, Sopron 141 p.

Horváth, A (2015) "Többműveletes fakitermelő gépek a hazai lombos állományok fahasználatában" Doctoral dissertation, Nyugat-Magyarországi Egyetem, Sopron 180 p.

Sudár, F (2018) " Kíméletességi vizsgálatok magasan gépesített fakitermelési munkarendszerekkel kezelt erdőkben" Soproni Egyetem, Sopron p. 75.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

COST AND PRODUCTIVITY OPTIMIZATION USING DIFFERENT MOUND PREPARATION METHODS

Kristaps Makovskis, Dagnija Lazdina, Edgars Dupuzs
Latvian State Forest Research Institute "Silava"
kristaps.makovskis@silava.lv

Abstract: *Forest site preparation before planting improves growth conditions in site and leads to better tree survival rates. In sites with high humidity level, mounding soil preparation method in Latvia is used. Mounding is done by special mounding or conventional buckets with excavators as base machine. In this study adapted and improved trapezoidal drainage bucket was used, where soil preparation was done together with ditch digging and 4 different soil preparation methods were used – ditch digging together with mounding, only mounding, reversed turf soil preparation and scarified area soil preparation method. All preparation methods were used and mixed together in the same site according to site conditions. Soil preparation work productivity, costs and quality were assessed and compared. Aim of the study was to compare different soil preparation methods by using the same soil preparation device, where different soil preparation methods are used in the same site changing them according to conditions in site. Assuming that it is necessary to prepare 2000 planting spots in hectare, using only ditch digging + mounding preparation method it will require 13 hours, doing only mounding soil preparation method 8.3 hours, doing reversed turf soil preparation method 7.2 hours and doing scarified area method 3.5 hours. Soil preparation costs for 2000 mound preparation using only ditch digging + mounding method is 540 EUR ha-1, doing only mounding soil preparation method 345 EUR ha-1, doing reversed turf soil preparation method 300 EUR ha-1 and doing scarified area method 145 EUR ha-1. All soil preparation methods meet the quality requirements of well prepared planting spot and therefore it is possible to provide appropriate soil preparation quality with all these soil preparation methods. Mixing these soil preparation methods using the same adapted trapezoidal drainage bucket in one site and use them according to particular site situation, it is possible to reduce soil preparation costs and improve growth conditions in site.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

INDICATOR BASED ASSESSMENT OF TRAFFICABILITY OF FOREST ROADS

Marian Schönauer [1], Franz Holzleitner [2], Dariusz Pszenny [3], Jarosław Kikulski [3], Gernot Erber [2], Dirk Jaeger [1], Markus Riegler [2], Stephan Hoffmann [1,4]

[1] Department of Forest Work Science and Engineering, Burckhardt-Institute, Georg-August-Universität Göttingen, Germany; [2] Institute of Forest Engineering, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences, Vienna, Austria; [3] Warsaw University of Life Sciences, Forest Utilisation department, Warsaw, Poland; [4] Chair of Forest Operations, University of Freiburg, Germany

marian.schoenauer@uni-goettingen.de

Abstract: *Year-round accessibility of forest road networks is crucial for an efficient wood supply chain, particularly for timber harvesting operations and transport activities. In this respect, detailed knowledge about the seasonal accessibility including the maintenance status of forest roads is highly recommended. The prerequisite for any approach to gain this knowledge is that it should be easily applicable to a large variety of forest road types. Therefore, the goal was to develop a nearly universally applicable, Pan-European forest road status and maintenance mapping approach. It should be capable of assessing the actual condition of forest roads for identifying maintenance needs on a Pan-European scale and can be used for a verifiable forest road classification.*

In a first step, an indicator set based on road construction standards was compiled. Based on this set, the approach has been developed in cooperation between Germany (University Goettingen, Department of Forest Work Science and Engineering), Austria (BOKU, Institute of Forest Engineering) and Poland (Warsaw University, Forest Utilization Department). During three pilot case studies, conducted in Austria (hilly/mountainous terrain), Germany (hilly terrain) and Poland (flat terrain), various roads have been surveyed and the approach was evaluated and adapted.

Starting at a GPS referenced designated point, data collection points are set at 50 m intervals following the preselected road direction. At every point, cross sectional road characteristics including general condition , profile, bearing capacity, and related infrastructure such as culverts were assessed and recorded. Roads bearing capacity was measured with a Light Weight Deflectometer. The other parameters were assessed by expert's valuation and measurement.

Overall, 9.1 km of forest roads representing three case studies are recorded according to the developed approach. Bearing capacity was captured for each case in spring and autumn. Hereby seasonal effects on trafficability between the measurements in spring and autumn became obvious.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

APPLICABILITY OF HARVESTERS IN SELECTIVE CUTTING

Attila László Horváth – Mihály Rátky – Katalin Szakálosné Mátyás
Institute of Forestry and Environmental Techniques
Faculty of Forestry
University of West Hungary
Bajcsy-Zsilinszky street 4., H-9400 Sopron, Hungary
ahorvath@uni-sopron.hu, szakalosne.matyas.katalin@uni-sopron.hu

Abstract: *As a result of new developments in technology, harvesters can used not only in pine forest but also in hardwood stands. This technology is now not only used in clear cutting, increment and selection thinning in Hungary, but also in selective cutting. These harvester are not only used in state and private forests, but also in protected forests of some national parks. We made measurements in the Őrség National Park where was selective cutting with a high mechanized logging work system. In order to analyze and evaluate the structure of the work day and performance of the harvesters, field surveys were done with continuous time measurement. Besides recording the duration of individual actions, among others the total volume of the timber processed in each cycle and the distances of changeovers were also recorded.*

Keywords: harvester, logging, performance, selective cutting, working day structure

1. Introduction

As a result of new developments in technology, harvesters may no longer be confined to softwood forests only. Several studies carried out in black locust, Turkey oak, beech and oak stands have justified the use of these machines in hardwood stands (Figure 1.). Evaluating the results of the cost and time analyses we concluded that harvesters are more efficient in several cases compared to traditional wood cutting with chainsaws.



Figure 1.: Harvesters in Hungary

2. Material and Methodes

2.1 Analysis and evaluation of the work with harvesters

Nowadays multi-operational logging machines work in both hardwood and softwood stands. In Hungary, depending on conditions of terrain, some of this equipment is primarily used in hardwood stands, while other types are almost exclusively used in softwood forests. Based on the foreign results in efficiency and productivity of harvesters, there is no doubt that these machines should be the first choice for domestic softwood forests too. However, their use in domestic hardwood stands raises many questions. In the past few years multi-operational logging machines have already been used for logging domestic forests (in black locust, alder, hybrid poplar, Turkey oak, hornbeam-oak, beech, hornbeam-Scots pine, spruce, Scots pine and black pine stands). Clearcutting, thinning, preparatory cutting and sanitary cutting, as well as selective cutting were all done with these machines.

In order to analyze and evaluate the structure of the work day and performance of the harvesters, field surveys were done with continuous time measurement. Besides recording the duration of individual actions, the total volume of the timber processed in each cycle and the distances of changeovers were also recorded. During the survey, the following types of actions were distinguished (Horváth A., 2012; Horváth A., 2015):

- Felling (F): equals the time required for the machine operator to place the harvester head onto the base of the tree, using the manipulator arm, and felling, preassembly, debranching of the log as well as the conversion into assortments and piling by assortments.
- Changeover (C): is the duration of machine displacement.
- Felling only (FO): time spent on logging very thin or poor quality (e.g. completely rotten) logs, which do not yield valuable assortments.
- Arranging branch material (B): transfer and rearrangement of branches obstructing the path of logging.
- Arranging timber (T): transfer and arrangement of timber stacks obstructing the path of logging.
- Rest period (R): time for meeting personal needs.
- Troubleshooting (TH): time for fixing technical defects in the machinery.
- Waiting (W): other time losses (e.g. phone calls).

2.2 Selective cutting using the Ponsse Ergo 6WD harvester

The selective cutting in a 97-year-old, 3,21 hectare total area of hornbeam – beech – Scotch pine mixed stand (Figure 2.) was done using a Ponsse Ergo 6WD multi-operational logging machine. The forest area



Figure 2.: Hornbeam – beech – Scotch pine mixed stand, Apátistvánfalva 28C

is protected, located in the Őrség National Park and is also part of the NATURA 2000 network. According to the data of the management plan – depending on the tree species –, the average height of the trees was 17 - 26 m, and average diameter at breast height was 20 - 40 cm (Table 1.). Before the logging, workers of the forest management unit had marked the trees intended for cutting with paint. The machine operator converted the logs into assortments as follows: 3.1 m, 4.1 m, 5.1 m, 6.1 m logs and 2 m pulpwood for boards from pine, as well as 2 m household firewood from beech and hornbeam.

3. Results

3.1 Working day structure

The field survey and data collection were done in 3 days (708,17 minutes). During the period of the measurement (Table 2., Figure 3.) 54,7% of the operating time was spent on felling trees, 21,3% was for changeovers. and around 4,2% of the time was spent arranging the branch material. This type of harvesting involves a relatively high frequency of changeovers. The average changeover distance was 6,8 m, and the average time needed for changeovers 0,7 min. The proportion of rest period was 15,5%.

Table 1.: Data of management plan, Apátistvánfalva 28C

Number	Canopy	Tree species name	Mixture rate (%)	Mixture mode	Aver. age (year)	Aver. height (m)	Aver. diam. (cm)	Canopy closure (%)	Blasa area m^2/ha	Wood stock (m^3/ha)	Wood stock in subcompartment(m^3)
1	Upper	Beech	23	Main species	77	20	25	77	8	78,01	250
2	Upper	Beech	4	Spread	97	26	40	77	1	20,00	64
3	Upper	Scotch pine	46	Spread	97	22	33	77	15	166,01	533
4	Upper	Pedunculate oak	9	Spread	97	25	39	77	3	32,99	106
5	Upper	Hornbeam	18	Spread	77	17	20	77	4	36,01	116
6	Lower	Hornbeam	100	Main species	37	15	17	25	6	45,02	145
								Total	**37**	**378,04**	**1214**

Table 2.: Data of action items, Ponsse Ergo 6WD harvester

Action items	Σ time	Rate	Element	Aver. time
	min	%	piece	min
Felling (F)	387,65	54,7	302	1,28
Changeover (C)	151,16	21,3	216	0,70
Felling only (FO)	21,00	3,0	31	0,68
Arranging branch material (B)	29,59	4,2	37	0,80
Arranging timber (T)	4,25	0,6	5	0,85
Rest period (R)	109,77	15,5	8	13,72
Troubleshooting (TH)	4,33	0,6	1	4,33
Waiting (W)	0,42	0,1	1	0,42
Total (Σ)	**708,17**	**100,0**		

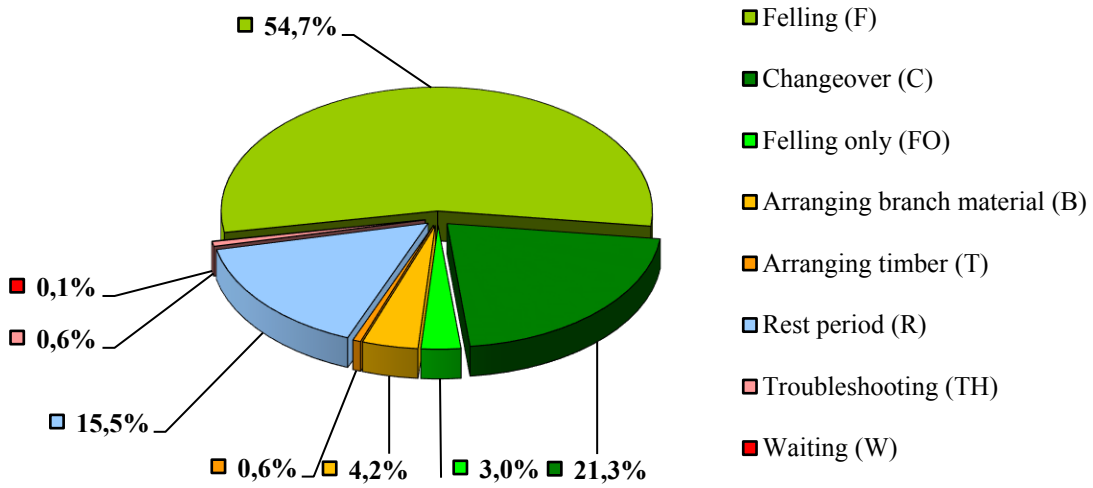


Figure 3.: Working day structure of Ponsse Ergo 6WD harvester (Rátky, 2019)

3.2 Performance of harvester

The volumes of harvested and processed timber (146,6 m^3) and the duration of the single actions were considered to estimate performance values. The hourly performance of the Ponsse Ergo 6WD multi-operational logging machine (working time) was 12,4 m^3/h. The shift performance in productive time was 118,5 m^3/shift (Table 3.).

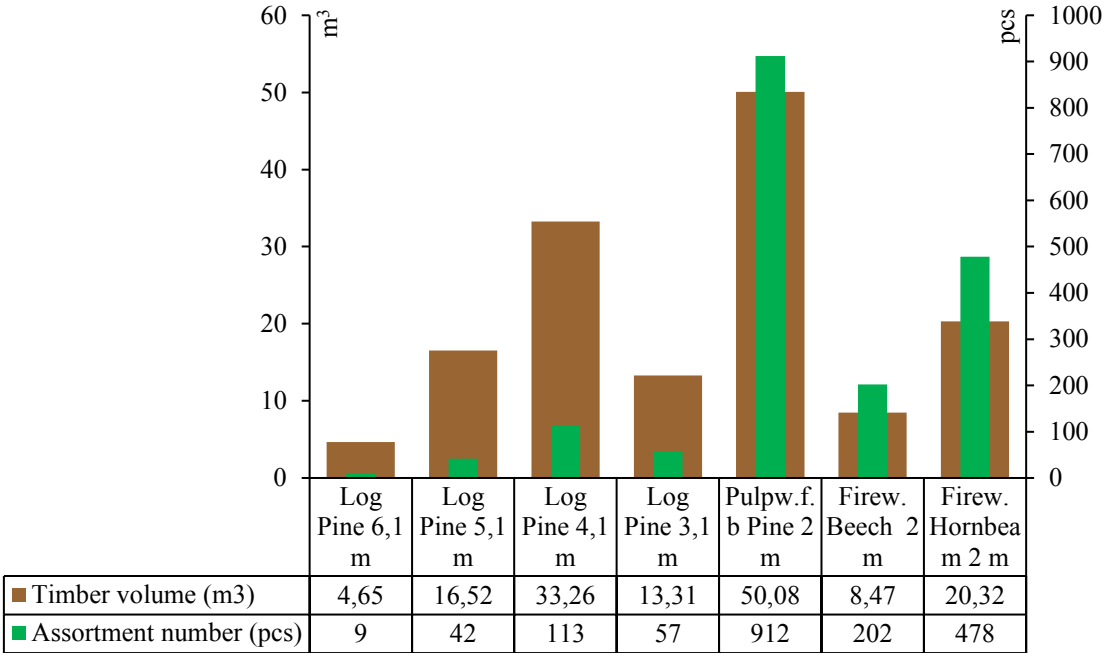
Table 3.: Performance of the Ponsse Ergo 6WD harvester (Rátky, 2019)

Performance		m^3/h	m^3/shift
Logging time	(F+C)	16.3	130,6
Productive time	(F+FO+C+B+T)	14,8	118,5
Working time	(Σ)	**12,4**	**99,4**

Altogether 331 trees were cut, which were 46,2% of Scotch pine, 39.6% of hornbeam, 12.4% of beech, 1.2% of aspen and 0.6% of pedunculate oak. The cut 146.6 m^3 of wood was made up of 1813 assortments (Figure 4.).

4. Discussion

Regarding optimal technological developments, logging done with harvesters can also be introduced to selective cutting and not just clearcutting and thinning. This however requires higher level professional attention and control.



	Log Pine 6,1 m	Log Pine 5,1 m	Log Pine 4,1 m	Log Pine 3,1 m	Pulpw.f. b Pine 2 m	Firew. Beech 2 m	Firew. Hornbeam 2 m
Timber volume (m3)	4,65	16,52	33,26	13,31	50,08	8,47	20,32
Assortment number (pcs)	9	42	113	57	912	202	478

Figure 4.: Assortment structure

5. Acknowledgements

The described work/article was carried out as part of the „Sustainable Raw Material Management Thematic Network – RING 2017", EFOP-3.6.2-16-2017-00010 project in the framework of the Széchenyi2020 Program. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

6. References

Horváth A. L. – Szné. Mátyás K..– Horváth B. (2012): Investigation of the Applicability of Multi-Operational Logging Machines in Hardwood Stands. Acta Silvatica et Lignaria Hungarica Vol. 8, Magyar Tudományos Akadémia Erdészeti Bizottsága, Sopron, ISSN 1786-691X, pp 9-20.

Horváth A. L. (2015): Többműveletes fakitermelő gépek a hazai lombos állományok fahasználatában. NYME EMK EMKI, Doktori disszertáció, Sopron, 180 p.

Horváth B., Marosvölgyi B., Neményi M., Sitkei Gy., Czupy I., Fekete Gy., Horváth A. L., Major T., Vágvölgyi A. (2016): Erdészeti gépek, Szaktudás Kiadó Ház Zrt., Budapest, ISBN:978-615-5224-69-0, 476 p.

Rumpf J., Horváth A. L., Major T., Szakálosné Mátyás K. (2016): Erdőhasználat, Mezőgazda Kiadó, Budapest, ISBN:9789632867199, 390 p.

Rátky M. (2019): Magasan gépesített fakitermelési munkarendszerek vizsgálata az Őrségi Nemzeti Park területén, Diploma work, Sopron, 49 p.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

NEW METHOD OF YOUNG STANDS TENDING OF DOUGLAS FIR IN NORTHRHINE-WESTPHALIA

Marian Schönauer, Dirk Jaeger
Department of Forest Work Science and Engineering
Faculty of Forest Sciences and Forest Ecology
Georg-August-Universität Göttingen
Büsgenweg 4, 37077 Göttingen, Germany
marian.schoenauer@uni-goettingen.de
dirk.jaeger@uni-goettingen.de

Abstract: *Eleven years after major windthrows caused by Kyrill in 2007, many forest owners are faced with the question of efficient management of young stands on afforested areas. For economic reasons, many forest owners in North Rhine-Westphalia were planting conifers such as Douglas fir. Together with ingrown natural regeneration these young stands became very dense, which makes the tending difficult due to limited accessibility. Internal preliminary investigations of "Wald und Holz NRW" in Arnsberg, Germany have shown, however, that early tending (especially in the case of Douglas fir) leads to an improved performance of the stands.*
So far, in the commonly used method, the tending has been divided into several separated work steps and carried out with a handsaw (pruning of potential crop trees) and a chainsaw (removal of competing trees):

(1) Planning and marking foot paths (access trails),
(2) clearing of access trails,
(3) marking of potential crop trees as well as of 1-2 competing trees of the potential crop tree,
(4) pruning of potential crop trees and removal of competing trees.

The new method combines steps (1), (3) and the pruning of potential crop trees in phase 1, as well as the creation of the access trails and the removal of competing trees in phase 2. The operator is equipped with a forestry clearing saw ("Spacer") and a cordless pruning shear.
By attaching a long-term ECG to the body of the person performing the work, the individual physical strain during the work process is recorded in high resolution. The additional video taping of the active person allows for analysis of body posture during work.
While the time required for phase 1 is the same between the common and the new method, there are significant differences in heart rate. Heart rate and time required in phase 2 show no differences between the methods, but when working with a chainsaw when applying the common method the posture is more stressful.

Keywords: young stand tending, Spacer, physical strain, time study

Acknowledgements

The thanks is directed to Lehr- und Versuchsforstamt Arnsberger Wald in Northrhine Westfalia, Germany, especially to Thilo Wagner and Martin Nolte.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 -Sopron, Hungary

OPTIMIZATION OF WOOD TRANSPORTATION THROUGH TRUCKS FROM WOOD CUTTING AREAS TO CUSTOM CENTER USING GIS TECHNOLOGIES

Tihomir Krumov
University of Forestry,Dept. of Technologies and Mechanization in Forestry
10, Kliment Ohridskiblvd., 1756 Sofia,
BULGARIA
t_p.krumov@abv.bg

Abstract: *In recent years there has been a significant development of the agrarian sector in Bulgaria and a lasting tendency for the consolidation of agricultural arable lands. The establishment of large arable land masses is made in order to simplify the technological operations in the management of agricultural land. In much of Bulgaria, the agricultural territories completely surround the forest fund. The treatment of Polish roads and the lack of access to forest areas leads to the hindering of any activity in forests - harvesting, icing, keeping, guarding special uses, hunting, etc. After analyzing the freight transport process and optimizing the freight routes, a 25-30% reduction in transport distances has been achieved, with productivity gains. The highest percentage of the transport cycle is at the expense of the movement of the transport machine on agricultural roads.*

Key words: transportation, wood, routes, efficiency, cost

Introduction

With the amendment of the Law on the Ownership and Use of Agricultural Lands (LAWA) (Supplemented SG No. 77 of September 18, 2018) and the normative acts in force thereto, and with the decisions of the Municipal Councils, the provision of real estate - field roads has been regulated, falling into arrays for use. According to Art. 37c para. 4 of the LPOS, only the roads designed in the land plan and in the map of the restored property can be included in the arrays. Although regulated as legal infringement, in many cases arable land lacks any arable land. In most of Bulgaria the agricultural territories completely enclose the forestry fund. The cultivation of arable roads and the lack of access to the forest territories prevents any activity in the forests - logging, icing, management, protection, special uses, hunting, etc.

Modern forestry is developing on the basis of modern and high-tech transport technology, which is unthinkable to be used effectively without a rational road transport network. The transportation of timber from logging sites to consumer centers (timber processing enterprises and direct consumers - households) is 100% mechanized. The proper organization of the transportation of timber affects the economic indicators: productivity of transport, production cost and profit [Zhekov,. 2003, Nikolov and Gadzhov, 2010, Nikolov, 2012]. In most of our country, high-throughput trucks are used. They are equipped with a loading platform equipped with terminals for the transport of different sizes (assortments) of timber [Stoilov, 2016]. In view of all the above, it is necessary to analyze the transport process of timber from the forestry fund through the agricultural territories and its delivery to consumers.

Methodology

The transport process consists of a series of sequential and interconnected operations. For the transportation of timber, the completed cycle (from temporary storage to transfer) of the transport process consists of the following operations [Hristov and Statkov 1978]:

- Move empty trucks to temporary warehouses;
- Timber loading;

• Moving trucks from temporary warehouses to consumers;
• Timber unloading.

Proper timber transportation enhances truck productivity. This can be achieved by complying with the following requirements:

- Complete sealing of the truck working day;
- Full utilization of truck capacity;
- Increasing truck performance (driving speed and more).

The complete cycle of the transport process, including: unladen movement, loading, loaded moving and unloading is called a course. The time (T_k) for which a course is taken is determined by the formula:

$$T_k = t_{нт} + t_m + t_{разт} + t_{тов} \quad (1)$$

Where $t_{нт}$ is the time the truck moves to the temporary warehouse (BC);

$t_т$ – the time the truck moves from the temporary warehouse to the customer center;

$t_{разт}$ – the time it takes to unload the truck at the temporary warehouse;

$t_{тов}$ – the time for which the truck is loaded;

The movement time with and without load must be created and diverted to the carriage and the speed of movement:

$$t_{нт} = \frac{l_{нт}}{V_{нт}} \quad \text{and} \quad t_m = \frac{l_m}{V_m} \quad (2)$$

Where $l_{нт}$ и $l_т$ – are respectively the distance traveled without load and with load;

$V_{нт}$ and $V_т$ – respectively, are the average speeds when unloaded and loaded.

From which it follows that the transport distance significantly affects the duration of the transport process.

The average transport distance also affects the productivity of the transport unit. It can be determined by the following formula. Also the distance of the truck affects the performance of the trucks. This is also evident from the shift performance formula [Stoilov, 2016]:

$$П_{см} = \frac{\varphi_т.\varphi_о.\gamma_{дин}.(T_{см}-t_{пз}).V_{Qном}.L_{ср}}{L.\frac{v_m+v_{нт}}{v_m.v_{нт}}+t_{тов}+t_{разтв}+t_{изч}}, \text{ m}^3\text{.km/см} \quad (3)$$

As timber truck transport routes involve traffic on different road conditions, we can develop the Shift Performance ($П_{см}$) formula [Stoilov, 2016] as follows:

$$П_{см} = \frac{\varphi_т.\varphi_0.\gamma_{дин}.(T-t_{пз}).V_{Qном}.(l_1+l_2+l_3+l_n)}{l_1.\frac{v_{т1}+v_{нт1}}{v_{т1}.v_{нт1}}+l_2.\frac{v_{т2}+v_{нт2}}{v_{т2}.v_{нт2}}+l_3.\frac{v_{т3}+v_{нт3}}{v_{т3}.v_{нт3}}+l_n.\frac{v_{тn}+v_{нтn}}{v_{тn}.v_{нтn}}+t_{тов}+t_{разтв}+t_{изч}}, \text{ m}^3\text{.km/см} \quad (4)$$

Where l_1 is a transport section of the primary forest road network;

l_2 - a transport section of the national road network;

l_3 - the road section of the municipal road network;

l_n - transport section along an agricultural road network;

From which it follows that the speed of movement with load and without load will be different, respectively $v_{т1}$ and $v_{нт1}$, $v_{т2}$ and $v_{нт2}$ and $v_{т3}$ and $v_{нт3}$, $v_{тn}$ and $v_{нтn}$.

When selecting optimization solutions for the choice of transport routes, it is necessary to use the coefficient of difficulty (K_m) . It reflects the actual operating conditions of a road, taking into account the greater or lesser difficulties encountered in a given transport route. The purpose of choosing an alternative transport route is to keep $K_т$ with minimum values.

$$K_m = \frac{L_B}{L_{ПП}} \quad (5)$$

Where $L_{ПП}$ – is the actual length of the road;

L_B- virtual road length [5].

$$L_B = L + (\sum \frac{i_k}{W}.l_k) - \left(\sum \frac{i_c}{W}.l_c\right) + (\sum \varphi.l_н) + (\sum \varphi.l_{кр}) + \sum l_{др} \quad (6)$$

Where L is the entire length of the road in question (the actual length of the road);

i_k and i_c– respectively the longitudinal slope of embarkation and descent;

l_k and l_c - respectively the length of the slope of embarkation and descent;

W - 4% - 0,04 - the movement resistance, including the air resistance for ordinary crushed stone in good condition;

φ – coefficient of resistance of the movement for the pavement in depending on the condition (0,15 - 0,60);

$l_н$ — the length of the road in the appropriate state of the pavement in medium, poor and very poor.

$l_{кр}$ — length of the curve.

Object of research

The subject of the study are the STEYR (forwarded trucks) high-throughput trucks, which are widely used in our country for transporting timber from forest areas to consumer centers (Fig. 1). The trucks are all-terrain and all-wheel drive. This allows to overcome significant irregularities in the terrain and allows it to move without difficulty under poor road conditions and in some cases without pavement. When traveling on the national road network, they are moving at a higher speed, which also achieves a high productivity of the transport process.



Fig. 1 High Passage Truck



Fig. 2 Timber transport routes

Timber transport routes The transport of timber was emigrated to northeastern Bulgaria, where agriculture is best developed (Fig. 2). Large agricultural blocks require truck traffic to be made around the periphery, and in some cases due to lack of road, even directly on arable farmland. In these areas, the conflict between forestry and agriculture is most severe.

According to the Law on Forests (amend. SG 13/02) and the amendments to Ordinance No 1 of 30.01.2012 (amended and supplemented, issue 79 of 13.10.2015) The EFA with wire control and use of forest territories, and in particular for lorry trucks, needs to be equipped with a GPS device, which should be used to control the transportation of the wood. The GPS tracking module continuously transmits real-time truck location information. GPS projects are located for routes using a vehicle.

Results analysis

The data received from the GPS transmitter mounted on the truck has been processed using gis software. Comparing the digital models of the Reclaimed Property Map and the Forests Maps of the designated administrative unit (municipality / forestry) in which the trucks operate, it is found that the agricultural area is

fully consolidated, leaving permanent field roads used. By destination and represent the boundary of the array to be used, ie. divide arrays naturally.

The data provided on truck routes using the tools in the gis software determines the actual transport routes when transporting timber from the place of their extraction to the users (Fig. 2). From the data obtained, it is found that the largest percentage of the transport cycle is at the expense of the road crossing (43%). Following is the time for traffic on national roads (38%) and only 19% for traffic in regulation. This is due to the low traffic speeds on the agricultural roads and within the settlements.It is therefore necessary to optimize the export on the part of the traffic on the agricultural roads by seeking the shortest and most economical route by the coefficient of difficulty.

The hauling is in most cases carried out on roads without permanent pavement, and in some cases even without roads (directly on arable land owned by different owners, which leads to conflicting precedents.Movement on unpaved roads leads to increased skidding, respectively, to increased fuel consumption. Also, the duration of a given operation increases.Also, the duration of a given operation increases. All this requires that in the initial development of the land use plans they should be coordinated with the Forest Management plans for the management of the forest territories.

Using Arcgis tools, potential optimal routes have been identified (Fig. 3). After further processing of the data and based on information from GPS transmitters, a reduction of the transport cycle time by 10% is achieved.

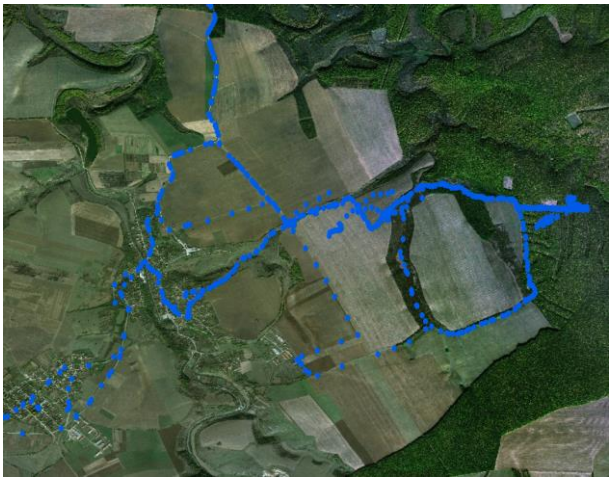


Fig. 3 Transport route of the truck based on GPS data



Fig. 4 Optimizing transportation routes

Analyzing the potential routes, it is found that the export distance can be reduced by 25-30%. Of course, this is theoretical data and the designed export routes are virtual. Additional field measurements are ahead as road conditions are quite dynamic.

Conclude

Based on the conducted research, the following conclusions and recommendations can be made:

1. When transporting timber, the highest percentage of the duration of the transport process is occupied by the traffic on the agricultural roads.

2. Due to the consolidation of agricultural land, a large part of the Polish roads are plowed, resulting in a considerable increase in the transport distances during the transport of timber.

3. Using GIS software programs, short haul distances and high cost efficiency can be determined.

4. Additional field studies are required to confirm optimal routes.

5. When drawing up annual land-use plans, it is necessary to take into account measures for the effective management of forest areas.

ACKNOWLEDGEMENTS

This document was supported by the grant No BG05M2OP001-2.009-0034-C01, financed by the Science and Education for Smart Growth Operational Program (2014-2020) and co-financed by the EU through the ESIF.

Literature

Hristov S., Statkov H.1978. Optimal Density of the Forest Network in Bulgaria . Zemizdat - Sofia, pp. 45-56

Nikolov V., 2012, Design and Construction of Roads, Publishing House of VTU "T. Kableshkov, pp. 34-45

Nikolov V., I. Gadzhov, 2010, Design and Construction of Roads, VTU "T. Kableshkov", 2010, pp. 5-6

Stoilov Art. 2016. Forest Transport Publishing House at LTU pp. 51-67

Zhekov G. 2003, Concept for the Analysis of the Forest Road Network and the Undeveloped Forest Basins in the Republic of Bulgaria, Publishing House at LTU pages 15-18

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

OPPORTUNITIES AND CHALLENGES OF FOREST BIOMASS UTILIZATION

Dóra Szalay*, Viktória Papp
Institute of Forest - and Environmental Techniques
Faculty of Forestry
University of Sopron
Bajcsy-Zsilinszky utca 4., H-9400 Sopron, Hungary
szalay.dora@uni-sopron.hu

Abstract: *The utilization of forest residue is becoming increasingly important in the energy sector. Its versatile usability justified to make a comparison of which form of use is the most favorable in the transportation from an energy point of view. The forest residue has slightly different characteristics due to high bark, ash and contamination content, so their use for liquid lignocellulose biofuels is a particular challenge. It is questionable whether it is a good solution to build new plants with high investment costs, or rather dendromass from forest should be utilized directly to the base material supply of combined heat and power production in the near future. During the work, we made a calculation to determine the amount of obtained electricity from one ton dendromass and the distance, which can be reached with electric vehicles.*
Keywords: dendromass, power plant, electricity, lignocellulose biofuel

1. Introduction

Biomass utilization plays an important role in the energy strategy of EU countries (Simon, 2010). It can be cultivated specifically for carbon storage or as a direct substitute of fossil fuels for energy purposes. Their use is becoming increasingly widespread, because it is reducing the greenhouse effect of the energy sector. Surveys show a significant potential of biomass, which is sufficient to triple the amount of bioenergy in the EU energy mix (Bioenergy Europe, 2019a). From this, about 70% provide by forests at present.

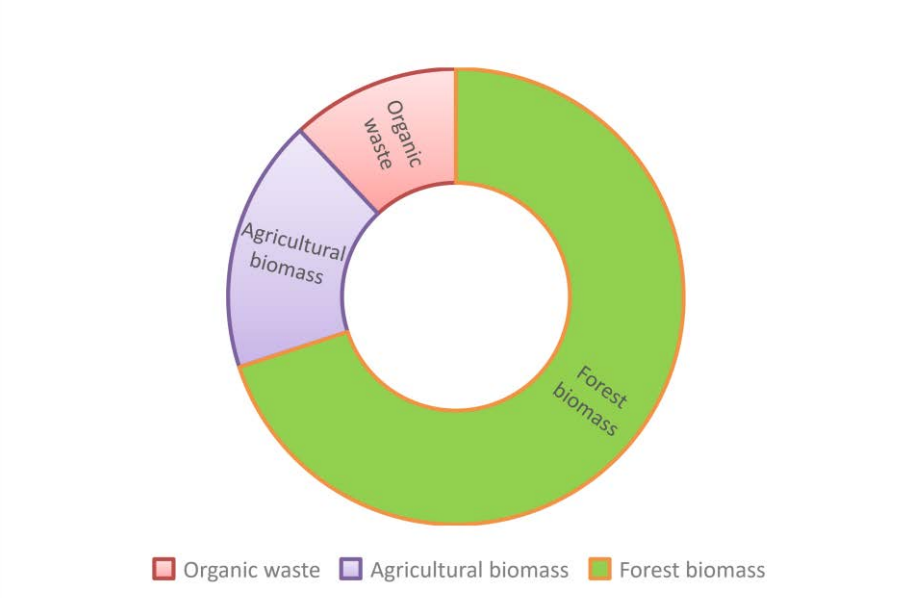


Figure 1: Distribution of different biomass feedstocks in EU energy production (Bioenergy Europe, 2019a)

Dendromass-based free potential may come from forest residues, which is generated as by-product. Nowadays it is only partially collected and is often sold to power- and heating plants, or in smaller quantities to pellet and briquette factories. Different information is available on the currently utilized amount, because the part of the by-product are sourced from foreign countries. According to literature sources, only about 4.5% of the generated thin wood is collected [Szakálosné et al., 2013]. Its role in transport can also be outstanding, because one of the most intensively developing sector is the biomass based renewable fuel production, which is also encouraged by EU regulations.

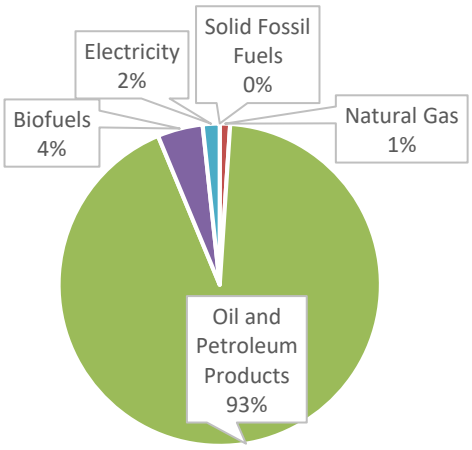


Figure 2: Final energy consumption of the different fuels used in the transport sector in 2017 in EU-28 (Bioenergy Europe, 2019b)

According to RED II (Renewable Energy Directive II) regulation, Member States will have to meet 14% renewable energy use in road and rail transport by 2030. Most of the current requirements are covered by conventional biofuels. Meanwhile, policy makers have recognized that crop-based biofuel production

reduced the arable land for food crops cultivation, through indirect land use. As a result, the maximum contribution of conventional biofuels will be frozen at 2020 consumption levels, plus an additional 1% with a maximum cap of 7% of road transport fuel in each Member State. With help of lignocellulose biofuels there's an opportunity for replacing them. The proportion of advanced fuels to be achieved was defined at the following values in the legislation:
- at least 0.2% by 2022,
- at least 1% by 2025,
- at least 3.5% by 2030.

In Hungary, according to the *Government Decree* No *279/2017* (IX. 22.), the share of biofuels added to conventional fuels must be 6.4% between 01.01.2018 and 31.12.2020. Currently, it is mainly covered by corn based bioethanol. As stated in the draft of National Energy and Climate Plan, the share of renewable energy in the transport sector in Hungary may be 8.1 percent by 2030 (NEKTt, 2019).

Meeting the targets will require major technology improvements in the future, because commercial-scale lignocellulose liquid biofuel plants are located only in five European countries at present. The high utilization rate of electricity in the transport sector is much more predictable in the near future due to technology and infrastructure availability.

2. The challenges of converting biomass into transportation fuel

The forest residues, which generated as free dendromass potential is collectable mainly in the state forestry. We can count with larger volumes on the areas where felling has been done as end use. This activity is generally less frequent in the mountains and more common in the hills and plains in Hungary [Lett-Stark, 2017]. In recent years, there has been an increasing emphasis on continuous forest cover methods, which do not result in a continuous cutting area. This allows the collection of forest residue at a higher cost and with a higher ecological impact.

Pécs Power Plant is the largest utilizer of forest residues in Hungary. We have found further example for firing in smaller quantities in the towns of Pornóapáti, Hangony, Csitár-Nógrádgárdony, Mátészalka, Szakoly, Miskolc, Pannonhalma, Homrogd, and Szombathely. In Tiszaújváros it is used for wood pellet production. Further common utilization forms of forest residues is residential collection. For forestry companies the collection is difficult due to the shortage of labor. Only with the development of mechanization would be possible in significant quantities, but this would lead to higher costs

The conversion of lignocellulose feedstock to liquid biofuels requires a much more complex technology than in case of first generation biofuels. Lignocellulose biofuel production is possible by biochemical and / or thermochemical methods. In general, thermochemical processes, like pyrolysis, gasification and direct thermal liquefaction show greater efficiency, and shorter reaction times than biochemical processes [Dou et al., 2017b; Alonso et al., 2010]. The most often used base materials are industrial by-products, while by-products from agriculture are a lesser extent. Forest biomasses are used especially in Finland for the production of bio-oil or bio-ethanol (Szalay, 2018). One of the most commonly used process is a pyrolysis, which can be converted up to 75% of the biomass into bio-oil, depends on the quality of the input materials (Jahirul et al., 2012, Extension). The ash content is particularly decisive, its amount of the forest residues can be up to 3-4%, which can reach up to 20-40% in thin twigs due to the high bark content [Bíró, 2012]. During the collection, the ash content will continue to rise as a result of contamination and cause excessive wear on treatment and processing systems and reduced oil yield. Furthermore, the product has low viscosity and a high water content of up to 15-20%, which requires further processing to become a substitute of fossil fuels. Overall, conversion rates and production capacity are lower, but the investment cost can be up to ten times higher, compared to advanced biofuels. So their presence in the market usually requires some form of support. As a result the current utilization of dendromass is mainly take place by combustion (Gyulai, 2006). In addition to liquid fuels, electric propulsion can play an important role in the near future of

transport. According to ING estimation up to 100% of newly registered vehicles will be powered by electric vehicles by 2035 (ING, 2017).

There are many technological options for generating electricity from biomass. CHP (combined heat and power) plants are operating an efficiency of 85-86% because heat is also utilized, in addition to electricity. The heat plants in the EU have an average efficiency of 80-84% and only electricity generating power plants of 24-32% [AEBIOM, 2015]. Power plants specifically developed for the use of forest residues and cuttings with relatively low calorific value and high moisture content of up to 30-40% are also already operating in Europe, where they are producing heat and electricity with high efficiently [Lako, 2010]. Use of high moisture biomass is also important property, because the production of bio-oil requires the drying of the base material to 5%, which, even when using waste heat or biomass, need a significant energy input.

Although the technology for generating electricity is mature and the product is directly usable, the batteries for electric vehicles still need improvement.

3. Methods and calculation

The question of how efficiently the electricity produced by Hungarian biomass power plants can be utilized in transport, has not been widely researched. Our calculations and results were based on statistical and special literature data, and on complex analysis of the regulatory background. In Hungary generating less than 50% of the electricity by combined heat and power plants, therefore we were considering the data of both CHP and only electric power plants.

During our calculations, the distance that can be reached by electric car projected for the use of 1 ton of biomass. For electric vehicles, we assumed an average fuel consumption of 20kWh/100km. At the determination of the amount of accountable energy, we used the multiplier defined in RED II. The energy content such as forest residues defined in Part A of its Annex IX, is only recorded at double multiplier for lignocellulose biofuels. However, the contribution of dendromass-based electricity to road transport has to be taken into account by a multiplier of four.

4. Results

During our calculation we selected two power plants in Hungary. In one case, heat is also utilized addition to electricit, while in the other case, only electricity is recovered. Table 1 summarizes the main features of the two power plants.

Table 1: Main characteristics of two Hungarian biomass power plants (based on the data Veolia, 2018)

Power plant	Base material	Efficiency of energy conversation (total) η_t [%]	Effective efficiency (electricity to network) η_e [%]	Effective efficiency (heat + electricity to network) η_{e+th} [%]
Szakoly	woody	28,4	25,4	25,4
Pannongreen	woody	45,9	26,6	40,7

The annual raw material consumption and heat and electricity production reported by the power plants are the following:

- Szakoly: 140-150 kt/yr woodchips

– Pannongreen: 133 GWh electricity
400 kt dendromas
312 GWh electricity
167 GWh heat

Based on the data above, we calculated the recoverable amount of energy and the distance, see Table 2.

Table 2: The amount of electricity can be production from 1 ton of wood and the distance, which can reach with electric vehicles

Type of energy	Technology	Energy-content [10^{-4} ktoe]	Distance [km]	Multiplier (RED II)	Account [10^{-4} ktoe]
Electricity (Szakoly)	Electric power plant	0.79	45	4	3.16
Electricity (Pécs)	Combined heat- and power plant	0.67	39	4	2.68

The result of our calculations is that it can be reached 39-45 km distance with use of 1 ton of wood-based biomass. According to the table 2 the length of the way can be much longer in the case of plant generated only electricity. But it is by no means negligible from the point of view of energy efficiency that the Pécs power plant, also generates an additional 1498 MJ of thermal energy from each ton of dendromass.

5. Conclusions

Commercially available technologies for the production of lignocellulose biofuels are not yet ready to contribute extensively the goals of renewable fuels through economical operation. Currently operating advanced biofuel plants are primarily located in western EU Member States. In the countries acceding after the 2000s to the EU, the production of conventional biofuels is the dominant one. In the near future, meeting the growing energy demand of transport may be mainly with increasing of renewable electricity production, because of lower investment needs. The potential for hydroelectric power generation is already highly exploited and therefore difficult to expand. Despite the increasing capacity of wind and solar energy utilization in recent years, the main solution is to use biomass with decentralized CHP plants with ecological benefits and relatively stable availability.

5 Acknowledgements

The described work was carried out as part of the “Sustainable Raw Material Management Thematic Network – RING 2017”, EFOP-3.6.2-16-2017-00010 project in the framework of the Széchenyi 2020 Program. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

6 References

AEBIOM (2015): Report on conversion efficiency of biomass. BASIS Project.
http://www.basisbioenergy.eu/fileadmin/BASIS/D3.5_Report_on_conversion_efficiency_of_biomass.pdf

Alonso D. M.; Bond, J. Q.; Dumesic J. A. (2010): Catalytic conversion of biomass to biofuels. Green chem, 12, 1493-1513.

Bioenergy Europe (2019a): Biomass Supply Statistical Report 2019, Brussels, p 35

Bioenergy Europe (2019b): European Bioenergy Outlook 2019, Biofuels for Transport, Brussels, p 25

Bíró B. (2012) Biomassza hasznosítás. Kézirat. Edutus Főiskola. p. 86

Dou, C.; Marcondes, W. F.; Djaja, J. E.; Gustafson, R.; Bura, R. (2017): Can we use short rotation poplar coppice for sugar based biorefinery feedstock? Bioconversion of 2-year-old poplar grown as short rotationcoppice. Biotechnol. Biofuels.

Extension: Farm Energy. Fast Pyrolysis Efficiently Turns Biomass into Renewable Fuels. https://farm-energy.extension.org/fast-pyrolysis-efficiently-turns-biomass-into-renewable-fuels/

Gyulai I. (2006): Biomassza dilemma. Magyar Természetvédők Szövetsége Kiadó. Budapest. Második átdolgozott kiadás. ISBN-10: 963-86870-8-8; ISBN-13: 978-963-86870-8-1

ING (2017): Breakthrough of electric vehicle threatens European car industry https://www.ing.nl/media/ING_EBZ_breakthrough-of-electric-vehicle-threatens-European-car-industry_tcm162-128687.pdf

Jahirul M. I.; Rasul M. G.; Chowdhury A. A., Ashwath N. (2012): Biofuels Production through Biomass Pyrolysis —A Technological Review. Energies (5), pp. 4952-5001 ISSN 1996-1073
Lako P (2010): ETSAP Energy Technology Systems Analysis Programme https://iea-etsap.org/E-TechDS/PDF/E05-BiomassforHP-GS-AD-gct.pdf

Lett B.; Stark M. (2017): Amit a számok mutatnak-Differenciált erdővagyon-gazdálkodás. Erdővagyon-gazdálkodási közlemények 7. Soproni Egyetem Kiadó, Sopron. ISBN 978-963-359-076-8.

NEKTt (2019): Magyarország Nemzeti Energia- és Klímaterve (tervezet). Innovációs és Technológiai Minisztérium. https://hirlevel.egov.hu/2019/05/12/nemzeti-energia-es-klimaterv-tervezet/

Simon T. (2010): A biomassza-felhasználás jelene és jövője Magyarországon – a 4Biomass projekt bemutatása. A Magyar Mérnöki Kamara Épületgépészeti Tagozatának Lapja.
https://www.e-gepesz.hu/cikkek/4812-a-biomassza-felhasznalas-jelene-es-jovoje-magyarorszagon-a-4biomass-projekt-bemutatasa

Szakálosné M. K.; Horváth B.; Major T.; Horváth A. (2013): Magyarországi erdők energetikai célokra hasznosítható faanyaga. Alföldi Erdőkért Egyesület Kutatói Nap: Tudományos eredmények a gyakorlatban. Lakitelek.

Szalay D. (2018): Energetikai célú dendromassza termesztés és hasznosítás lehetséges szerepe a lignocellulóz biohajtóanyag üzemek alapanyag ellátásában. PhD dissertation. University of Sopron. p. 151.

Veolia (2018): Erőműveink
https://www.veolia.hu/hu/letesitmenyeink

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

THE CURRENT STATE OF THE RUSSIAN FOREST INDUSTRY COMPLEX AND CALCULATION OF COSTS OF FOREST OPERATIONS ON THE BASIS OF ACTIVITY-BASED COSTING IN THE RUSSIAN FEDERATION.

Evgeny A. Tikhomirov [1], Maxsim A. Bykovskiy [2]
[1] Bauman Moscow State Technical University, Russia; [2] Faculty of Forestry, Forest Harvesting, Wood Processing Technologies and Landscape Architecture, Moscow State Forest University, Russia
Tihomirov@mgul.ac.ru

Abstract: *The current state of the Russian forest industry complex and calculation of costs of forest operations on the basis of activity-based costing in the Russian Federation.*

The current state of Russian forest industry complex, including such aspects as: quantity and quality of forests, logging, reforestation, results of the woodworking industry, exports and imports of wood and wood products in the article are described. A model for calculating the cost of forest operations based on functional cost analysis in the Russian Federation is given.
Key words: logging, woodworking industry, forest economics, activity-based costing

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

INFLUENCE OF ENVIRONMENTAL FACTORS ON SEDIMENTARY SAND OF CROSS DRAIN IN OPERATION ROAD

Masashi Saito*, Tokito Takezawa, Masaru Watanabe, Shirasawa Hiroaki, Tatsuhito Ueki
Shinshu University Graduate School, Ina, Japan;
Minami Minowamura 8304 Nagano, Japan
Iwate University Faculty of Agriculture, Morioka, Japan (Current position);
3-18-8 Ueda, Morioka, Iwate, Japan
msaito@iwate-u.ac.jp

Abstract: At each rainfall event, the sediments in rubber crossing grooves (82 places) were measured. Also, since the capacity varies depending on the cross-drain, sediment relative to the maximum capacity was calculated as the filling rate. We investigated the following environmental factors that are thought to have influence on sediment deposition and analyzed relationship with sediment volume. Rainfall amount, rainfall intensity, longitudinal gradient, lateral gradient of cross drain, installation angle, water collection area, cross drain spacing, soil quality, vegetation coverage of road surface. Particularly, the deposition amount in the cross drain arranged in the decomposed granite soil tended to increase even with a small rainfall event. It was revealed that soil and vegetation affected small sediment deposition. In carrying out maintenance work, it is thought that priority should be judged from the situation of soil and so on and work should be done.

Keywords: Operation road, Cross drain, Sediment, Maintenance work

1. Introduction

Most operation roads in Japan are not paved. The surface of the road body is made of soil, and overland flow are generated by rainfall, causing road surface erosion (Fig 1). If erosion progresses, the risk of road collapse will increase, and a large cost will be required to repair the road surface. Therefore, a cross drain is installed on the work road as an erosion prevention measure (Forestry Agency, 2011). However, in recent years, unprecedented rainfall has occurred and surface currents are often generated. Also, in such a situation, sediment movement increases and sediment tends to accumulate in the cross drain. If sediment is left deposited in the cross drain, the surface flow will eventually overflow the cross drain, increasing the damage caused by road surface erosion. Therefore, care must be taken before a disaster occurs in order to maintain the function of the cross drainage and not to spend a large amount on maintenance. Therefore, it is necessary to maintain the cross drain regularly in order not to spend a great deal on repairs. However, there is no clear period or frequency for the maintenance interval of the cross drain. In this study, in order to examine the maintenance interval of the cross drain, the amount of sediment deposited in the cross drain on the operation road was measured for each rainfall event. The effects of rainfall intensity, surrounding environment, and installation conditions of cross drainage on sediment accumulation were analyzed.



Figure 1. Operation road where the surface was eroded

2. Study Site and methods

2.1 Study Site

The study site is Shinshu University Experimental Forest, the area is 227.9ha, the altitude is 900m ~ 1,200m, the precipitation is about 1300mm / year, and the average road network density is 91.13m / ha. The survey was conducted on 82 rubber cross drainage (Fig 2), which are installed most frequently in the Experimental forest. Standards for transverse drainage are 400cm in length, 7cm in height of rubber, and 10cm in width of wood (Fig 3). The soil sediment in the range of 7cm in height and 10cm in width was measured. At the start of the survey, the soil sediment was removed upstream. In subsequent surveys, it was decided that soil discharge would be carried out whenever it was judged that it was approaching full sand and overflowed. Sediment was measured immediately after the 10-minute rainfall exceeded 1 mm (Ichihara 1987). The one-year probability rainfall in this area is 18.4mm / hr (Nagano Prefecture, 2017), and the rainfall intensity set as the standard is normal rainfall.



Figure 2 Rubber cross drain

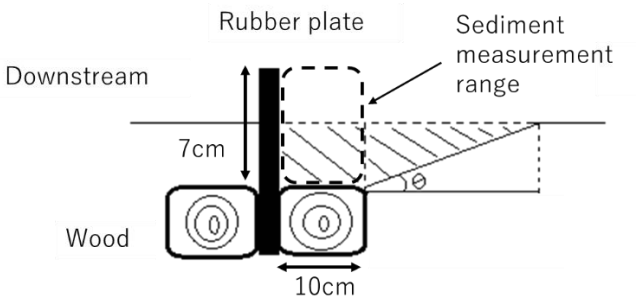


Figure 3 Cross drain structure and measurement range

2.2 Measurement and estimation method of sedimentation amount

The accumulated sediment was measured directly using a straight and curved scale (Fig 3-4). A measure was stretched from the valley side, and the sediment height, sediment width, and sediment height at 10 cm width were measured every 10 cm (Fig 4). This measurement was performed 13 times in total from June 23, 2017 to November 1. In order to obtain the sediment volume from the sedimentation data, the average cross-section method was used. The formula of the average cross section method is shown below.

$$V=(S0+S10)/2\times 10 \qquad (1)$$

V: Volume between cross sections. S0 and S10: Cross-sectional area measured every 10 cm

The total volume between each cross section is the volume in one transverse drain. The formula is shown below.

$$Vs=\{(S_0+S10)/2\times 10+(S10+S20)/2\times 10+\ldots+(Sn-10+Sn)/2\times 10\} \qquad (2)$$

Vs: Sediment volume in one transverse drain. n: Effective cross drainage length.

In addition, since the capacity varies depending on the cross drain the filling rate was calculated by dividing the sediment volume by the maximum depositable amount of each cross drain.

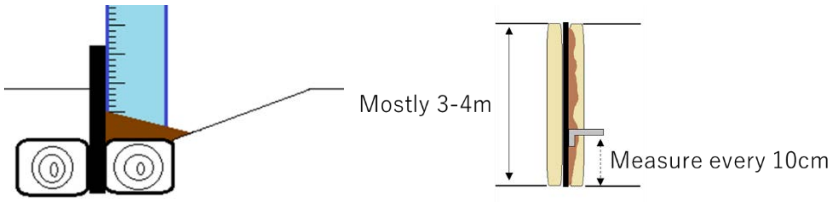


Figure 4 Measuring method of height(Left) and measurement in transverse direction(Right).

2.3 Investigation of factors affecting sedimentation

2.3.1 Rain fall event

The rainfall data was obtained from the rain gauge installed in the training forest. We collect rainfall data every 10 minutes from June to October 2017. This time, the maximum rainfall for 10 minutes, maximum hourly rainfall, and total rainfall during the measurement were obtained.

2.3.2 Environment around the cross drain

(1) Soil quality: The classification was done by observing the cut slope and road surface near each cross drainage. There are four classifications: granite, loam, mixed granite and loam, and metamorphic rock.
(2) Vegetation coverage of cut slope: During the summer vegetation season, the cut slope slopes were observed on site. The vegetation coverage was divided into four categories: low (0-33%), medium (34-66%), high (67-100%), and protective retaining walls.
(3) Vegetation coverage of road surface: Similar to the cut slope, the road surface was also classified for vegetation coverage. The road surface was divided into three types: one with little or no vegetation (low), one with vegetation over other than the ridge (middle), and one with vegetation over the entire road surface (high).

2.3.3 Installation conditions for cross drain

(1) Longitudinal slope: The longitudinal gradient was measured using a hand level 10m above the slope from the center of the transverse drainage ditch.
(2) Lateral slope of cross drain: The lateral gradient of the transverse drainage was measured by slant.
(3) Installation angle: Measured the slope of the transverse drainage with respect to the center line of the operation road.
(4) Cross drain spacing: The position information of the cross drain was acquired by GPS, and the length of the interval between two cross drain was calculated using QGIS.
(5) Catchment area: Using the 10m mesh DEM published by the Geospatial Information Authority of Japan, the value of the water catchment area at the point just above the cross drain was calculated using the topographic analysis function of GIS.

3. Results and discussion

3.1 Rainfall events and sediment volume

The result of the rainfall event is shown (Fig 5). The correlation between the maximum 10-minute rainfall, maximum hourly rainfall, total rainfall, and average sediment volume in each cross drain is shown in Fig 6-8. Although it was a weak correlation, there was a tendency for the average sediment volume to increase with the increase in maximum hourly rainfall and total rainfall. In addition, as a result of analysis by combination of each rainfall intensity, the correlation between rainfall per hour and total rainfall was high. In other words, it can be said that sedimentation is likely to occur when it rains for a certain amount of time.

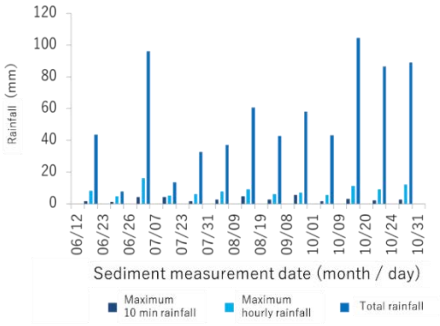


Figure 5 Rainfall events and measurement dates

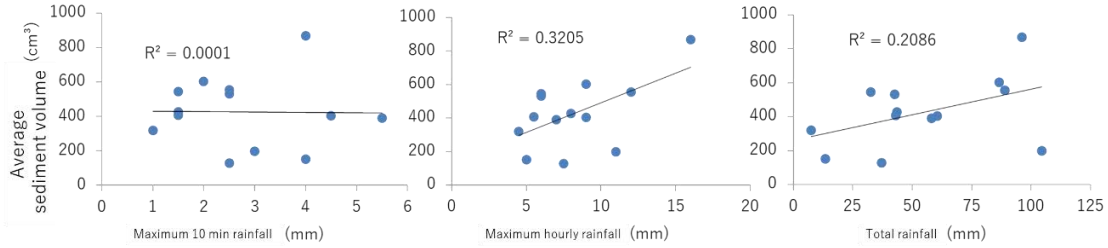


Figure 6 Each rainfall intensity and average sediment volume

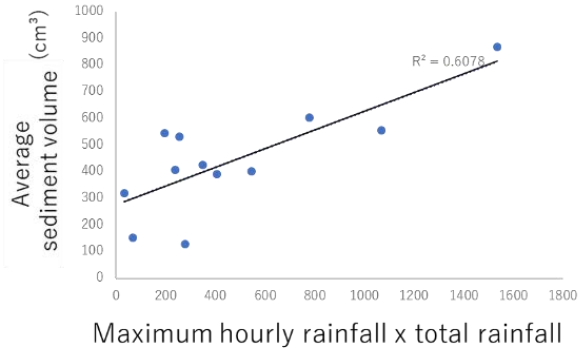


Figure 7 Rain event combinations and average sediment volume

3.2 Environment around and filling rate.

The result of the surrounding environment of the cross drainage and the sediment volume is shown. The classification according to the soil was 9 places for granites, 30 places for mixed, 36 places for loam, 5 places for rock. Based on this classification, the transition of the average filling rate (Fig. 8) shows granite, mixed, loam, and rock in descending order of average filling rate. At the end of 13 measurements, there was a difference of about 10% between granite and loam. According to the Steel-Dwass test, a significant difference of 5% was obtained for granite and loam on almost all measurement days.

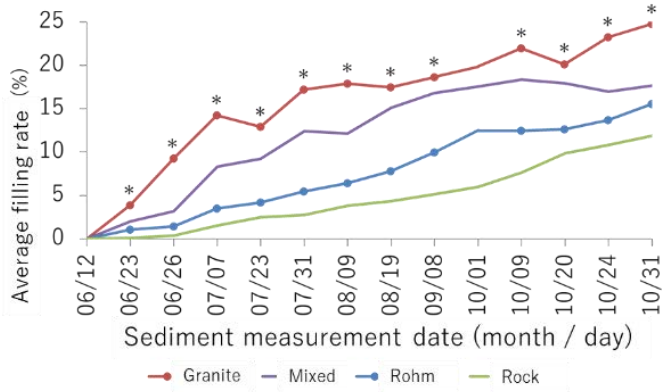


Figure 8 Changes in soil quality and average filling rate (＊ : p＜0.05)

The cutting slopes vegetation coverage were 22 places for low, 27 places for medium, 29 places for high, and 4 places for protective retaining walls. The transition of the average filling rate by this classification (Fig. 9-10) was low, medium, high, and protective retaining walls in descending order. At the end of the measurement, there was a difference of about 9% between low and high, and a difference of about 13% between low and protective retaining wall. In addition, there was a significant difference between low and high on more than half of the measurement days.

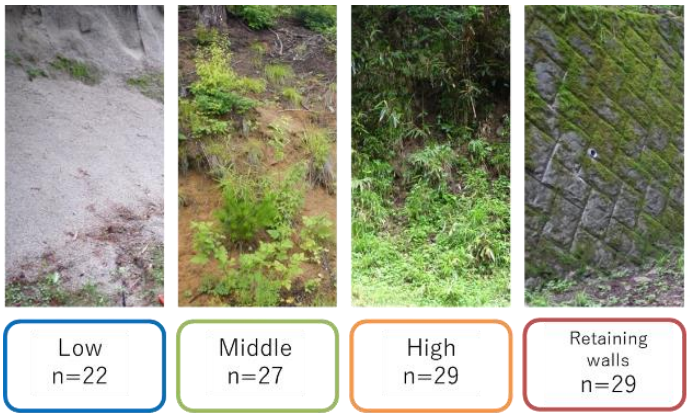


Figure 9 cutting slopes vegetation coverage situation.

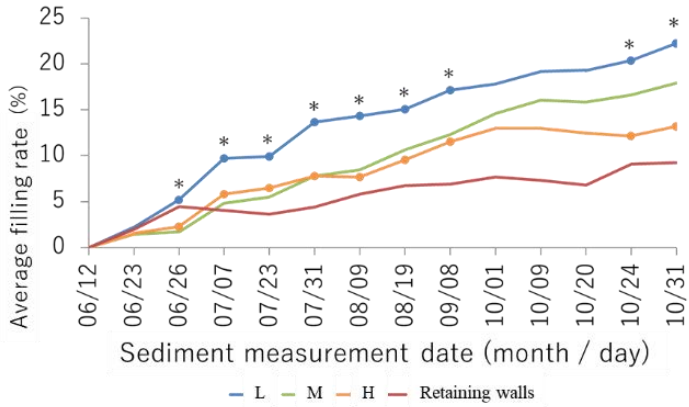


Figure 10 Changes in Slope vegetation and average filling rate

According to the vegetation coverage of the road surface, there were 47 places for low, 25 places for medium, and 10 places for high. Looking at the change in average filling rate (Figure 14), those with low vegetation coverage were higher than those at medium and high. The difference became large after August 19, and when 13 measurements were completed, there was a difference of 11% between low and high and 7% between low and high. In addition, there was a significant difference between all the measurement days after the 5th measurement in the low slope coverage with the highest average filling rate and the lowest slope coverage.



Fig 11 Road surface vegetation coverage situation

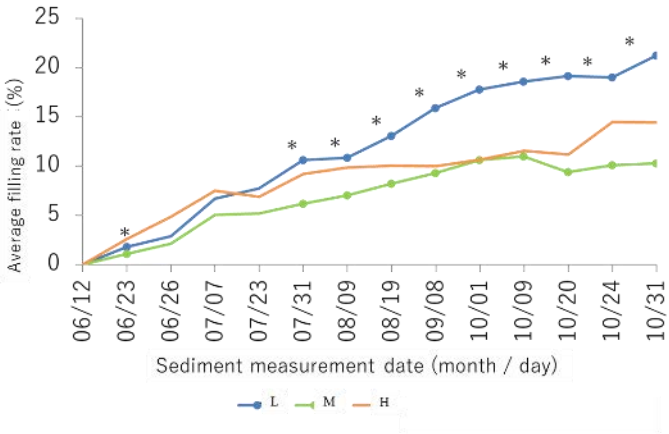


Figure 12 Changes in Road surface vegetation coverage and average filling rate

3.3 Installation conditions of cross drain and filling rate.

The results of the installation conditions of the cross drain and the sediment volume are shown. Considering the fact that the rainfall intensity differs each time, the relationship between the installation conditions and the increase / decrease of the filling rate was taken in each scatter plot, and no correlation or trend was found under any of the conditions. In addition, no correlation or trend was found even when the classification was performed according to soil quality. The following (Fig. 13) present the data obtained on July 7 (third measurement) on behalf of 13 results.

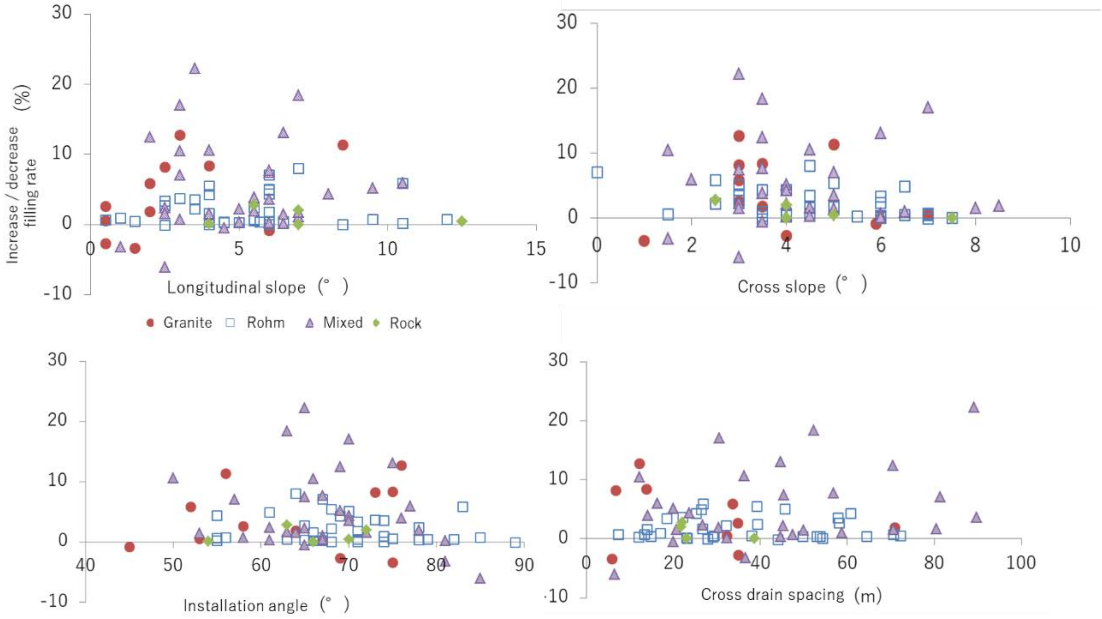


Figure 13 Each installation condition and Increase / decrease filling rate

3.4 Discussion

In this study, there was a slight trend between the maximum hourly rainfall and the average sediment movement. From this, it is considered that the sediment volume tends to increase when there is heavy rainfall in a short time. It is considered that the intensity of rainfall affects the movement and sedimentation of sediments rather than the amount of rainfall during the period.

There was a tendency among soil quality, slope cut slope vegetation coverage, vegetation coverage of road surface and average filling rate surrounding the crossing drain. In terms of soil quality, granite is poor

in viscosity and often collapses on the surface layer. On the other hand, loam is less viscous than granite due to its high viscosity, resulting in less sediment.

Since the landslide movement occurs due to the erosion caused by rain on the cut slope, the average filling rate was higher because the sediment was more likely to flow out in places where the slope coverage was low compared to those with high vegetation coverage. On the road surface, surface flow tends to occur especially at the ridge where there is little vegetation and is low compared to other places on the road surface (Noguchi et al 2014), so the average filling rate was high in places with low road surface coverage.

On the other hand, no relationship was found between the installation conditions of the cross drain and the amount of sediment. Previous studies have pointed out that surface flow velocity increases with increasing longitudinal gradient and road surface scouring becomes deeper (Arakawa, et al 2012). Therefore, it was expected that the amount of earth and sand movement increased as the vertical gradient became steep, but no correlation with the vertical gradient was observed.

This is thought to be due to the fact that the installation interval was narrow in the section with a steep vertical gradient, and the action of flowing sediment in the cross section due to an increase in the feeding force.

There is a report that the installation angle is ideal if the longitudinal gradient is 11 degrees or less, and the installation angle is 57 degrees or less with respect to the center line. However, in this result, the amount of sediment was dependent on the amount of sediment that reached the transverse drainage channel and did not show a clear relationship.

Depending on the shape of the road surface between the cross drain, it may be drained along the way. The cross drain spacing and the surface flow rate of the section are not always the same value.

Therefore, it is considered that the relationship between the cross drain spacing and the catchment area could not be found.

From these results, it became clear that the environmental conditions such as soil quality and vegetation are more strongly affected than the installation conditions. In other words, it is considered that the environment in which sediment production occurs has a greater influence on the sediment volume in the cross drain than the sediment movement.

4. Conclusion

In this study, the following three points were clarified to improve the efficiency of maintenance work on the operation road.

(1) When heavy rain falls on the basis of rainfall per hour, the amount of sediment will increase, so the accumulation status should be confirmed.

(2) Cross drain installed in areas with soils including granite should be preferentially maintained.

(3) The cut slope with less vegetation and the cross drainage on the road should be preferentially maintained.

In the future, it will be possible to predict the sediment volume more accurately by investigating the long-term survey and the actual surface flow.

In addition, sediment does not accumulate evenly in the cross drain, and if there is a significant deposit even at one location, the surface flow may overflow. Therefore, it is a problem to examine the installation method and the shape of the cross drain so that uneven deposition does not occur.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number 19H02991 and Ministry of Agriculture、Forestry and Fisheries Contract research 16783181.

References

Forestry Agency (2011) “Forest road regulations and detailed rules for forest road regulations” http://www.rinya.maff.go.jp/j/seibi/sagyoudo/pdf/kitei.pdf (Mar/9/2018).

Ichihara Kouichi (1987)“Analysis of runoff from a logging road” J Jpn For Soc 69:329-342

Nagano Prefecture (2017) “Nagano rainfall intensity formula” https://www.pref.nagano.lg.jp/kasen/infra/kasen/keikaku/documents/h28_kyoudosiki.pdf (Mar/9/2018)

Sumihiko Arakawa, Kenichi Nakamura, Kazushi Arai, Haruo Toriumi, Rikuo Shishime, Kazuhiro Yabe, Izumi Sugawara (2012) “Ditching and Collapsing of Spur Roads Built on Typical Steep Slopes in the Tama area of metropolitan Tokyo” Bulletin of Tokyo Metropolitan Agriculture and Forestry Research Center, 8: 19-34, 2013

Shoji Noguchi, Tomonori Kaneko, Masanori Kitada, Hidenori Suzuki (2014) Generation of Overland Flow on a Constructed Spur Road: Analysis of Field Observations and Vegetation Survey. J Jpn For Soc 96: 342-347

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

INFORMATION-SHARING SYSTEM FOR A NEW HARVESTER EQUIPPED FOR AUTOMATIC ASSESSMENT OF LOG QUALITIES

Masahiko Nakazawa, Yukari Matsumura, Wataru Tanaka, Takumi Uemura, Hideo Kato, Hiroko Muneoka, Chikashi Yoshida, Seishiro Taki, Kengo Usui, Yuji Ikami, Kiyohiko Fujimoto, Yosuke Matsuda
Forest Research and Management Organization
Forestry and Forest Products Research Institute
1 Matsunosato, Tsukuba, Ibaraki 305-8687, Japan
naka1978@ffpri.affrc.go.jp

Yutaka Kanazawa
Nanseikikai Co., Ltd
22-1 Yoshidomi, Shisuimachi, Kikuchi, Kumamoto 861-1201, Japan
y-kanazawa@kum-nansei.co.jp

Norio Shirai
Komatsu Ltd.
2-3-6 Akasaka, Minato-Ku, Tokyo, 107-8414 Japan
norio_shirai@global.komatsu

Abstract: *This study aims to develop an information-sharing system for the Japanese forestry by developing a new harvester head with the aid of ICT and robot technology. While processing, this harvester can assess log qualities (warp, Young's modulus, and density) automatically. In our previous report, we made a prototype of the information-sharing system that was implemented in relation to StanForD for Japanese forestry. In this study, we upgrade our system by adding some new tools.*

Keywords: StanForD, information sharing system, ICT, harvester

1. Introduction

This study aims to develop an information-sharing system for the Japanese forestry by developing a new harvester head with the aid of ICT and robot technology. While processing, this harvester can assess log qualities (warp, Young's modulus, and density) automatically. In our previous report (Nakazawa et. al., 2018), it was clear that 1) StanForD (Standard for Forest machine Data and Communication) would also be a useful tool for the Japanese forestry, 2) information on the location and time for both, the processing and transportation of all logs, would be necessary, and 3) not only the information on the length and top-end diameter but also the butt-end diameter, young's modulus, and wood density would be necessary. We subsequently made a prototype of the information-sharing system implemented in relation to StanForD for the Japanese forestry. In this study, we upgrade that system by adding some new tools.

2. System development

2.1 Developing a new harvester head

Figure 1 shows the outline of the whole system with the new harvester. The development concept of our new harvester increases the profitability using shared data with the following points: (1) automatic assessment of log straightness (warp) for the efficiency in operating, operator work saving, and objective assessment; (2) estimation of log strength (Young's modulus) and density prior to processing for the increasing log price at landing by sorting the logs by quality, (3) efficient use of log data from the harvester for the use of unused data (skipping the log acceptance inspection) and matching between supply and demand. As for (1), we have been developing a log straightness evaluation system using a 3D scanner (Figure 2 and 3). As for (2), we have developed a log strength evaluation system using sonic velocity sensors and its driven resistance or mass measurement corresponding to the log density.

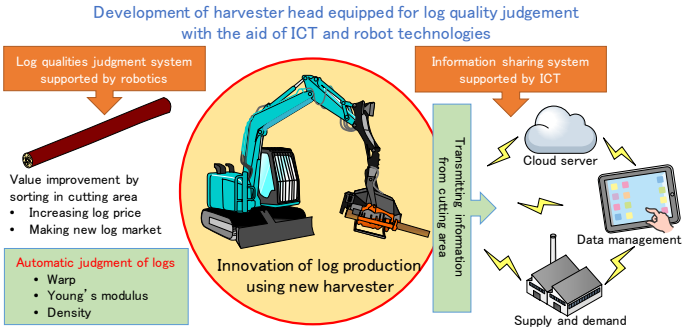


Figure 1. System outline

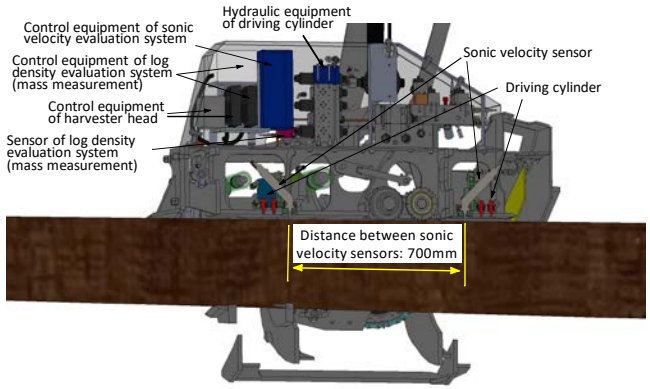


Figure 2. Schematic of new harvester head

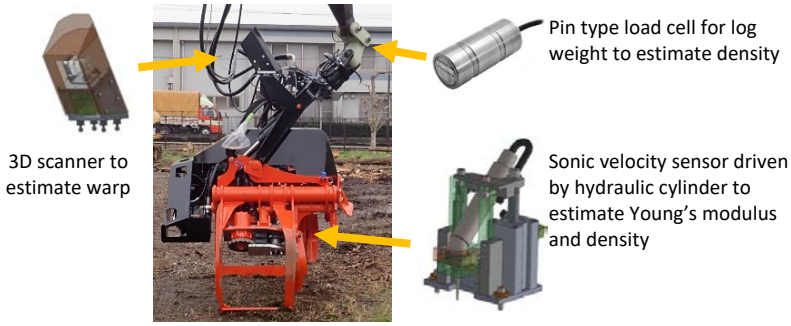


Figure 3. New harvester head with 3D scanner and sonic velocity sensors

2.2 Developing an information sharing system

To achieve the above-listed point (3), we have developed an information-sharing system. In our previous report (Nakazawa et. al., 2018), we conducted a hearing investigation about the current procurement techniques and the necessary information of raw woods for sawmills in the domestic and foreign forestry areas. Following points have been clarified. In Sweden, (1) StanForD (Standard for Forest Machine Data Communication — the forestry sector's standard for management of data to and fro the forest machines) is used for the instruction on the log price and amount from industrial customers, product instruction from forest companies to contractors, production report from machines, and so on. (2) StanForD is useful for optimizing a wood supply chain. (3) StanForD leads not only to the operation efficiency but also the stabilization of price and volume due to information-sharing. For Japan, (1) StanForD would also be a useful tool for the Japanese forestry. (2) Log information of the location, time, and number for both, the processing and transportation, would be necessary. (3) Not only the information on the length and top-end diameter but also the butt-end diameter, young's modulus, density, and weight of wood would be necessary. We subsequently made a prototype of the information-sharing system implemented in relation to StanForD for Japanese forestry (Figures 3 to 5). We added the log quality data (butt-end diameter, young's modulus, density, and weight) into the extended partition. In this study, we upgrade our system by adding the following new tools: (1) value bucking based on the log qualities, (2) aggregated harvesting report (hpr), (3) map interface showing the location of the logs, (4) conversion of the other harvester data to the StanForD, and so on.

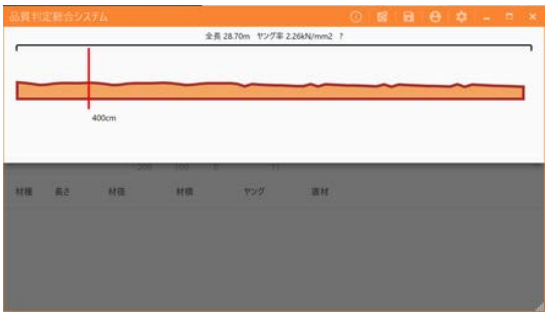
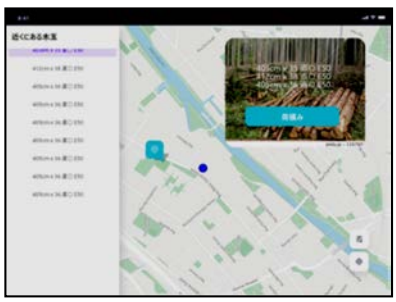


Figure 4. Value bucking tools based on the log qualities



Figure 5. Aggregated harvesting report including log quality data from hpr files


Figure 6. Map interface

3. Acknowledgements

This project is supported by grants from the Project of the Bio-oriented Technology Research Advancement Institution, NARO (the special scheme project on advanced research and development for next-generation technology).

4. References

Masahiko Nakazawa, Yukari Matsumura, Hiroko Muneoka, Takumi Uemura, Chikashi Yoshida, Seishiro Taki, Yuji Ikami, Kiyohiko Fujimoto, Wataru Tanaka, Yutaka Kanazawa, Norio Shirai (2018) Developing information sharing system for Japanese forestry. Edition of the International Symposium on Forestry Mechanization, PROCEEDINGS, Madrid, Spain, 24th-28th Sep, 2018, 51:461

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

BIOMASS YIELD AND FUEL PROPERTIES OF DIFFERENT POPLAR SRC CLONES

Dinko Vusić, Davorin Kajba, Ivan Andrić, Ivan Gavran, Tin Tomić, Ivana Plišo Vusić, Željko Zečić
University of Zagreb, Faculty of Forestry, Zagreb, Croatia
vusic@sumfak.hr

Abstract: *The goal of the research was to determine the biomass yield and fuel properties of ten different poplar clones. The research was conducted in an experimental plot established in Forest administration Osijek, Forest office Darda, in the spring of 2014. The layout of the plot consisted of three repetitions per clone with 40 plants per repetition in spacing 3 x 1 m. Based on the DBH distribution, in the early spring of 2018, one sample tree of an average DBH per repetition was selected, thus forming a sample of 30 trees.*

Average survival rate of the investigated trees was 74.54±13.85% ranging from 52.08% (Koreana) to 91.67% (SV885 and SV490). Average DBH of the sample trees was 8.2±1.9 cm, height 9.3±1.8 m and root collar diameter 10.7±1.9 cm. Moisture content in fresh state (just after the felling) ranged from 51.6% (Hybride 275) to 55.9% (SV885). Bark content averaged 18.4%, from 15.4% (Baldo) to 21.1% (V 609). Average nominal density of the sampled trees amounted to 383.5±35.9 kg/m3. Bark ash content was in average ten times bigger (6.44±0.65%) than the wood ash content (0.64±0.07%) resulting with average ash content of 1.7±0.1% (taking the bark content into account).

The clone SV490 showed the highest biomass yield with 15.8 t/ha/year, while the lowest biomass yield was recorded for the clone Hybride 275 with 2.8 t/ha/year.

High inter-clonal productivity variation stresses the importance of selection work to find the most appropriate clones with the highest productivity potential for the given area where the poplar plantations are to be established.

Due to high initial moisture content, if direct chipping harvesting systems are preferred wood chips could be efficiently used in CHP (Combined Heat and Power) plants that operate on the principle of biomass gasification (where a gasifier is coupled to a gas engine to produce electric power and heat). In several CHP gasification plants operating in Croatia wood chips with high initial moisture content (from traditional poplar plantations) are used as a feedstock that has to be pre-dried using the surplus heat. In this respect SRC poplar wood chips could make an ideal feedstock supplement.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

SOIL COMPRESSION DEGREE IN STUDIES OF VIBROCOMBINATOR TILLAGE TECHNOLOGIES

Boja Nicusor[(1)], Boja Florin[(1)], Vidrean Dan[(1)], Teuşdea Alin[(2)], Pica Adrian[(3)], Popescu Ilie[(3)]

[(1)] Department of Engineering and Informatics, Faculty of Economics, Informatics and Engineering, "Vasile Goldiş" Western University of Arad, 91-93 Liviu Rebreanu Street, AR 310414, Romania.

[(2)] Department of Animal Science and AgroTourism, Faculty of Environmental Protection, University of Oradea, Gen. Magheru 26, 410396 BH, Oradea, Romania

[(3)] Department of Forest Engineering, Forest Management Planning and Terrestrial Measurements, Faculty of Silviculture and Forest Engineering, Transilvania University of Brasov, nr. 1, Sirul Beethoven Street, 500123 Brasov, Romania

bojanicu@yahoo.com

Abstract: *In order to carry out the research, we settled in six parcels in the plains of the West of Romania so that we could have three different types of soils which are representative for that specific area. From each profile was collected soil samples in three steps of 6, 12 and 18 cm. For each sample were performed six repetitions (N = 6). We started by measuring the particle size distribution (granulometric composition) and the main physical properties of the soil (moisture, bulk density, total porosity and soil compression degree).Advanced methods of statistical analysis (univariate three-way ANOVA and multivariate analysis, PCA, Manova and HCA) began to be successfully used in recent years for the study of soil behavior at the interaction with the working bodies. Seedbed preparation for crop establishment (sowing) is one of the most important agricultural works, as is done with high energy consumption and high costs. The quality of this work influences in large measure the germination of crop and the productivity that can be obtained per hectare. Therefore, at present, there is different equipment from the ones found in classical cultivation technologies, which in single pass can achieve tillage with minimum energy consumption, thus creating optimal conditions for sowing and for obtaining higher yield without soil degradation. These devices are called combinators. Of all the existing combinators, most performant are the vibro-combinators.*

Keywords: vibro-combinator, soil tillage, bulk density, total porosity, compression degree

1. Introduction

The paper presents a study on the optimization of working regime of vibro-cultivators based on environmental impact assessment for use in seedbed processing. Study presents a method to determinate some phisical and mechanical proprieties before and after soil tillage works of aggregates consisting of tractor and vibro-cultivators, in three parcels in the plains of the West of Romania.

Vibro-cultivators are machines for seedbed preparation. They are equipped with tools sustained by elastic suspension. The elasticity of supports facilitates the oscillations of working tool – elastic support assembly. This set has a natural mode shapes which corresponds to a natural frequency of vibration (Cardei P. et al, 2015).

Modern agricultural operations now demand the utilization of a wide variety of equipment and specialist machinery systems, with many having rotary elements such as axles, gears, pulleys etc. With these

agricultural machinery systems which have rotary elements, uncontrolled vibrations may become an important problem to consider. When the initial 'switch-on' frequency meets with the natural frequency of a machine element in the system, undesired noise, high levels of vibration and mechanical failures may occur during operation (Celik H et al, 2010; Petrescu H.A. el al, 2015).
Generally, combinators consist of a vibro-cultivator A (cultivator for total processing of soil), composed of: frame 1, coupling device at the power source 2, wheels for limiting of working depth 3, soil loosening bodies 4, and a helix harrow B, which consists of frame 5, two rodrotors 6, and horizontality adjustment system 7 (Fig. 2). Worldwide, more and more prestigious companies have incorporated into the range of products such vibro-combinators.

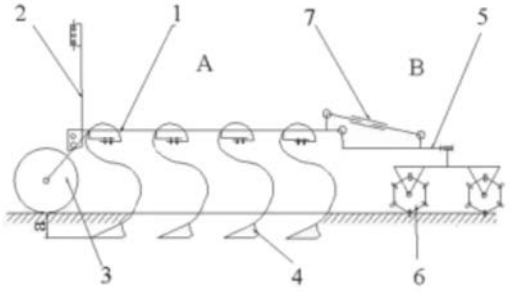


Fig. 2 General scheme of a vibro-combinator (Caproiu St. et al, 1982; Biris S.St. et al,2015)

Deep tillage tools are one of the primary components of agricultural equipment which experience high level soil reaction forces during tillage operations. These forces may cause plastic deformation or failure which is undesirable for tillage machines/tools. The active tillage elements of agricultural machineries require extensive studies in order to obtain a proper soil fragmentation and displacement (Petrescu H.A. el al, 2015).

2. Material and method

In order to obtain a global image on the impact of the new vibro-combinator (the prototype SANDOKAN 2) (table 1) in terms of the physical-mechanical properties of the soil, it was necessary to determine its properties before the passage of the equipment (in the state of the soil), and after its passage on all the three parcels and trials. These parcels will be suggestively named: soil 1, soil 2 and soil 3; and the three types of active elements (Gamma, Delta1 and Delta2) (fig. 3-4).

Table 1 Main characteristics of the prototype vibro-combinator SANDOKAN 2

No. crt.	Characteristics	MU	Values
1	Mass	kg	5670
2	Length in transport	m	6.6
3	Height in transport	m	3.95
4	Width in transport	m	2.93
5	Width of the gamma active parts, reversible chipper type	mm	35
6	Width of the delta 1 active parts, arrow type	mm	150
7	Width of the delta 2 active parts, arrow type	mm	250



Fig. 3 The prototype vibro-combinator SANDOKAN 2 equipped with the three types of active elements (GAMMA, DELTA1, DELTA2)



Fig. 4 Geometrical models for the three active elements (Petrescu H.A. el al, 2015)

The physical properties were determined by using the method of the cylinders with a constant volume of 100 cm^3, carrying out six repetitions at different depth, from 6, 12 and 18 cm. The methods of analysis and interpretation of the results as well as the work procedure for the determination of the physical – mechanical properties are those indicated in the specialized literature (Boja et al, 2012; Boja et al, 2013).
Statistical analysis. All data were subjected to univariate three-way analysis of variance (ANOVA, P = 0.05) and done with KyPlot (Kyplot Version 5.0.2, http://www.kyplot.software.informer.com). The ANOVA factors were: Soil (soil type), h (depth), Device (active element) and their three order interaction. The means pairwise comparisons were investigated by Tukey's post-hoc test (P =0.05). Multivariate analysis: principal component analysis (PCA) was performed with P.A.S.T. version 3.04 statistical software, (Palaeontology Statistics, Copyright Oyvind Hammer and D.A.T. Harper (November 2014), http://folk.uio.no/ohammer/ past/), (Hammer et al, 2001).

3. Results

When analysing the granulometric curves presented in figure 5 and table 2, one can notice the fact that there was a sandy-clay-dusty texture in soil 2 and 3 encompassed in the experiment at a participation quota that scarcely varies, with the exception of the 1st soil where the particle size distribution is different: clay-dusty-sandy texture.

Table 2 Average values of the granulometric analysis at different depths of prelevation

Type of soil			SOIL 1 (S1)			SOIL 2 (S2)			SOIL 3 (S3)		
Depth of prelevation,		(cm)	6	12	18	6	12	18	6	12	18
Values of the granulometric analysis	Sand,	%	26.2	26.8	27.4	35.7	35.1	35.1	43.4	43.2	43.2
	Dust,	%	28.6	28.7	28.7	30.2	30.2	30.1	27.8	28.1	28.5
	Clay,	%	44.8	44.3	44.4	34.5	34.8	34.7	28.5	28.7	25.9

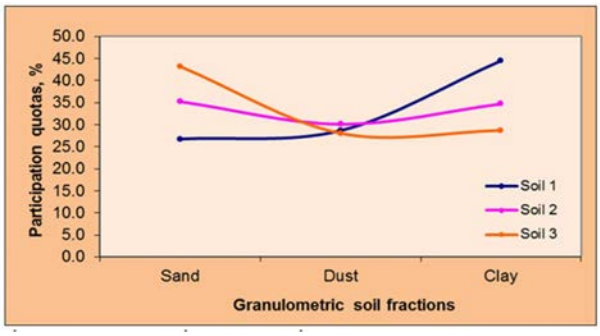


Fig. 5 Granulometric curves analysis of the soils

From the analysis of the values gathered for the participation quotas of the granulometric fractions, we could infer some interesting differentiations among the three types of soil in which we tried the vibro-combinator, as follows: All the three types of soil that we tried on the vibro-combinator are a relatively close mix, but in different proportions among the three granulometric fractions; The sand fraction (gravel + fine) is predominant in the soil 3 (43,2 %); For the dust fraction (I + II), the differences among the three types range only for 2%, the highest value being registered on the soil 2 (30,1 %); The participation quotas of the clay granulometric fraction are among the biggest, varying between 28,7 % (soil 3) and 34,7 % (soil 2), and reaching 44,5 % for soil 1; The dust granulometric fraction is almost constant for all the three types of soil.

To synthesise more efficiently the data taken and to be able to describe completely the intrinsic characteristics of the sample, it was chosen a statistic processing with the aid of the program KyPlot. The results obtained are given in Table 3, having as a purpose to underline the variance of apparent density, soil moisture, total porosity and soil compression degree, and comparative with each types of soils and three active elements (Gama, Delta 1, Delta 2). Thus, for each types of soils included in the experiment resulted in eight statistical indicators for each technical work use a new vibro-combinator, but also witness sample. The mechanical processing of the soil through traditional and modern methods is currently put under question due to the high energy consumption and the continuous degradation of the arable horizon through erosion and excessive compaction.

It is known that the bulk density varies between 1-2 g/cm^3, according to the type soil and horizon, being generally lower in the case of the soils rich in humus and in the structured soils as compared to the unstructured soils. The values of the bulk density are in tight correlation with the degree of settlement of the soil. The high bulk density means a decrease of the capacity to retain water, of the permeability, of aeration and an increase of the mechanical resistance opposed by the soil during its sampling. On the contrary, low bulk densities can reduce the bearing of the soil, making difficult the mechanized execution of the works, even the driving of the operation machinery (Spoljar et al, 2009; Spoljar et al, 2011; Boyraz D. and Atilgan M.C., 2014; Boja et al, 2016; Calistru et al, 2016; Vidrean et al, 2018).

By analyzing the values of total porosity, we can say that for the 1st type of soil we noticed an increase of the total porosity from 40,19 %, which represents the initial state of the soil, to 44,36 % (value obtained after the working of the soil with the vibro-combinator equipped with Gamma elements), 45,64% (with Delta 1 elements) and 45,71% (with Delta 2 elements).

The degree of settlement for the 1st type of soil presents values > 18%, which means that the soil is strongly settled for all levels of depth and after the passage with the three types of active elements of the cultivator.

The values gathered for the 2nd type of soil varies from weakly settled (1…10%) to moderately settled (11…18%). However, it is important to specify the fact that the lowest values of the degree of settlement appeared after preparing the germination bed with the aid of the active elements Delta 2.

In the case of the 3rd type of soil, we had negative values for this mechanical index of the soil at all depth, especially for the types of active elements, which means there is a soil moderately loose (-17…-10%) - fact that can be explained by the fact that this parcel has been annually worked.

Analyzing the influence of the active elements on the different types of soils, some conclusions can be made (Table 3 and Fig. 6-10): in terms of apparent density values (Da), the lowest value is found on all soil types (S1, S2, S3) when working with the active elements Delta2; the total soil porosity has maximum values when the vibrocombinator is equipped with the Delta2 active elements, logical situation

due to the existing relation to density and porosity; soil moisture values reach peak values after processing with Delta2 to S1 and S2, and in S3 the maximum value of soil moisture is reached after processing with Delta1; the soil compaction degree has a similar humidity variation, namely: minimum values for S1 and S2 using Delta2 and in S3 following the use of Delta1.

Analyzing the impact of active organisms on soil depth, some conclusions can be drawn (Table 3 and Figure 6-10): apparent density (Da) records minimum values when using Delta2 for all three depths (6 cm, 12 cm, 18 cm); total porosity has an inverse variation such as that of apparent density: the highest values are found for all three depths when working with Delta2; and soil moisture values respect the same law that: for all three depths the maximum value occurs after processing with Delta2; the soil compaction degree has a similar variation, that is, the smallest values are recorded at all depths when working with Delta2; when working with Delta2 active elements, all physico-mechanical soil indicators have optimal values regardless of working depth; the same legality is preserved (with few exceptions) and when analyzing the impacts of the active organ of the vibrocombinator on the soil types contained in the experimental field.

Table 3 Results for the soil physical and mechanical properties (values are expressed as mean ± standard deviation) for the interaction factor Soil*h*Device (CTRL, Gama, Delta1, Delta2)

Device*h*Soil	Soil moisture (%)	Bulk Density (g/cm3)	Total Porosity (%)	Soil compression (%)	Water retention (m3/ha)
CTRL.06.S1	16.18j±0.09	1.50cde±0.02	42.18hij±0.63	19.23cdef±1.20	361.69ef±4.29
CTRL.12.S1	20.25r±0.09	1.56ab±0.01	40.19kl±0.40	23.16a±0.77	150.91k±1.61
CTRL.18.S1	22.25t±0.09	1.41bc±0.03	45.71jk±1.32	12.62bc±2.52	186.58m±6.33
CTRL.06.S2	22.36s±0.16	1.46ab±0.01	43.91kl±0.29	15.92defg±0.55	404.69h±5.18
CTRL.12.S2	29.86r±0.16	1.45def±0.06	44.36ghi±2.22	15.19ab±4.25	141.00lm±4.31
CTRL.18.S2	33.93mn±0.15	1.74a±0.01	33.27l±0.40	36.29cd±0.77	421.44f±3.84
CTRL.06.S3	20.93u±0.28	1.75cd±0.01	32.89ij±0.40	37.05defgh±0.77	698.62op±6.12
CTRL.12.S3	28.23l±0.28	1.41defgh±0.02	45.64efghi±0.63	12.74ab±1.20	86.92k±1.59
CTRL.18.S3	35.03mn±0.28	1.63cdef±0.19	37.31ghij±7.27	28.56cde ±13.92	343.31g ±40.44
Delta1.06.S1	10.25f±0.19	1.31defgh±0.06	49.81efghi±2.16	1.61fghi±4.27	186.63hi±10.22
Delta1.12.S1	20.05v±0.19	1.69fghi±0.17	34.87defg±6.51	33.24defgh±12.47	568.50q±57.85
Delta1.18.S1	22.15g±0.19	1.44defg±0.02	44.71fghi±0.80	11.68efgh±1.59	192.88ij±2.54
Delta1.06.S2	21.75e±0.19	1.48defg±0.02	43.17fghi±0.80	14.80fghi±1.59	529.47b±6.80
Delta1.12.S2	28.75mno±0.19	1.52fghi±0.02	41.41defg±0.63	20.73defgh±1.20	607.34no±6.89
Delta1.18.S2	31.25h±0.19	1.39defgh±0.01	46.54efghi±0.34	8.07fgh±0.68	179.45j±1.41
Delta1.06.S3	21.03f±0.28	1.46defgh±0.03	44.04fghi±1.11	13.09ghi±2.19	548.55c±11.79
Delta1.12.S3	28.43u±0.28	1.54defgh±0.03	40.83efghi±1.12	21.83efgh±2.16	717.94p±19.57
Delta1.18.S3	35.33g±0.28	1.35efgh±0.03	48.17efgh±1.24	4.84fghi±2.46	175.88j±5.73
Delta2.06.S1	22.03i±0.28	1.19kl±0.01	54.17ab±0.38	-9.11kl±0.76	149.62k±2.42
Delta2.12.S1	23.13de±0.28	1.45defgh±0.04	44.42efghi±1.47	12.33ghi±2.90	498.59b±16.30
Delta2.18.S1	25.93no±0.28	1.48hij±0.02	43.27cde±0.72	14.58hij±1.42	961.56nop±13.47
Delta2.06.S2	23.83hi±0.28	1.18l±0.01	54.68a±0.40	-10.14l±0.80	144.60k±2.36
Delta2.12.S2	29.43a±0.28	1.44defg±0.06	44.81fghi±2.16	11.58ghi±4.26	506.86a±24.65
Delta2.18.S2	34.33k±0.28	1.46ijk±0.04	43.85bcd±1.36	13.44ij±2.68	821.35no±24.74
Delta2.06.S3	20.83i±0.28	1.16l±0.01	55.42a±0.37	-11.62l±0.75	146.23kl±2.60
Delta2.12.S3	28.03m±0.28	1.49efgh±0.02	42.79efgh±0.81	15.53ghi±1.59	908.47n±11.63
Delta2.18.S3	34.73op±0.28	1.45ghi±0.06	44.42def±2.16	12.31jk±4.26	893.03nop±41.97
Gama.06.S1	16.25pq±0.19	1.22l±0.02	53.05a±0.70	-7.77l±1.43	755.55p±13.88
Gama.12.S1	17.55i±0.19	1.15kl±0.01	56.00ab±0.41	-12.79l±0.83	142.96kl±2.15
Gama.18.S1	18.65cd±0.19	1.19kl±0.02	54.33a±0.65	-9.36l±1.31	405.10de±9.42
Gama.06.S2	21.52q±0.15	1.21l±0.02	53.62a±0.70	-8.94l±1.43	766.76p±15.14
Gama.12.S2	31.42bc±0.15	1.22jkl±0.02	53.08abc±0.60	-6.84l±1.20	413.25d±8.82
Gama.18.S2	36.22bc±0.15	1.18kl±0.01	54.90ab±0.55	-10.52l±1.12	394.34de±8.03
Gama.06.S3	20.93q±0.28	1.19l±0.02	54.20a±0.64	-10.11l±1.30	744.34p±12.74
Gama.12.S3	28.23b±0.28	1.21kl±0.02	53.75ab±0.65	-8.20l±1.31	399.72d±8.70
Gama.18.S3	35.03q±0.28	1.24l±0.02	52.37a±0.66	-6.40l±1.34	780.73op±14.00

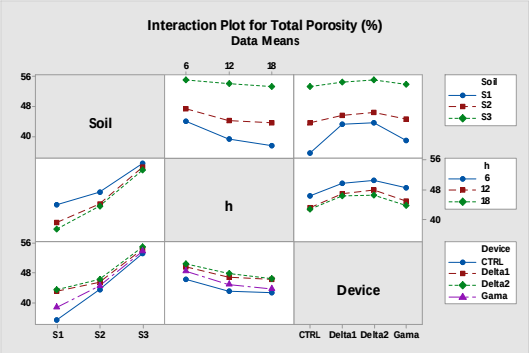


Fig. 6 Interval plot for total porosity (from three-way ANOVA) for soil types (factor Soil), depth (factor h) and active elements (factor Device).

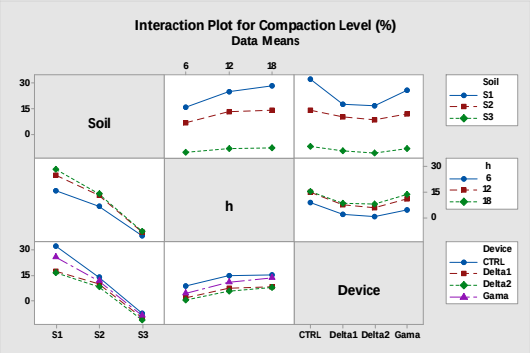


Fig. 7 Interval plot for compression level (from three-way ANOVA) for soil types (factor Soil), depth (factor h) and active elements (factor Device).

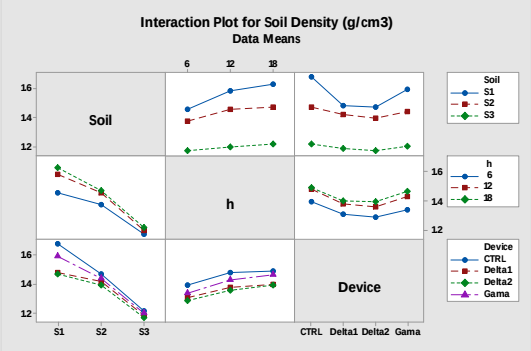


Fig. 8 Interval plot for bulk density (from three-way ANOVA) for soil types (factor Soil), depth (factor h) and active elements (factor Device).

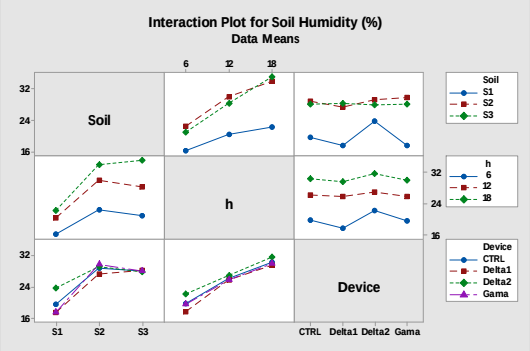


Fig. 9 Interval plot for soil moisture (from three-way ANOVA) for soil types (factor Soil), depth (factor h) and active elements (factor Device).

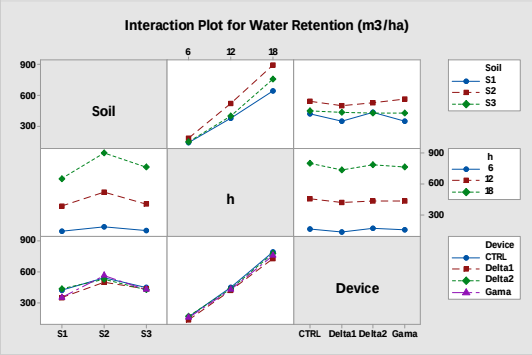


Fig. 10 Interval plot for water retention (from three-way ANOVA) for soil types (factor Soil), depth (factor h) and active elements (factor Device).

Multivariate analysis

To evaluate the vibro-combinators soil tillage performances were studied the variables: apparent density (g/cm^3), total porosity (%) and soil compression (%). To evaluate the soil environmental impact of the vibro-combinators were considered the variables: soil moisture (%) and water retention (m^3/ha). In order to assess simultaneously the vibro-combinators soil tillage performances and environmental impact, was involved the multivariate analysis: principal component analysis (PCA) and multivariate analysis of variance (MANOVA, P = 0.05). The PCA and MANOVA were done separately for each soil types S1, S2 and S3. The PCA method involved as input data the variables correlation matrix and between sample groups algorithm. The MANOVA algorithm used as input data the first two principal components (PCs) coordinates of the group samples. The group samples were described by the interaction factor Device*h (i.e. active elements*depth).

Statistical results for PCA for soil types are presented in Table 4. For all soil types the first two PCs present eigenvalues greater than unity and a cumulative percentage of explained variance greater than 95.0%. Due to this reason these PCs are sufficient to describe the experiment with statistically significance.

Table 4 Principal components analysis statistics for soil factor (PC represents the principal component).

S1	PC	Eigenvalue	% variance
	1	3.578	71.567
	2	1.258	25.166
	3	0.163	3.2669
	4	1.22E-05	0.0002
	5	5.49E-09	1.10E-07
S2	PC	Eigenvalue	% variance
	1	4.380	87.614
	2	0.585	11.710
	3	0.033	0.673
	4	0.0001	0.002
	5	6.86E-06	0.0001
S3	PC	Eigenvalue	% variance
	1	4.239	84.793
	2	0.743	14.877
	3	0.0158	0.3172
	4	0.0006	0.0120
	5	4.01E-05	0.00080181

For all soil types the first two PCs present eigenvalues greater than unity and a cumulative percentage of explained variance greater than 95.0%. Due to this reason these PCs are sufficient to describe the experiment with statistically significance.

The PCAs biplots gathers in the same graphical representation the samples scores and variable loadings (Fig. 11-13). The sample groups are marked by points inside a convex hull and the variables are represented by vectors with the staring points in the coordinate system origin. The variable vectors end points shows the direction that describes the highest abundance (or levels) of the corresponding variables. This means that the group samples placed in the one vector direction (marked by its end point), have high abundance/level of that variable. When the sample groups are placed in the opposite direction, they have lowest abundance/levels for that variable. Analysing Fig. 11-14, for the soil type S1, the PCA biplot prescribe (table 5-7).

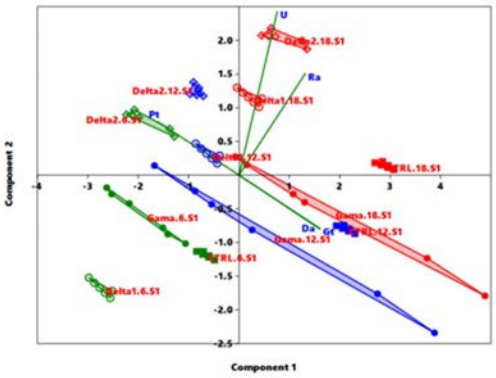


Fig. 11 Principal component analysis (PCA) biplot for different depths (factor h) and for the three active elements (factor Device) for soil type S1.

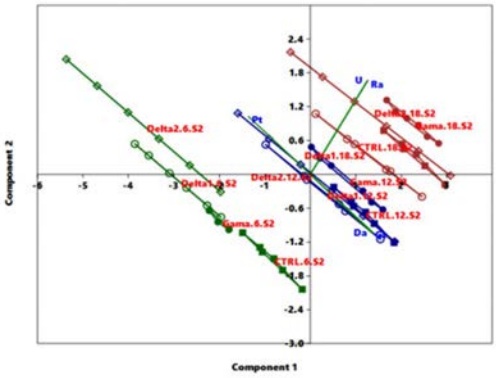


Fig. 12 Principal component analysis (PCA) biplot for different depths (factor h) and for the three active elements (factor Device) for soil type S2.

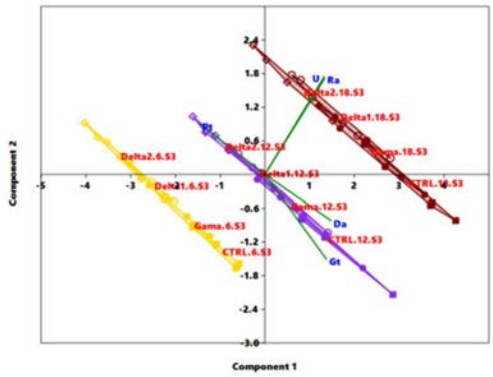


Fig. 13 Principal component analysis (PCA) biplot for different depths (factor h) and for the three active elements (factor Device) for soil type S3.

Table 5 Statistical significance values of multivariate analysis of variance (MANOVA, P = 0.05) for the soil type S1.

MANOVA	CTRL.6.S1	Delta1.6.S1	Delta2.6.S1	Gama.6.S1	CTRL.12.S1	Delta1.12.S1	Delta2.12.S1	Gama.12.S1	CTRL.18.S1	Delta1.18.S1	Delta2.18.S1	Gama.18.S1
CTRL.6.S1		0.000	0.000	2.239	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delta1.6.S1	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delta2.6.S1	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gama.6.S1	2.239	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CTRL.12.S1	0.000	0.000	0.000	0.000		3.940	0.001	0.002	0.000	0.000	0.000	0.000
Delta1.12.S1	0.000	0.000	0.000	0.000	3.940		0.001	0.003	0.000	0.000	0.000	0.000
Delta2.12.S1	0.000	0.000	0.000	0.000	0.001	0.001		0.000	0.000	0.000	0.000	0.000
Gama.12.S1	0.000	0.000	0.000	0.000	0.002	0.003	0.000		0.000	0.000	0.000	0.000
CTRL.18.S1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.241	0.000	0.000
Delta1.18.S1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.241		0.000	0.000
Delta2.18.S1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000
Gama.18.S1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

Table 6 Statistical significance values of multivariate analysis of variance (MANOVA, P = 0.05) for the soil type S2.

MANOVA	CTRL.6.S2	Delta1.6.S2	Delta2.6.S2	Gama.6.S2	CTRL.12.S2	Delta1.12.S2	Delta2.12.S2	Gama.12.S2	CTRL.18.S2	Delta1.18.S2	Delta2.18.S2	Gama.18.S2
CTRL.6.S2		0.793	0.001	0.352	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delta1.6.S2	0.793		0.001	2.592	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delta2.6.S2	0.001	0.001		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gama.6.S2	0.352	2.592	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CTRL.12.S2	0.000	0.000	0.000	0.000		0.069	13.997	0.004	0.000	0.000	0.000	0.000
Delta1.12.S2	0.000	0.000	0.000	0.000	0.069		0.327	0.000	0.000	0.000	0.000	0.000
Delta2.12.S2	0.000	0.000	0.000	0.000	13.997	0.327		0.002	0.000	0.000	0.000	0.000
Gama.12.S2	0.000	0.000	0.000	0.000	0.004	0.000	0.002		0.000	0.000	0.000	0.000
CTRL.18.S2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.938	0.000
Delta1.18.S2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000
Delta2.18.S2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.938	0.000		0.002
Gama.18.S2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	

Table 7 Statistical significance values of multivariate analysis of variance (MANOVA, P = 0.05) for the soil type S3.

MANOVA	CTRL.6.S3	Delta1.6.S3	Delta2.6.S3	Gama.6.S3	CTRL.12.S3	Delta1.12.S3	Delta2.12.S3	Gama.12.S3	CTRL.18.S3	Delta1.18.S3	Delta2.18.S3	Gama.18.S3
CTRL.6.S3		0.957	0.210	42.092	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delta1.6.S3	0.957		21.324	3.674	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delta2.6.S3	0.210	21.324		0.564	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gama.6.S3	42.092	3.674	0.564		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CTRL.12.S3	0.000	0.000	0.000	0.000		1.358	1.110	2.199	0.000	0.000	0.000	0.000
Delta1.12.S3	0.000	0.000	0.000	0.000	1.358		36.244	3.884	0.000	0.000	0.000	0.000
Delta2.12.S3	0.000	0.000	0.000	0.000	1.110	36.244		2.363	0.000	0.000	0.000	0.000
Gama.12.S3	0.000	0.000	0.000	0.000	2.199	3.884	2.363		0.000	0.000	0.000	0.000
CTRL.18.S3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		2.540	1.089	0.278
Delta1.18.S3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.540		4.215	0.228
Delta2.18.S3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.089	4.215		1.277
Gama.18.S3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.278	0.228	1.277	

4. Conclusions

The advantages of using vibro-combinators are: perfect preparation of seedbed in difficult working conditions and preservation of soil moisture. Such important factors can ensure fast, uniform and early germination of seeds, these requirements standing at the basis of abundant harvests. The research investigated the soil tillage performances and the environmental impact of several active elements of the vibro-combinators, at certain soil depths and soil types.

The multivariate analysis allowed to assess for each soil type which active elements performs both best soil tillage and environmental protection of the soils. From the technical point of view, the 6 cm depth is the most important to soil tillage for crop production. For this depth the active elements of the vibro-combinator: Delta2 and Delta1 are those that performs both best soil tillage and environmental protection of the studied soils.

5. References

Cardei P., Rigon L., Muraru V. M., Muraru-Ionel C., Constantin N., David A., (2015), A method of calculating the optimal speed of operation for vibro-cultivators, Proceedings of 43. International Symposium Agricultural Engineering, Actual Tasks on Agricultural Engineering, vol. 43, p 211-221.

Celik H., Kursat and Topakci, Mehmet and Canakci, Murad and Rennie, Allan and Akinci, Ibrahim, (2010), Modal analysis of agricultural machineries using finite element method: a case study for a V-belt pulley of a fodder crushing machine, Journal of Food, Agriculture & Environment (JFAE), 8 (3-4). pp. 439-446.

Petrescu H. A., Martin R., Vlasceanu D., Hadar A., Parausanu I., Dan R., (2015), Modal analysis using fem of three active elements for an agricultural machine, Proceedings of 43. International Symposium Agricultural Engineering, Actual Tasks on Agricultural Engineering, vol. 43, p 201-209.

Căproiu Şt., et al, (1982), Agricultural machinery for soil tillage, seeding and crop maintenance. Didactic and Pedagogic Publishing House, Bucharest.

Biris S. ST., Bungescu S. T., Manea D., Boja N., Cilan T. F., Martin R., (2015), State of art approach to vibro-combinators soil tillage implements construction, Proceedings of 43. International Symposium Agricultural Engineering, Actual Tasks on Agricultural Engineering, vol. 43, p 177-188.

Boja N., Boja F., Teuşdea A., Carţiş Mihaela, Puşcaş Simona, (2012), Study on the Impact of Soil Processing on Some Physico-mechanical Properties, Journal of Environmental Protection and Ecology (JEPE), vol. 13, no.2A/2012, p. 941-950.

Boja N., Boja F., Teusdea A., Dărău P. A., Maior C., (2013), Research regarding the uniformity of sprinkler irrigation, Journal of Environmental Protection and Ecology (JEPE), vol. 14, no.4 / 2013, p. 1661-1672.

http://www.kyplot.software.informer.com.

Hammer O., Harper D. A. T., Ryan P. D. Past, (2001), Paleontological Statistics Software Package for Education and Data Analysis. Palaeontologia Electronica, 4 (1), 9.

Spoljar A., Kisic I., Birkas M., Kvaternjak I., Marencic D., Orehovacki V., (2009), Influence of tillage on soil properties, yield and protein content in maize and soybean grain, Journal of Environmental Protection and Ecology (JEPE), Vol. 10, No 4, p. 1013–1031.

Spoljar A., Kisic I., Birkas M., Gunjaca J., Kvaternjak I., (2011), Influence of Crop Rotation, Liming and Green Manuring on Soil Properties and Yields. Journal of Environmental Protection and Ecology (JEPE), Vol. 12, No 1, p. 54–69.

Boyraz D., Atilgan M. C., (2014), Use of Mechanical Properties for Evaluating Engineering Behaviour of Soils with Different Textural Classes, Journal of Environmental Protection and Ecology (JEPE), Vol. 15, No 1, p. 78–84.

Boja N., Boja F., Teusdea A., Dărău P.A., Maior C., (2016), Soil porosity and compaction as influenced by tillage methods, Journal of Environmental Protection and Ecology (JEPE), vol. 17, no.4 / 2016, p. 1315–1323.

Calistru A. E., Topa D., Rostek J., Puschmann D. U., Peth S., Horn R., Jitareanu G., (2016), Soil Physical Properties and Winter Wheat Yield as Affected by Different Tillage Systems, Journal of Environmental Protection and Ecology (JEPE), Vol. 17, No 3, p. 978–989.

Vidrean D., Boja F., Teuşdea A., Dragomir C., Boja N., (2018), Assesment of soil impact after using a vibro-combinator, Proceedings of 46. International Symposium Agricultural Engineering, Actual Tasks on Agricultural Engineering, Opatija, Croatia, 27 February - 01 March 2018, vol. 46, p 169-179.

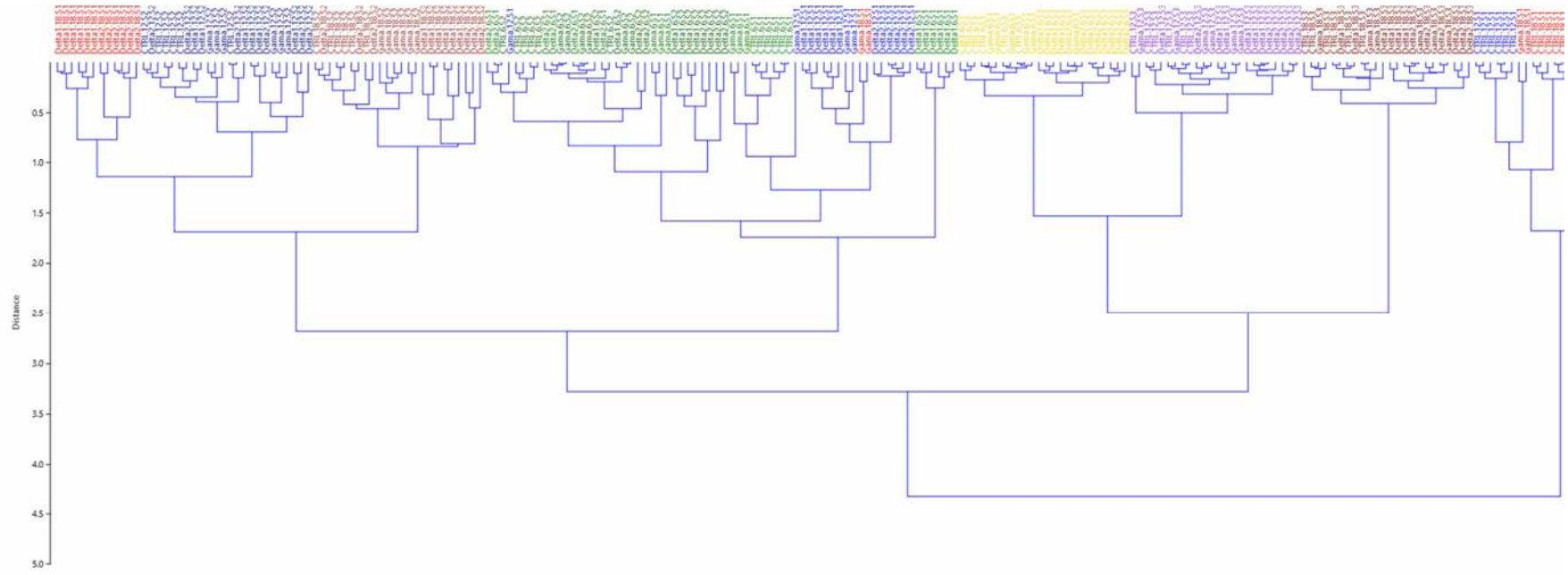


Fig. 14 Hierarchical cluster analysis (HCA) dendrogram with the clustering information for different types of soils, different depth 6, 12 and 18 cm and for the three active elements: Gama, Delta1, Delta

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

ASSESSMENT OF COSTS IN HARVESTING SYSTEMS USING THE WOODCHAINMANAGER WEB-BASED TOOL

Matevž Triplat, Nike Krajnc
Slovenian Forestry Institute, Ljubljana, Slovenia
matevz.triplat@gozdis.si

Abstract: *The rationalization of working procedures during difficult market conditions is gaining increasing importance. For rational production it is necessary to always be aware of what and how much to invest in the business process to obtain the desired products or services without economic loss. Calculations enable the comparison of individual and total costs between products or services and thus offer a choice of measures to reduce costs and increase business economy and profitability. Recently an increasing number of tools for calculations have been adapted for the needs of various groups.*
The WoodChainManager is a Web-based tool for the assessment of costs in harvesting systems. WoodChainManager is a tool composed of three modules intended for the assessment of material costs of individual machines or the total costs of all selected machines in a forest harvesting system. Users can test the impact of individual technologies on the total material costs of the harvesting system and thus optimize operation processes. The tool for describing harvesting systems is the matrix, which visualizes cutting and hauling from the stand to the end user. The tool has built-in algorithms that prevent the selection of an illogical harvesting system. The selected method for calculating costs for individual machines is simple, but still reflects the state of the actually incurred costs. The WoodChainManager deals with the majority of techniques used in forestry under conditions ubiquitous in south-eastern Europe. For all techniques, default values are provided for the calculation of costs. Users can adapt these default values relative to the characteristics of their own mechanization.
Calculation provides useful information on the costs of a certain technology, as well as on the entire harvesting system. The main advantage of the Web-based tool is the fact that it is publicly available. Users have the possibility to compare cost calculations with other users. Moreover, WoodChainManager is regularly updated in terms of default values. Calculation of costs is crucial when deciding which technique to apply and enables optimization of forest operations. The authors wish to increase awareness and understanding of cost calculations and to offer the possibility to directly compare different harvesting systems.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

OPTIMIZATION OF RAW WOOD SUPPLY CHAIN

Lorenz Diefenbach, Martin Ziesak
Bern University of Applied Sciences (BFH)
School of Agriculture-, Forest- and Life Sciences (HAFL), Bern, Switzerland
Länggasse 85, CH-3052 Zollikofen, Switzerland
lorenz.diefenbach@bfh.ch, martin.ziesak@bfh.ch

Abstract: *The supply of peripherally located wood resources is associated with high transport effort and entails a significant amount of transport costs global warming potential (GWP). Raw wood transport costs vary strongly depending on many given factors. Regarding the situation in Switzerland, transport costs are up to 50% higher compared to the neighboring countries such as Germany.*
This study investigates combined rail and truck traffic for raw wood (CT), which is the raw wood transport from the wood supplier in the forest to the customer through combining both trucks and trains. We use time studies, GPS localizations and expert interviews to quantify the technical and environmental optimization potentials.

Keywords: Raw wood logistics, combined truck and train transport, supply-chain

1. Introduction

In general transport costs depend on many complex details of geography, infrastructure, administrative barriers and structure of transport industry (Limao and Venables 2001).
Considering raw wood transport costs, it could be shown that they vary strongly by many given factors such as transport distance, infrastructure, transport process, regulations by law or small forest owner structures (Hamelinck et al., 2005).

Especially raw wood transport in mountain areas are affected by higher raw wood transport costs (Wiggins and Proctor 2001). More in detail Gautschi et al. (2017) found out that for Switzerland, which has an accurate proportion of mountain areas, transport costs are up to 50% higher compared to the neighboring countries such as Germany. In total, raw wood transport costs are responsible for 25% to 30% of total raw wood resource costs in Switzerland. Another issue is the global warming potential of raw wood transports trough truck transports. For example, Tashkiri et al. (2016) estimated a non-negligible CO_2 equivalent of 0.063 kg per ton kilometer. With this background information, particularly the wood industry has interest in reducing raw wood transport costs and considering more sustainable transport systems.

This study's aim is to identify and quantify technical optimization potential, aiming at reduced raw wood transport costs and improved eco-impact. More in detail, this study investigates combined rail and truck transport for raw wood (CT), which is the raw wood transport from the wood supplier in the forest to the customer through combining both trucks and trains. Our study regards two different train container systems and one train and truck container system. Together with partners from two train companies and stakeholders from forest and timber industry we conduct practical tests. The tests track starts in the east of Switzerland, in the canton of Grisons and ends in central Switzerland in the canton of Lucerne. This combined traffic is compared versus classical truck transport, applied to identical source and sink locations. We use time studies, GPS localizations and expert interviews to quantify the cost saving potential.

2. References

Gautschi M., Hagenbuch M., Taverna R. (2017). Transporte in der Schweizer Wald- und Holzwirtschaft: Situationsanalyse und Optimierungsmöglichkeiten

Hamelinck, C. N., Suurs, R. A., & Faaij, A. P. (2005). International bioenergy transport costs and energy balance. Biomass and Bioenergy, 29(2), 114-134

Limao, N., & Venables, A. J. (2001). Infrastructure, geographical disadvantage, transport costs, and trade. The World Bank Economic Review, 15(3), 451-479

Taskhiri, M. S., Garbs, M., & Geldermann, J. (2016). Sustainable logistics network for wood flow considering cascade utilisation. Journal of cleaner production, 110, 25-39

Wiggins, S., & Proctor, S. (2001). How special are rural areas? The economic implications of location for rural development. Development policy review, 19(4), 427-436

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

THE IMPACT OF WEATHER CONDITIONS ON PRODUCTION OF COST OF WOOD FUELS IN ESTONIAN CONDITIONS - A CASE STUDY

Marek Irdla [1], Allar Padari [2], Peeter Muiste [3]
Estonian University of Life Sciences,Tartu, Estonia
marek.irdla@student.emu.ee

Abstract: *Estonia has ratified the Paris Agreement on Climate Change and contributing the EU commitment to a 40 percent reduction in emissions by 2030. Our national goal according to the Long-term Development Programme for the Estonian Energy Sector up to year 2030+ is to decrease the GHG emissions by year 2050 by 80% compared with the year 1990. Achieving the targets, the use of wood fuels should increase. But due to different environmental restrictions the harvesting volumes are forecasted to decrease and therefore there will be less wood for energy sector available. To supply the increasing number of consumers, the production of wood fuels should be carried out perennially and efficiency of production becomes especially essential. Among different factors influencing the supply chain is the air temperature. During mild winters the processing and local transport of wood fuels is taking place on soft and unfrozen soils, which increases the fuel consumption of machines. But higher temperature may create more favourable conditions for processing of unfrozen raw material. As the precise data about weather conditions and the costs of production of wood fuels of a specialized producer were available for a several year period, the goal of the case-study was defined - to analyse the impact of precipitation and air temperature to the price formation of whole chain of production of comminuted wood fuels in Estonian conditions.*

The initial data from TMK Energy Lõuna company covered 2 different types of chippers (Jenz HEM 582, Jenz HEM 593) and 4 different types trucks (Volvo FH 460, Volvo FH 500, MAN TGX and MAN TGA). All machines were equipped with a GPS tracking device (Dynafleet by Volvo and Navirec) which records the route and the fuel consumption. During the study all costs and revenues related to the concerned machines were accounted. The data about the precipitation and air temperatures were got from the Estonian Weather Service. As a result of analysis of meteorological data and the data of the machines, the impact of weather conditions on production costs of wood fuels was determined.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

SOIL PREPARATION MECHANIZATION - DEVICES MADE IN LATVIA FOR FUTURE FORESTS.

Dagnija Lazdina, Andis Lazdins, Karlis Dumins, Toms Arturs Stals, Kristaps Makovskis, Janis Liepins
LSFRI Silava, Riga street 111,Salaspils, Latvia, LV 2169
dagnija.lazdina@gmail.com

Abstract: *Soil preparation in the forest facilitates the growth of planted trees,as it reduces competition with herbs, creates marked planting spots, promotes the mineralization of organic matter and the natural regeneration of forests with seeds, it is a widely used practice. If previously the focus has been on the cost and productivity of soil preparation work, then in recent years more and more attention is paid to the impact of the selected soil preparation on the soil and soil condition throughout the clearing of ground vegetation, and compaction of the soil. The task of the research is to compare the environmental impact of the soil preparation devices and the basic machines, which are produced in Latvia and applied in practice as well as the suitability for soil preparation in heterogeneous conditions. Three different soil tillage machines were tested - MPV-600 mounding device, MCR-500 stump lifting device , UOT - M22 moving mounder and disc harrow – UOT 3000, 2000, 1000 and 500 and their basic machines - excavator, forwarder, tractor adapted for forestry work. Measurements of prepared planting sites, soil scarification, quality of prepared planting spots and number per ha were taken. The most versatile soil preparation unit is the rotary mounder on the forwarder, the cheapest is the farm tractor with disc trenchers, the smallest scarified area is built up by mounding with the excavator, but the stump lifter equipped with a mounding device improves soil aeration in compacted soils.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

INFORMAL WORK IN A NEW BOOK ON WORK IN TROPICAL FORESTS

Siegfried Lewark
Chair of Forest Work Science
Faculty of
University of Freiburg
Werthmannstraße 6, D-79085 Freiburg, Austria
siegfried.lewark@fobawi.uni-freiburg.de

Abstract: *All forest dependent people have to work in the forests for securing their living. The knowledge about the work of forest workers is mostly based on work study on stress and strain and on performance of formally employed forest workers, studied by Forest Work Science. But by far most of the work in tropical forests is done in the informal economy. There are other scientific disciplines that contribute to the knowledge, especially Anthropology, which have done e.g. time allocation studies that reveal times devoted to different activities.*

This text is a continuation of another text in these proceedings.[1] *Both texts are drawing from "Work in Tropical Forests", a book under preparation.*[2] *A comprehensive approach has been taken on work in tropical forests, including a view on all kinds of working people and all forms of employment. Research questions may be: What is different between working conditions in formal and informal employment? Which knowledge from work study in formal employment in forestry may be transferred? Which knowledge may help improving the working situation in informal employment?*

Keywords: work science, tropical forests, forest utilization, working conditions

1. Employment in Tropical Forests

1.1 People Working in Tropical Forests and their Ways of Forest Utilization

In the forests of the tropics people have lived for very long time, with the forests and from the forest resources. Forest dwellers living in harmony with the forests is a popular and perhaps romanticizing view, which would include a stress-free life, with leisure time and work in an equilibrium. This perception is connected with the notion of affluent societies.

The people living from the forests were hunting and gathering, or living by planting agricultural plants in gaps of the forests, doing shifting cultivation, or they cultivated home gardens, in a traditional way of agroforestry. They used Non Wood Forest Products (NWFP) as well as wood, primarily as fuel wood and construction material. This was done – and to some degree still is – in a subsistence economy, with more or less immediate consumption and some provisions stored. On this level of local consumption, of the family or the community, there was limited labour division, between women and men and between age groups. Today nearly everywhere adaptations of different degrees of transition to market economies are found, which typically started with bartering for tools.

1 Lewark (2019a)
2 Lewark (2019b)

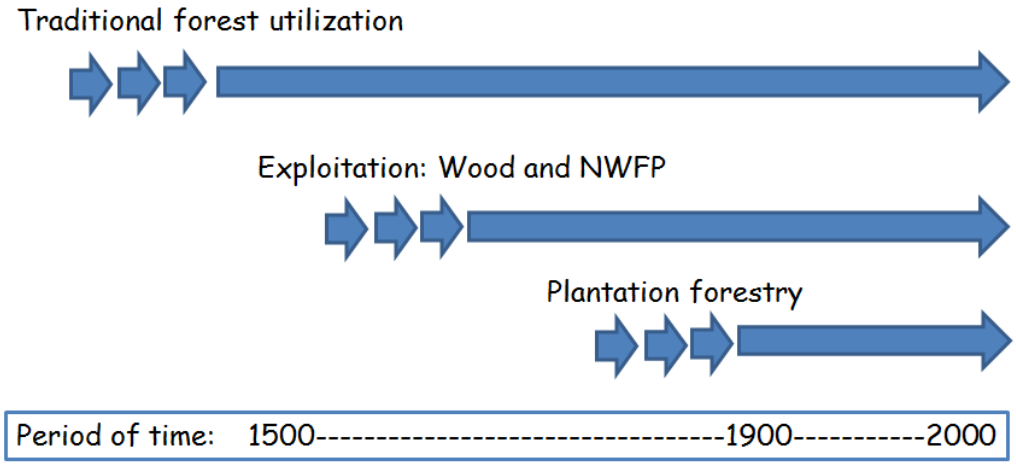


Figure 1: Forms of utilization of tropical forests over time

Traditional forest utilization is still going on, but at the same time retrieval of industrial wood from natural forests needs and provides employment, though only in small parts in Sustainable Forest Management (SFM). The role of employment in plantation forests in many regions is growing, very much so also in subtropical forests (Fig. 1).

1.2 Numbers of People in Forest Work

There are 13.2 million formal jobs in the forest sector "across the world", exceeded by far by the 41 million of informally employed (FAO 2014). Out of the 13.2 million 3.5 million jobs are in forestry, 5.4 million are employed in enterprises producing solid wood products, and 4.3 million in pulp and paper production, distributed unevenly over the different regions of the world. The breakdown into continents given in FAO (2014) shows 2.5 million formally employed in forestry in Africa, Asia and Oceania, Latin America and the Caribbean together, and a share of 0.1% of the total workforce in forestry in any of the continents, 0.4% for the forest sector. These data are of very different quality, often based on estimations, and must therefore be compared with caution.

Forest owners are another group of people benefitting from income in the forest sector, though 79 % of the forests of the developing countries are public owned (White and Martin, 2002). At least 30 million people belong to this group globally, with big differences between regions, 18.5 million outside Europe and North America.

1.3 Forms of Employment

We distinguish between self-employed labour and employed labour. Employment in forests may be provided directly by forest owners or holders of rights of use or by contractors doing the work for them. The term employment may mean dependent work under an employment contract, but also just occupation or working activity, without an employer, why we may talk also about subsistence employment (Poschen 2019).

Basically dependent work is done under employment contracts by directly employed or under commercial contracts in contractor work. Direct employment has for long time been considered normal work, at least in industrialized countries, where it developed since times of industrialization. Today contractor work is gaining more and more importance in the forestry sector worldwide, while contractors may have employees, for their part.

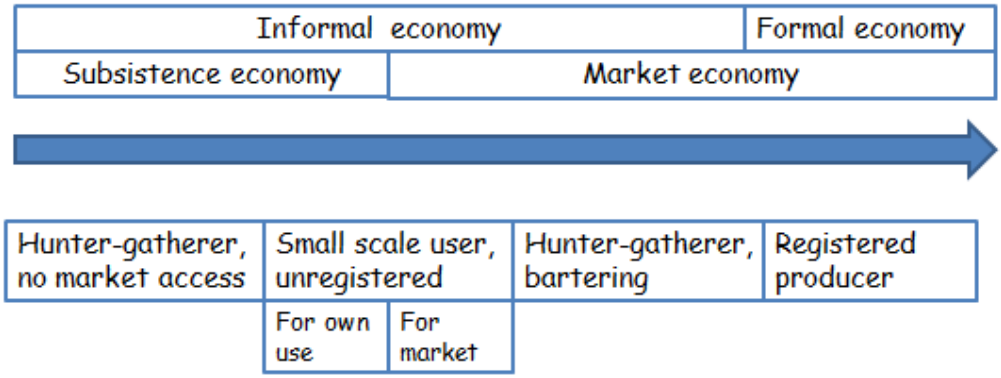


Figure 2: Subsistence and Self-employed Activities in Tropical Forests

Many people work independently of any employer like owners of small forest lots and all those in subsistence employment. They are called self-employed as defined by OECD (2015). There are two meanings of the term self-employed: It may be somebody working independently of an employer informally or referring to registered independent work of somebody paying taxes. Likewise a forest contractor may be considered as own-account worker or a secondary employer working for a principal employer or as self-employed, having a service-contract, not an employment contract (Egger, 1997). A contractor may thus belong to the formal or to the informal sector. Types of informal employment of traditional forest users are described by ILO (2015):

> "The forestry sector is characterized by a high degree of informality (75.65 per cent), particularly in developing countries. This is in large part due to the expansion of illegal logging activities. Illegal logging includes some proportion of unregistered traditional use of forests, which if properly controlled, can have a positive impact in controlling forest destruction.
> There are six categories of informal workers, all of which should be targeted by policy to address informality in the forestry sector:
> • Own-account workers (self-employed with no employees) in their own informal economy enterprises;
> • Employers (self-employed with employees) in their own informal economy enterprises;
> • Contributing family workers, regardless of type of enterprise;
> • Members of informal producers' cooperatives (not established as legal entities);
> • Employees holding informal jobs as defined according to the employment relationship (in law or in practice, jobs not subject to national labour legislation, income tax, social protection or entitlement to certain employment benefits);
> • Own-account workers engaged in production of goods exclusively for own final use by their household."

So the people considered as informally employed according to the definitions above are a very heterogeneous group (Fig. 2).

2. Studies on Working and Living Conditions

2.1 Which Work in Informal Employment to Look at in Forest Work Science?

Most work in tropical forests is done outside the forestry business, mostly in informal employment. We saw that there is informal employment of very different character. We find informal employment in a great variety of activities and operations in utilization of natural forests, for wood and NWFP, retrieving wood for industrial use as well as for household use, and also in work in plantation forests. That calls for attention for this work, also by Forest Work Science.

We observe big changes of employment of traditional forest users towards wage labour in the forest sector and outside, often connected with out-migration. Out-migration of men often leaves women and children for the household work, which changes the patterns of activities.

When we exclude all unsustainable forest utilization and illegal activities in the forests from our considerations about studying informal work we are left with work in traditional forest utilization in natural forests, in the first place. Of course work in unsustainable utilization and illegal activities in the forests also deserve scientific attention, but this would need approaches still further away from traditional forest work study.

So in principle the work to be studied includes all forest based work, but also other subsistence work for the livelihood of forest dependent people. Clearly collecting, harvesting, processing and trading of forest products is forest based, while at the same time even more work is done in agroforestry and use of trees outside of forests. This work so far practically does not occur in publications from forest work study.

Some studies have been published on activities connected with collecting, harvesting, processing and trading of fuelwood and charcoal, also for small scale production of sawn wood for local and distant markets. Looking beyond Forest Work Science we also find studies on retrieval of e.g. NWFP, food, fodder and medicine, also for own consumption as well as for trade. Clearly any work study starts with a definition of the workers and their tasks. This is where challenges for work study in informal employment start and time allocation comes in.

Firewood retrieval and charcoal production as well as transport of both belong to the most important work done. Transport is still often done by head-loading and back-loading, which was studied by Lloyd et al. (2010). Studies on numbers of people occupied have already been mentioned in Lewark (2019a). Here two more sample work studies will be presented.

2.2 Work Studies on On-site Conversion into Sawn-wood

Because of the dimensions of the trees and the difficulties of extraction and further transport one line of operations led to conversion of logs to planks and boards near the felling site worldwide, which is nicely documented in older texts and photos. It has been done to begin with by hewing with axes. Next was pit-sawing, i.e. digging a pit under the felled tree or next to it and rolling the log over the pit, and then sawing with a ripsaw with one man standing on the log, the other in the pit underneath, the underdog. This operation is still found, but more and more replaced by chainsaw milling.

Pit-sawing is very dangerous and hard manual work, beginning with the labour intensive excavation of the saw pit under the felled tree or next to it and then the rolling of the log. Body postures of both men are awkward, while the one underneath also gets sawdust from above and in addition is endangered by working under a heavy log, which has to be fastened securely. The physical workload of the sawing is in any case very high, so sharpening of the saw is crucial.

More recently racks or platforms have been developed for the manual sawing to boards with the same operation principle, one man on top of the log, the other underneath. The racks can be constructed on the

spot from small stems, as trestles, but also light metal constructions have been developed. This saves the workers from digging, but still leaves the moving of the logs to the rack. The dangerous task of getting the log on the rack, manually in the case of the wooden racks, has been facilitated and made less dangerous by pulleys.

Pit-sawing with a wooden rack and sawing using a metal rack, without pit-digging, are studied in Tanzania by Rurangwa et al. (2011) (Table 1). The results show that digging the pit is the hardest work, with unduly peak values of heart rate. Skidding respectively rolling of the logs has been done in both compared operations, as well as the sawing itself, which was found to have equally high workload. So simple developments may still improve manual processing considerably, contributing to use of appropriate technology.

Table 1: Sample Work Study on Pit-sawing by Rurangwa et al. (2011)

Study background	
Research question	Physical workload and performance in pit-sawing with two different platforms
Country, region	Tanzania
Study set-up	Experiment
Operation details	
Studied operations	Sawing of logs into planks, secondary tasks
Tree species	*Hardwood spec.*
Work site	Agroforestry farms
Working system	
Work method, task	Sawing on portable platforms
Working tools	Two man ripping saw (5kg); wooden and steel platforms, pulley
Working cycle, elements	1) pit excavation, platform assembling, rolling to pit, manual loading, sawing 2) platform assembling, rolling, loading with pulley, sawing
Working persons	
Study groups	4 male subjects
Age, anthropometric data	40 years, 1,66m, 60kg, resting heart rate 64
Familiarity with tasks	Used to manual timber sawing
Work organization	Crews with 2 men
Ergonomic assessments	
Parameters	Heart rate
Performance	Time study
Hours studied	Totally more than 40 hours
Influencing factors	Log volume
Specific health risks	Accidents with handling of logs, body postures, saw dust

Producing planks is more and more done using chainsaws. At first freehand sawing was done from above, with the stem on cross logs. Mostly it is done by one operator and an assistant. Meanwhile more or less sophisticated attachments for better control of the saw are available at relatively low cost (Pasiecznik, 2010), but in the tropics they are still seldom in use. With use of these attachments sawing of the logs on racks can be done in mostly upright position from the side and even by one operator, and the moving the log onto the rack can also be facilitated by specific devices.

Chainsaw milling is also demanding and dangerous, especially freehand sawing. In addition to the handling of heavy logs, also to be done here, and the awkward work postures there is the specific strain of chainsaw work from noise and vibration, again depending on the state of maintenance of the saw. And there is the inherent risk of accidents of chain-sawing, especially if protection equipment and training are lacking.

There are mobile sawmills used for on-site conversion, especially for thicker and longer logs. They are based on different technology, using band saws or circular saws. These would also deserve attention, but no work study was found.

2.3 Subsistence Time Allocation in East Kalimantan

Out of her anthropological research over many years in Kalimantan Colfer (2008) reports about time allocation studies in groups of resettled people. The group of Uma'Jalan Kenyah people earlier were self-sufficient, cultivated rice, had garden plots and harvested in the forest. They were moved from their traditional longhouses to a village with single family dwellings. One of the changes, after the move, was the access to chainsaws, outboard motors and rice-hulling machines. This contributes to higher work productivity, which allows cultivation of bigger ricefields and better access to markets for rice. All the changes also have a big impact on the gender roles.

Based on her studies Colfer concludes that "all human activity in the forest has the potential of being harmful" and observes:

> "Ironically, the governmental programs encouraging interior plateau people to resettle in the lowlands were at least partially designed to discourage shifting cultivation and its perceived negative impacts on the environment. The actual impact seems to have been the reverse: The comparatively non-destructive form of shifting cultivation practiced by the Kenyah […] has evolved into a considerably more forest-destroying form." (Colfer, 2008)

The activities were observed during daytime for women and men, recorded according to age groups, based on randomized household visits with assessments of the activities of all household members. 171 household visits distributed over nearly one year in 129 households resulted in 1,593 individual observations.

The main activity of adult women (39%) was in agriculture, as compared to 28 % of adult men. The study includes food preparation as a forest related activity because firewood collection, the use of banana, forest leaves and bamboo are integral to the food preparation process. 57% of the different forest related activities together was found for women and 69% for men. Wage labour in the timber industry, as part of the forest related activities, accounted for 28% of the time of adult men, 2% of the adult women. Children over 8 years old contribute to productive activities.

2.4 Physical Exertion and Time Allocation in Papua New Guinea

43 married men and women of three groups of Huli, living in villages in hilly and flat terrain and in a small town, were studied by Yamauchi et al. (2000) within the discipline of Human Ecology in a School of Medicine. The main aim was finding out about the energetic adaptation in different natural and socio-economic environments, according to categories of activity. The authors report on times spent per activity and day. The work of the rural groups was totally self-employed, that in town all paid work, according to the types of work probably mostly in formal employment.

Most of the subsistence activities were in the category of gardening, which included tasks as digging ditches around the home-gardens and felling trees. These were slightly more energy-consuming and done by men, whereas women undertook more time-consuming activities like planting and harvesting sweet potatoes, which were lighter work, according to the energy expenditure. Occupational activities of men

and women in town were similar: 251 and 258 min/day. In contrast in the two rural groups there were clear differences between men and women: in the hilly village women had three times, in the flat village two times longer activities as compared to men; the activities were devoted to cultivation of sweet potato and pig husbandry.

Physical exertion has been assessed based on heart rate measurements and expressed as Physical Activity Level (PAL) and connected to body weight and Basal Metabolic Rate (BMR). The PAL values partly correspond to a moderate activity level, partly to a moderate-heavy level and only for the women of the flat village to heavy level. The highest exertion values were found in gardening activities, not different between the activities in flat and in hilly terrain. Overall energy expenditure was not different between activities in the villages and in town, as the higher values for gardening activities were compensated by longer occupational activity in town.

The town group in that study lived and worked in a small town nearby the villages, whereas in a connected study by the same group of researchers (Umezaki et al., 2002) a time allocation study was done of rural sedentes (441 observation days from the same villages as before) and 175 observation days of Huli migrants to the capital Port Moresby (with more than 300.000 inhabitants), where women only worked in the informal sector, men partly as well, but slightly more of them in paid jobs.

The findings are connected to the social traditions: In the villages Huli men live in men's houses, women and children in women's houses. Men cultivate sweet potatoes for themselves and are responsible for social-political matters, the women are responsible for the children and for farming, which may include food supply for the men. The Huli living under urban conditions live in family households.

One striking observation from both studies are the quite short activities for gathering and total occupational activities: 50 and 70 minutes per day in the two villages by men, 152 and 138 minutes by women, whereas even in the town study groups they report 251 minutes for men and 258 minutes for women. No time was allocated to collecting wood fuel, which is needed for cooking, also no time allocated to collecting construction material and for constructing of homes. Possible explanations are: These activities may have been outside of the study times, or done by other persons, perhaps children, or the times used may have looked insignificant.

3. Towards an "Integrative Forest Work Science"

A full picture of work in tropical forests will include work for retrieval of industrial wood as well as all work of forest dependent people, working for their livelihood, thereby a huge variety of operations, work methods, tools, and of working and living conditions. The traditional sectoral Forest Work Science covers only a small fraction of the connected issues. It is essentially focussed on:

- formal employment
- physical ergonomics
- work organization and design

Other issues are covered in technically oriented disciplines like Forest Operations Engineering and Management, which also takes a sectoral perspective. For broadening our view we must take note of research activities and insights from many other scientific disciplines, which also study issues of work in tropical forests. Examples have been presented above. More are included in "Work in Tropical Forests" (Lewark, 2019b).

This broader view may be adopted by an "Integrative Work Science", which has been developed in an earlier research project "WALD"[3] (Lewark and Kastenholz, 2007; Lewark et al., 2011). Issues covered or taken note of by this Integrative Work Science have been collected in a mindmap (Fig. 3), which can not

3 Research project "WALD", funded by the German Ministry for Education and Research as part of the programme „Zukunftsfähige Arbeitsforschung" under No. 01 HN 0120

be a complete collection though. It stems from research in German forests, and the situation in Central Europe is certainly different from that in tropical forests, but the sketch may give an impression of the variety of relevant issues traditional and new ones.

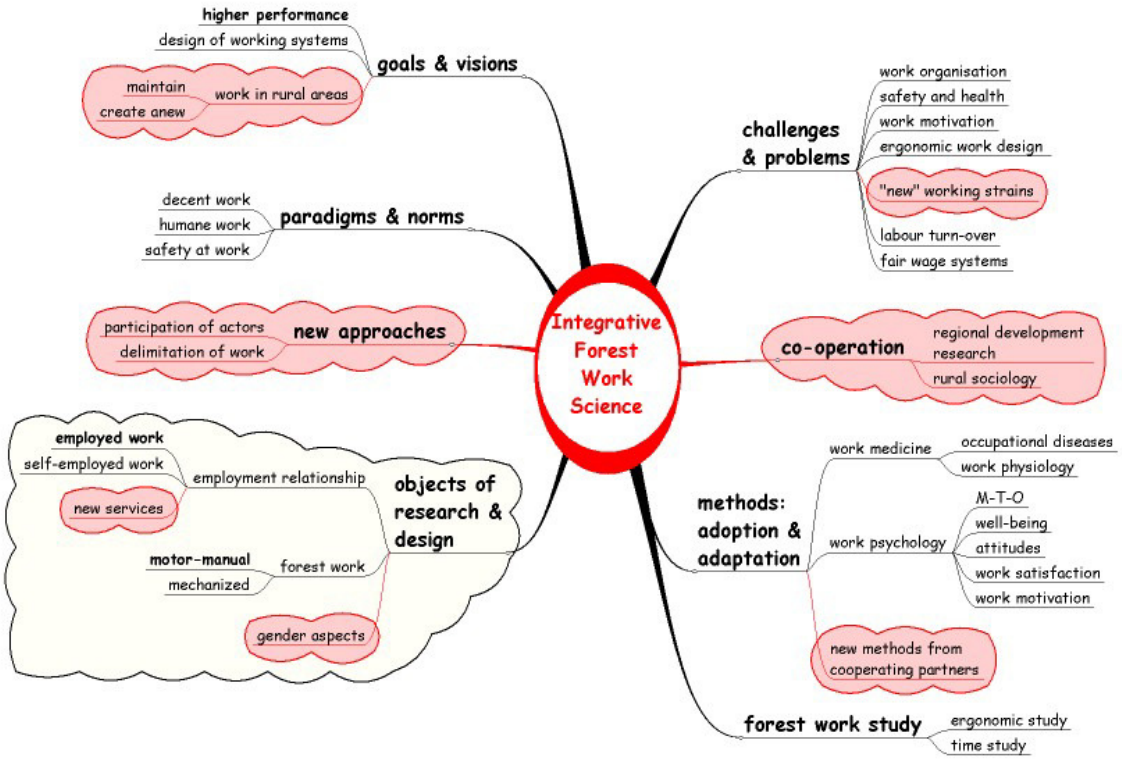


Figure 3: Integrative Forest Work Science (from Lewark and Kastenholz, 2007, adapted)

A comprehensive approach is proposed here on work in tropical forests, including a view on all kinds of working people and all forms of employment. All forest dependent people have to work in the forests for securing of their living. The knowledge about this work is mostly based on work study on stress and strain, and on performance of formally employed forest workers. But there are other scientific disciplines that contribute to the knowledge, especially Anthropology, Rural Sociology, Development Studies or Human Geography. Anthropologists have done time allocation studies that reveal the time of different population groups devoted to different employment.

Further development of Forest Work Science should acknowledge the approaches and research results from this broader view, to the extent applicable to specific work situations in tropical forests and the respective research questions. Forest work research should attempt for co-operation with the more specialized disciplines, in order to take a holistic and problem oriented approach.

The future of forests worldwide and especially of tropical forests and the fate of the respective societies living in and from the forests and the global society are dependent on the forests and at stake today. Work of many is the basis for it as outlined. It should be decent work. Here lies the challenge and responsibility of foresters and forest scientists, in particular of the human oriented forest work scientists.

4. References

Colfer, C. J. (2008) “The Longhouse of the Tarsier: Changing Landscapes, Gender, and Well being in Borneo”, Borneo Research Council Monograph Series, 10, Borneo Research Council, Phillips, ME.

Egger, P. (1997) Contract Labour and Employment: Some Proposals for Further Consideration. In: ILO (ed) Contract Labour, Looking at Issues, Nine Country Cases, Geneva, 3-15.

FAO (2014) State of the World's Forests 2014: Enhancing the Socioeconomic Benefits from Forests, Rome.

ILO (2019) Decent Work. www.ilo.org/global/topics/decent-work/lang--en/index.htm (Retrieved August 2019).

Lewark, S. (2019a) Forest Work in the Tropics in the Focus of Work Science. This volume.

Lewark, S. (2019b) Work in Tropical Forests. Under Preparation

Lewark, S. and Kastenholz, E. (2007) Sustainability of work as challenge for forest work science. In: International symposium "Bottlenecks, solutions, and priorities in the context of functions of forest resources" Proceedings. Istanbul, 375-384. www.kwf-online.de/deutsch/pdfopen/comforopen/SLEKSustWorkIstanbul.pdf (Retrieved August 2019).

Lewark, S., Kastenholz, E. and Westermayer, T. (2011) Ländliche Arbeit im Wandel. Nachhaltige Gestaltung forstlicher Dienstleistungsarbeit. Kessel: Remagen-Oberwinter, Germany.

OECD (2015) Self-employment Rate, https://data.oecd.org/emp/self-employment-rate.htm (Retrieved August 2019).

Poschen, P. (2012) Industries Based on Biological Resources: Forestry. In: ILO, Encyclopaedia of Occupational Health and Safety. 3rd ed. Rome, 68.1-68.41.

Rurangwa, F.A., Migunga, G., Kweka, A. E. and Mauya, E. (2011) “Productivity and Energy Expenditure by Sawyers when Using Pitsawing and Portable Steel Log Sawing Platforms in Agroforestry Farms”, Rwanda Journal, Series C: Mathematical Sciences, Engineering and Technology, 23, 70-79.

White, A. and Martin, A (2002) Who owns the world's forests? Forest tenure and public forests in transition. Forest Trends; Center for International Environment Law: Washington,

Yamauchi, T., Umezaki, M. and Ohtsuka, R. (2000) “Energy Expenditure, Physical Exertion and Time Allocation among Huli-speaking People in the Papua New Guinea Highlands”. Annals of Human Biology, 27, 571-585.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

QUANTIFICATION OF METABOLIC STRAIN DURING CABLE WORKS WITH A MINI FORESTRY CRAWLER

Ferréol Berendt*, Stephan Hoffmann, Janine Schweier
University of Freiburg, Germany
Chair of Forest Operations
Ferreol.berendt@foresteng.uni-freiburg.de

Stephan Hoffmann, Dirk Jaeger
University of Göttingen, Germany
Department of Forest Work Science and Engineering

Stephan Prettin
Medical Center of the University of Freiburg, Germany
Institute for Exercice and Occupational Medicine

Abstract: *Besides increasing productivity, fully mechanized systems reduce the risk of accidents for forestry workers. Nevertheless, terrain slope, forest structure, political and societal willingness or forest certification hampers the extension of fully mechanized systems. Such conditions often require integrated winching operations, as for example conducted by remote-controlled mini forestry crawlers. Pulling out a steel cable is a highly physical demanding work and therefore, the overall sustainability assessment of a work system needs to be considered. However, the inclusion of human factors through complex ergonomic rating approaches is challenging. Oxygen consumption is a direct measure of the metabolic process and can be used to quantify physiological workload intensity of activities, for example through metabolic equivalents (METs). Thus, the goals of this study was: (i) to monitor physical forces forest workers have to apply during cable works with a small forestry crawler under different extraction settings and (ii) to examine physiological workload forest workers are exposed to during these activities. Three corridors with a corridor length of 50 m, allowed a subject monitoring under controlled conditions on-site for (i) flat, (ii) uphill and (iii) uphill, angled winching directions. Pulling force, measured through a tensiometer, relative heart rate (%HRR) and METs, quantified through a mobile spiroergometry unit, were analysed statistically for ergonomic rating. Results showed that peak values of HRR (70 %) and METs (11.6) were observed on the flat scenario which is in line with highest pulling forces (27.9 kg) recorded at the end of outspooling. On the contrary, in the uphill scenario, highest HRR (60 %) and METs (9.2) were observed at the end of walking back while winching. Looking more specifically on METs as an indicator of physiological workload, classifies winching over distances of 50 m as vigorous physical activity.*

Keywords: winching, skidding, spiroergometry, pulling force, work fatigue

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

FORMULATION OF THE IMPACT ON YARDING CABLE USING SPRING-DASHPOT MODEL

Midori Uenohara* (1), Takeshi Matsumoto (2), Masahiro Iwaoka (2)
(1) United Graduate School of Agricultural Science,
Tokyo University of Agriculture and Technology,
Saiwai-cho 3-5-8, Fuchu city, Tokyo, Japan;
(2) Institute of Agriculture,
Tokyo University of Agriculture and Technology,
Saiwai-cho 3-5-8, Fuchu city, Tokyo, Japan
Dolly.uenohara@gmail.com

Abstract: *The skyline of cable logging overhead wire vibrates greatly due to the impact received during work. When there is operating lines such as a houlback line, the vibration is suppressed. In the case of a simple line, the vibration is increased because there is no vibration control by the cable. The purpose of this study was to experimentally elucidate the impact generated on the skyline. To describe with spring-dashpot model, experimented of a small-scale cable, the variation of the skyline tension when rapidly changed by generating a shock loading mass. The tension of the impacted skyline showed a behavior that first attenuated greatly, then attenuated and followed by small fluctuations. we tried to model this with damped vibration.*

Keywords: damped vibration, skyline, tension oscillation, experiment using small scale cable, work safety

1. Introduction

The vibration of skyline ropes during cable yarding operations sometimes becomes greater than that in stationary states because of various reasons. When there are operation lines, especially a haulback line, the vibration is suppressed because the cable has a vibration control function. In the case of a simple logging cable there is no operation lines, since the line is not damped, the vibration is large.

Previous studies have been conducted on the vibration phenomenon of the logging cable. Irie (1957) reported the natural vibration of the cable with the carriage hanging in the middle, it was clarified that in the vertical vibration of the cable tension with a small droop ratio and no difference in height, the frequency decreased due to the influence of the support. Hori (1979) studied the impact of the load on the skyline and operation lines when operating the lifting line or hoist line to raise or lower the load and illustrated the history of the dynamic action of the load. Matsuhisa.et.al (1993) approximated the carriage with a pendulum and examined the vibration when it was subjected to crosswind.

In this way, although research on the vibration of the gathering logging cable has been conducted sporadically, the vibration of a simple cable has not been investigated in recent years. The objectives of this study are to apply the damped spring model to the vibration of a simple logging cable. For that purpose, first, the impact that occurred was measured using a small-scale cable with a simple structure. Second, a physical model of the impact condition was constructed, and then the physical model was verified using experimental values.

2. Materials and Methods

2.1 Experimental cables for impact tension measurement experiments

To conduct the experiments, a short span cable was set up during the period between October 7 and November 23, 2016 at the campus of the Tokyo University of Agriculture and Technology (Fuchu, Tokyo). The cable span was 15.82 m with leveled skyline slope, the midspan percent deflection was 0.03. The skyline tension was measured with a load cell (A&D Co. Ltd., LC-1205-T001, 10 kN), which was inserted outside of the cable span. The lifting line tension was measured with a load cell (LC-1205-K500, 4.9 kN), which was hung from the skyline and connected with the lower weight (see Figure 1).

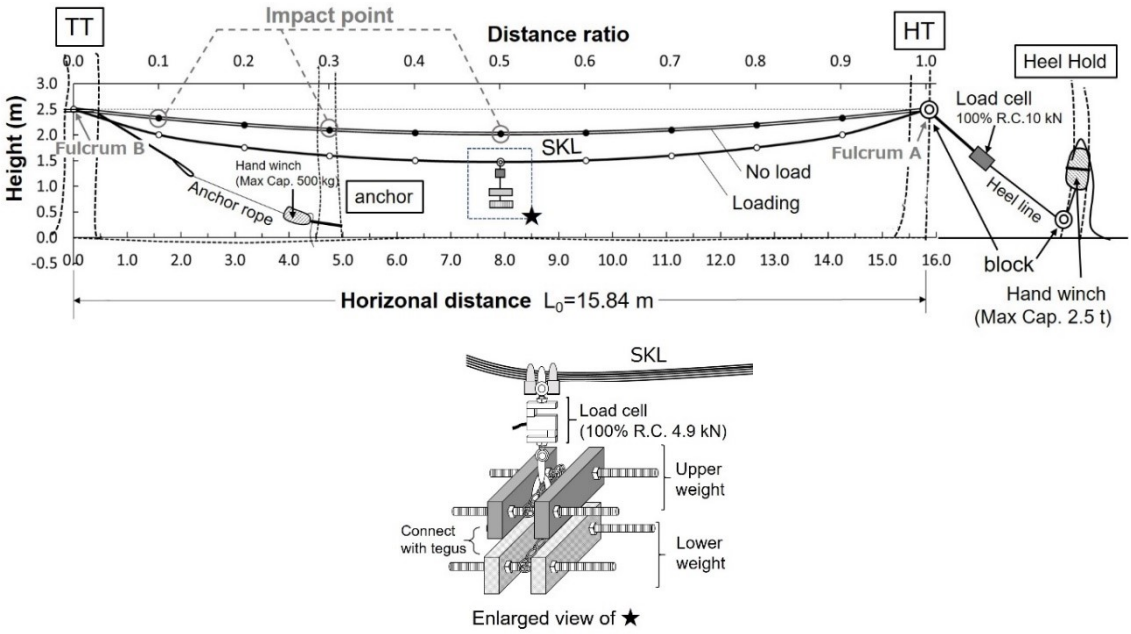


Figure 1 Schematic diagram of the experimental line

Impacts were generated by cutting off a part of the weight to simulate the impact that occurred with the release of logs caught by obstacles such as stumps and convey parts of the ground. Upper weight is 13.0 kg, lower weight is 12.0 kg.

2.2 Spring-dashpot model

When an impact is applied to the skyline, the load suspension rope tension observed at the impact point dampens (see Figure 2).

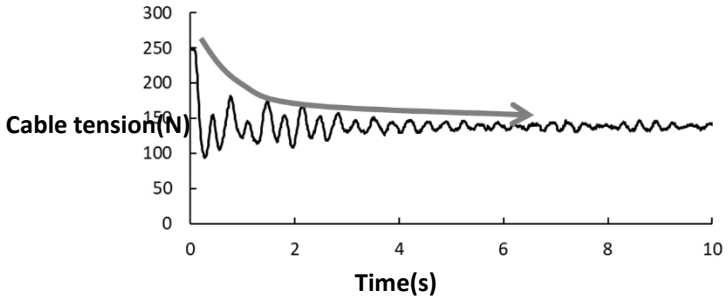


Figure 2 Tension damping

This damped vibration was considered as the motion of the mass-spring-dashpot system (see Figure 3).

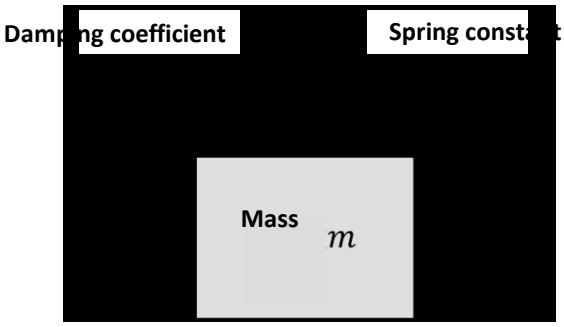


Figure 3 Spring-dashpot model

The equation of motion of the damped vibration is expressed by equation (1).

$$m\ddot{x}+2m\gamma\omega_n\dot{x}+m\omega_n{}^2x=0 \quad (1)$$

where m, ω_n , γ, $\ddot{x}$(m/s^2), $\dot{x}$(m/s), x(m) are the Mass, Natural angular frequency, Attenuation rate, Acceleration, Velocity and Displacement

The solution of the damped vibration is expressed by equation (2). The parameter ω_n, A, γ in Equation (2) was estimated from each value measured in the experiment, and the solution of the model free vibration was determined.

$$x_{(t)}=Ae^{-\gamma t}\cos\left(\sqrt{\omega_n{}^2-\gamma^2}t+\theta_0\right) \quad (2)$$

where A and t(s) are the Amplitude and Time

To derive the parameters, we used load tension data measured in small-scale overhead wire experiments. First, a graph was created with the load suspension line tension on the vertical axis and the elapsed time on the horizontal axis, and the damped natural angular frequencyf_d was determined from the frequency per second (see Figure 4). The natural angular frequency ω_n was obtained using equation (3) using f_d.

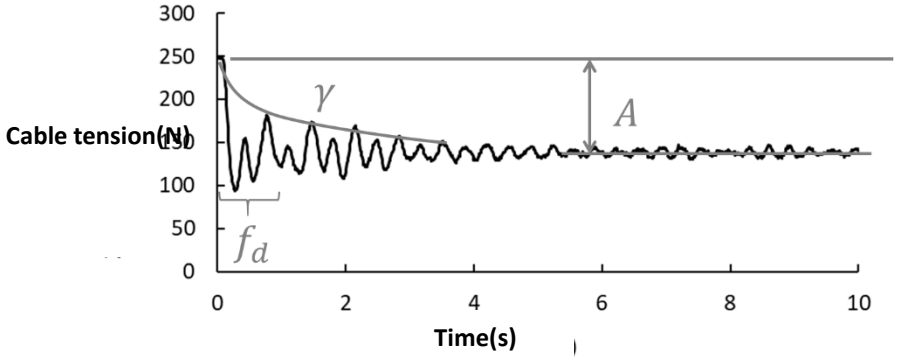


Figure 4 Derivation of parameters

$$\omega_n = \frac{2\pi f_d}{\sqrt{1-\gamma^2}} \tag{3}$$

A is defined as the difference between "the load suspension line tension of impact" and "the average of the load suspension line tension after the vibration has converged". 5 seconds after the impact was applied, the vibration was considered to have converged, and the average tension until the measurement was completed was set as the average load suspension tension after the vibration had converged.

Figure 4 shows that odd waves are small and even waves are large. As for the impact coefficient, the problem is that the impact is large (the tension is large), so the odd-numbered wave immediately after the impact is ignored here. Therefore, the inflection point of the tension immediately after the impact was considered as peak 0, and the values of peak 4 and peak 7 to peak 11 were extracted thereafter, and γ was obtained from equation (4).

$$log\frac{x(t_i)}{x(t_{i+1})} = \frac{2\pi\gamma}{\sqrt{1-\gamma^2}} \tag{4}$$

3. Results

3.1 Parameters

When ω_n, A *and* γ were calculated,

$\omega_n = 18,$
$\gamma = 0.74,$
$A = 110$

and parameters were obtained.

3.2 Model curve

Figure 5 shows the model curve created by substituting the parameters into equation (2). The solid line in the figure is the model, and the dotted line is the experimental value.

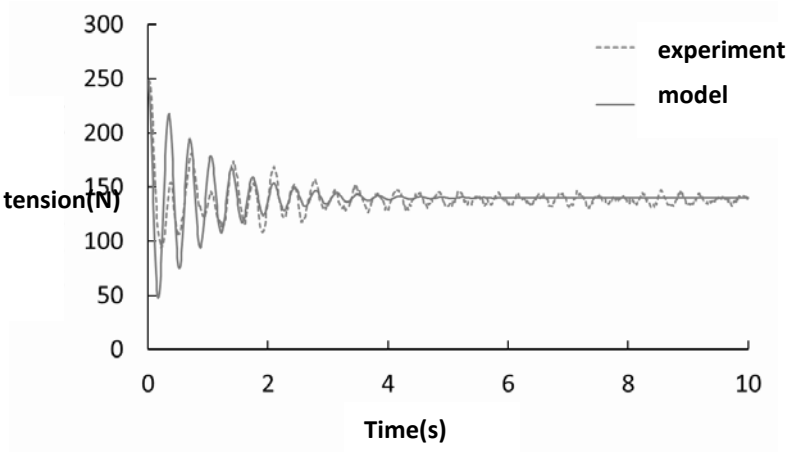


Figure 5 Model curve and experimental carve

When comparing the experimental value with the model value, the experimental value shows large tension damping immediately after the impact is applied, and the vibration does not converge completely, and the fine vibration continues. Furthermore, the model value oscillates symmetrically with the convergence value as the boundary, but the experimental value shows that the peak below the convergence value is extremely small, and the oscillation is not symmetric.

The model values were relatively well applied to the experimental values at the point of the highest tension (peak 4) after the impact was applied, and peaks 8 to 10 almost coincided. The value of peak 11 was also used to determine γ, but the reproducibility of peak 11 was not very good.

3.3 Fit of the model

In order to investigate the goodness of the model curve with the experimental value, the vertical axis was taken as the load carrying rope tension and the horizontal axis was taken as the model value, and the correlation was examined (Figure 6). The experimental values used in the survey were 7 points, peak 0, peak 4, and peaks 7 to 11, which were used to derive the parameters.

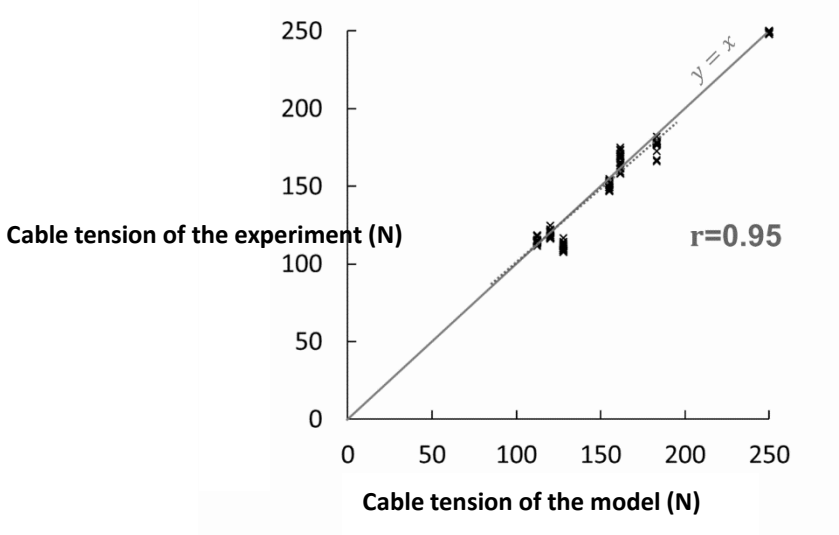


Figure 6 Correlation between experiment and model

In Figure 6, the range where the markers are concentrated is each peak. Using the impact point (peak 0) as a reference and drawing a line with y = x, we found that the peak appears almost on this line. Distant from the line is peak 11, which was not very good.
The correlation coefficient of the extracted peak showed a high value of $r = 0.95$

4. Conclusions

In this study, we assumed an abrupt load applied to the skyline at the moment when the material was caught on the ground convex part during the gathering and released according to the winding of the rope, and the tension of the load suspension rope when this load was applied was assumed. The aim was to adapt the spring-dashpot model to fluctuations.

Although all the assumed damped vibration phenomena could not be explained by a damped one-degree-of-freedom system, it was confirmed that the peak with the largest tension after impact could be applied.

5. References

Fukuda, J. (1960) “Episode of Cableway Experiment (3).” For. Mech. Inf. (temporary translated by the author) 83:34–50. (in Japanese with English summary).

Hori, T. (1983) “Experiment by Field Test Equipment on Impact of Yarding - Impact Effects of Raising or Lowering Loads.” Proc. Mtg. Chubu Br. Jpn. For. Soc. 31:237–240. (in Japanese with English summary).

Irie, T. ed. (1962) “On the Performance and Tension of Tree Length Logging by Yarder (Part 2).” Proc. Mtg. Chubu Br. Jpn. For. Soc. 10: 39–44. (in Japanese with English summary).

Kato, S. (1955) “Studies on the Skyline Logging Cables for their Planning and Inspection.”
Bull. Tokyo Univ. Forests. 49:1–157. (in Japanese with English summary).

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

Mechanized harvesting operation in windthrow damaged stands: a case study in the Northeast Italy

Alberto Cadei [1], Omar Mologni[2], Stefano Grigolato [1], Raffaele Cavalli [1]
[1] Department of Land, Environment, Agriculture and Forestry, Università degli Studi di Padova
Viale dell'Università 16, 35020 Legnaro PD, Italy
alberto.cadei@studenti.unipd.it; stefano.grigolato@unipd.it, raffaele.cavalli@unipd.it
[2]Department of Forest Resources Management, University of British Columbia
2424 Main Mall, Vancouver BC, V6T 1Z4, Canada
omar.mologni@ubc.ca

Abstract: *Salvage logging due to large scale windthrow is increasing in Central Europe because of the growing of severe atmospheric events due to climate changes. Sustainable forest operations in these conditions are challenging in term of both productivity performances and safety of the operators. Fully-mechanized harvesting systems are the preferred solution on trafficable terrains and proper slopes. However, different work methods and logistic organization of the operations could largely change the overall performances.*
This study aims to analyse the productivity of different fully-mechanised salvage logging operations based on the use of harvester and forwarders.
The work will be conducted in spring 2019 in the Nord-Eastern Italian Alps on large scale windthrows due to the Vaia storm of late October 2018. The research will be based on time and motion study through video recording of the whole operations using action cameras mounted on the machine cabs. GNSS sensors and high-frequency accelerometers mounted on the machines allowed to continuously record their position and inclination during each work cycle.

Keywords: *windthrow; harvesting productivity; forwarder; harvester; productivity*

1. Introduction

In these years forest disturbances damaged a huge quantity of timber in all European forests. Windstorms damage 53% of total damage from 1950 to 2000 (Kärhä et al., 2018; Seidl et al., 2014).
The most destructive windstorms in Europe were Lothar and Martin that damaged than 240 Mm3 of timber in 15 countries, in France this damage represents over than 3 times of annual felling (Gardiner et al., 2013). In the 2017-2018 only in Central Europe (Austria, Germany, Czech Republic) more than 50 M of cubic meter has been damaged by storm and bark-beetle attack (Ebner, 2018). In Italy and Austria at the end of 2018, on the last November Vaia storm damaged about 10 M of cubic meters (Chirici et al., 2018; Motta et al., 2018).
The critical aspects to be addressed in salvage logging are different from the ordinary logging operation conditions, with an increment of the risk for the safety of the forest operators. Furthermore, as in the case of the Vaia storm in the eastern Alps, the high presence of damaged wood material in steep and very roughness terrain determines a really complex operation condition.
The complex conditions require highly specialized operators to apply special logging techniques and procedures. The productivity of salvage logging operations is lower compared to ordinary situations both in case of motor-manual system based on operators with chainsaw and the use of forest tractors as well in the case of fully mechanized operations with harvester and forwarder (Enache and Stampfer, 2014).

In a recent study in the Baltic area, it has been highlighted that the harvester and its components are more stressed when they work in salvage logging operations. As a consequence, also the cost of the intervention will be 10-30% higher than ordinary situations with a productivity reduced up to 33% compared to ordinary conditions (Kärhä et al., 2018). The experience of the operator is a fundamental element that plays on the factor of productivity and consequently on costs, in fact, if the operator of the harvester has little experience the difference in costs between ordinary and extraordinary interventions rises, reaching a maximum increase by 70% (Purfürst and Erler, 2011). This condition is a key factor for many Italian forest enterprises, which, due to the need to reduce the safety risk and to increase the logging productivity in salvage logging operations, are moving to full mechanized system with the introduction of harvester and forwarder machines.
As a consequence, the objectives of the present study are to analyze time consumption and the productivity of full mechanized Cut-to-Length system using wheeled harvester and forwarder in windthrow conditions in the Italian alps.

2. Material and method

2.3.1. Monitoring protocol

Global Navigation Satellite System (*GNSS*) was installed in forwarder and harvester in order to collect the position of the machines.The landing points were market using the AvenzaMap® app.
Hight frequency accelerometer was mounted on the chassis of harvester and forwarder.
Three action cameras were installed in the harvester and forwarder cabs and collected video in micro SD memory. Three power banks of 20000 mAh insured the power of GNSS devices and action cameras. Both cameras were set to at 720 ppm and time stamp function active.
During any loading phases high-quality photos were taken orthogonally to the machine in order to reduce perspective distortions.
StanForD data (.hpr, .pri) were thus downloaded from on-board computer at the end of the field activities.

2.3.2. Characteristics of harvesting area and machines

The study was conducted during the spring of 2019 in two areas located in Trentino-Alto Adige region in the the northeastern Italy. Areas were located in Passo Vezzena (Levico Terme, TN) and Redagno di Sopra (Aldino, BZ).
First harvested area (site A) was composed by a mature forest stand of spruce (*Picea abies*) and silver fir (*Abies alba*). The second harvested (site B) area was composed by old-growth forest of spruce (*Picea abies*), silver fir (*Abies alba*) and Larix (*Larix decidua*).
Both the harvesting areas were damaged by windstorm, harvesting system used is full mechanized system with harvester and forwarder. Site A was composed of many little gaps, site B was composed by a large quantity of damaged wood inside the same gap.
Contractor in Site A didn't have a dedicated chainsaw operator. In this case, the harvester operator, in case of difficulty stop the harvesting operation and use the chainsaw to separate the tree from the stump. In the Site B a dedicated chainsaw operator was used to separate the tree from the stump.

Tab. 1 - Harvester technical details

Site	A	B
	General description	
Model	Komatsu 931.1	Ecolog 590D
Engine power (kW)	193	240
Wheels (n°)	6	6
Weight (kg)	19400	27000
Hydraulic capacity (l/min)	313	592
Working pressure (bar)	280	260
	Crane	
Maximum extension (mm)	10000	11500
Gross lifting tourque (kNm)	225.3	310
	Felling head	
Model	Komatsu 365.1	Logmax 7000C
Weight (kg)	1235	1627
Saw bar length (mm)	650	850
Maximum roller opening (mm)	650	713
	Other	
Year	2012	2013
Transmission	Hydro-mechanical	Hydrostatic
Traction force (kN)	175	210
Cabin	Self-levelling	Self-levelling
Production protocol	StanForD 2010	StanForD

Tab. 2 - Forwarder technical details

Site	A	B
	General description	
Model	John Deere 1210E	Ecolog 574B
Engine power (kW)	136	129
Wheels (n°)	8	8
Weight (kg)	18100	17000
Maximum load capacity (kg)	13000	14000
Hydraulic pump (cm^3)	140	ND
Working pressure (Mpa)	24	ND
	Crane	
Model	CF7	Loglift 83
Maximum extension (mm)	10000	8400
Gross lifting torque (kNm)	125	76
Gross rotation tourque (kNm)	32	26.1
	Other	
Year	2017	2007
Transmission	Hydro-mechanical	Hydro-mechanical
Cabin	Self-levelling	Fix

2.3.3 Time and motion study

Time and motion study of the harvester was carried out based on other research studies (Gerasimov et al., 2012; Labelle, 2018; Nurminen T, Korpunen H, 2006) and modify to the present study show in Tab. 4.

All activities associated with the movement and cutting a group of three were considered as a cycle.

Tab.3 - Harvester work phases

Work phases	Description	Priority
Boom-out	Starting when boom extending towards tree to the positioning of the head on the tree	2
Felling	Starting when the head is in vertical position and end when the tree crown touches the ground	1
Processing	Starting when the feed rollers are activated and end with the last stem processed	1
Miscellaneus	Other activities not related to processing (moving tops and branches, piling, manipulation of logs)	4
Moving	Starting when the traction system is activated and end when the traction system is deactivated, or other work phases dominate	3
Traveling	Movement inside the same harvesting area or to other harvesting areas, where the machine did some work phases during the movement	3
Transfering	Movement from/to landing site from/to harvesting area	3
Operational delays	Any delay related to organizational issues shorter than 15 minutes	4
Non-operational delays	Any delay related to personal or mechanical issue shorter than 15 minutes	4

The movements of the harvester were divided into three elemets: moving: movement related to the working cycle, inside or nearby the working area; transfering: movement from the previously working area to the nearest working area, where the harvest do some working phase during the movement; traveling: first or finally movement from or to the landing site, not related to any working phase, to the harvesting area.

Logs volume were calculate from .pri and .hpr data downloaded from on-board computer. StanForD 2010 is able to collect time, length, diameter of any processed stems. StanForD isn't able to save the time of the processing. As a consequence, on-cabs videos were used to synchronize the daily stems processed

The time and motion study was carried out analyzing video collected by the on-board camera. three action camera was mounted on harvester and forwarder. Any video was manually analyzed in order to divide the activity into different work phases. Work elements of forwarder (Tab. 3) have been defined following other research studies (Fernandez-lacruz et al., 2013; M R Ghaffarian et al., 2007; Holzfeind et al., 2018; Proto et al., 2018).

If two elements overlapped, the activity with high priority was recorded (1 highest priority; 3 lowest priority). The HD photo taken in-field activity was previously correct, ans scaled. The measure of log diameters and log lengths, measure directly on CAD software, were used to calculate load volume assuming logs are pure cylinder (Mologni et al., 2018).

Tab 4.- Forwarder work phases

Work phases	Description	Priority
Travel empty	Starting when the machine starting from the landing site and arrive at the harvesting area, end when the operator moves the crane from base position	2
Loading	From the movement of the crane at the first loading point to positioning of the crane to base position	1
Driving while loading	Starting when the wheels move from the first loading point the next loading point	2
Travel loaded	Starting when the wheels move from the last loading point to the unloading point	2
Unloading	Starting from the first movement of the crane at the unloading point to the last unloading activity (included drive while unloading activities)	1
Delays	Interruption equals or shorter than 15 minutes	3

3. Results and discussions

3.1 Distribution of harvester time consumption and productivity

Data collection refers to 383 cycles and 31,44 hours of harvester operations (Fig. 1). Total stem processed was 785 (254 site A, 531 site B) into 2330 logs (1037 site A, 1293 site B) and a total harvested volume of 518,78 m^3 (237,49 m^3 site A, 281,29 m^3 site B). Minimum, average and maximum value of element per cycle is shown in Tab. 5, the relative value of average work phases is shown in Fig. 2 and Fig. 3.

Tab. 5 - Harvester time consumption

Element	Site A			Site B			Units
	Min	Average	Max	Min	Average	Max	
Boom-out	2.00	5.93	29.00	2.00	6.36	77.00	sec/cycle
Processing	0.00	52.67	560.00	0.00	102.81	792.00	sec/cycle
Felling	0.00	22.15	309.00	0.00	28.32	283.00	sec/cycle
Moving	0.00	17.12	226.00	0.00	16.19	199.00	sec/cycle
Miscellaneus	0.00	1.22	55.00	0.00	1.04	52.00	sec/cycle
Operational delays	0.00	0.16	25.00	0.00	6.27	640.00	sec/cycle
Non-operational delays	0.00	4.91	413.00	0.00	11.75	804.00	sec/cycle
Total average cycle	9.00	104.16	830.00	7.00	172.74	1005.00	sec/cycle
Average slope	7.60	23.75	56.30	8.33	30.00	69.34	%
Average cycle distance	0.00	19.85	109.88	0.00	12.12	146.02	m

Because time study elements were defined with cumulative stem process, some work cycles were considered complete when harvester after boom-out, some process or miscellaneous activities was done. Minimum time consumption of some elements could be 0 seconds per cycle.
Traveling and transferring was not considered in the time consumption analysis, work cycle containing traveling or transferring had minimum moving of 0 seconds per cycle.
Average cycle distance has been evauated zero when harvester moving was shorter than 2 seconds.
Operational delays are shorter (about 6.16 s/cycle) in site A then site B, these difference should be linked with the chainsaw operator. Harvester Ecolog 590D sometimes waiting for the operation of chainsaw operators. When the harvester operated along the forest road sometimes had to shift in order to further forwarder passage.



i) ii)

Fig. 1 - Komatsu 931.1 working at site A (i) in small group of damaged trees and Ecolog 590D working in site B (ii) in large widnthrow damaged area.

The average harvester productivity was 18.53 m^3/PMH_{15} in site A and 15.11 m^3/PMH_{15} in site B converted in 19.48 m^3/PMH_0 in site A and 16.87 m^3/PMH_0 in site B.

Brzózko et al. (2009) estimating harvester productivity in pine wind-damage stands for Rottne H-14 (168 kW) harvester and Valmet 941 (201 kW) harvester in 17.29 m^3/PMH_0 and 25.48 m^3/PMH_0. Again, Brzózko et al. (2012) show that cycle time for inexperienced operators in non-ordinary harvesting conditions was more than twice as long. In particular, the greatest difficulty for inexperienced operators was for high-lying overthrown three with roots while the harvesting time of undamaged trees is similar to ordinary conditions.

Also in this case, operators in site B has few months of experience at the moment of the field survey. Also this condidion could affect the productivity of the harvesting operation. In the case of site A, the operator has more of ten years of experience and it could be one of the reason why site A showed the highest productivity even if the operational conditions consisted on processing small group of damaged trees within a partially damaged forest.

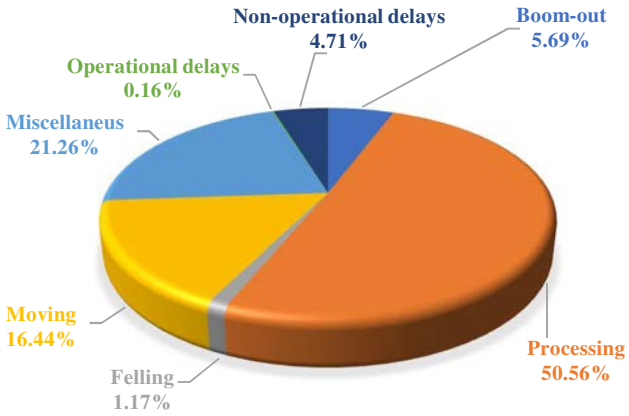


Fig. 2- Site A harvester work elements distribution

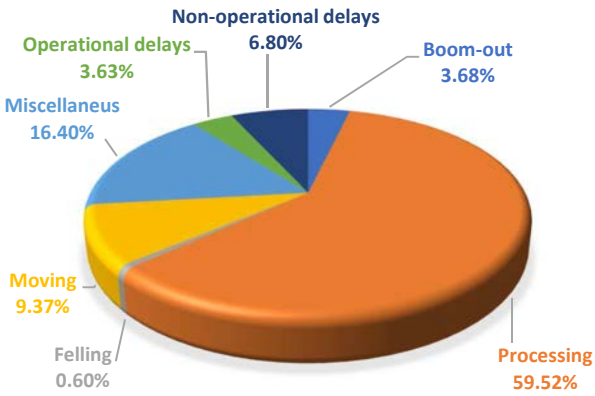


Fig. 3 - Site B harvester work elements distribution

3.2 Distribution of forwarder time consumption and productivity

Data collected refers to 50 forwarder cycles, 34,35 hours of forwarding operations and 647 m^3 of timber was extracted (Tab. 6, Fig. 4, Fig. 5)

Tab. 6 - Forwarder time consumption

Element	Site A			Site B			Units
	Min	Average	Max	Min	Average	Max	
Travel empty	2.07	6.22	11.05	1.38	4.47	11.05	min/cycle
Loading	9.07	13.69	18.78	4.03	18.39	31.32	min/cycle
Driving while loading	0.17	2.48	8.83	0.00	2.77	9.68	min/cycle
Travel loaded	4.42	6.31	11.18	0.90	4.02	13.60	min/cycle
Unloading	3.50	7.91	10.77	1.35	7.95	14.38	min/cycle
Delay	0.00	2.51	15.33	0.00	4.58	12.95	min/cycle
Total cycle	25.92	39.12	51.97	13.12	42.18	68.62	min
Log volume	0.10	0.34	0.67	0.15	0.33	0.81	m^3
Log number	26	55	104	21	41	65	n°
Assortment number	1	3	4	3	7	10	n°
Load volume	10.14	13.93	19.65	6.29	12.48	18.69	m^3
Average slope	11.09	17.29	90.21	12.65	24.43	68.93	%
Average cycle distance	867	1945	3199	349	1424	4370	m

Travel empty phases, on average, during less in site B then site A, this time consumption could be related to the lowest average cycle distances.

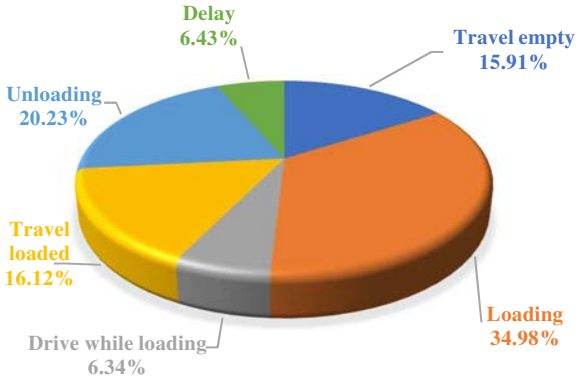


Fig. 4 - Site A forwarder work elements distribution

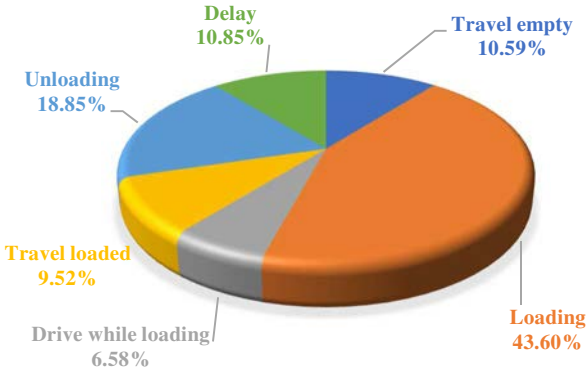


Fig. 5 - Site B forwarder work elements distribution

Loading phases during, on average, less in site A then site B. Loading took over 43% of total time in site B, where the average assortment number (7) is higher than site A (3) and average load volume is lower in site B (12.48 m3) then site A (13.93 m3).

The average forwarder productivity was 21.37 m^3/PMH_{15} and 17.75 m^3/PMH_{15} respectively in site A and site B converted in 22.83 m^3/PMH_0 in site A and 19.91 m^3/PMH_0 in site B.

Highest forwarder cycle distance was observed in site B (4370 m) due to the lack of forest roads in the area. As a consequence, it is therefore appropriate to consider that many variables can affected forwarder productivities in ordinary operations like number of logs, average log volume, load volume, (Mohammad Reza Ghaffarian et al., 2007; Nurminen T, Korpunen H, 2006; Proto et al., 2018), in particular productivity of forwarder is significantly related to extraction distance.

4. Conclusions

The present work is a preliminary study on some full-mechanized CTL systems in the recovery of damaged timber in the context of the eastern Alps in Italy after Vaia storm of October 2019. This preliminary study reports an average hourly productivity similar to the productivity

previously highlighted in similar conditions. It is clear, however, that the recorded productivity is affected both by the operating conditions (accidentality, slope of the land and accessibility of the area) and by the skills and training of the operators and the type and characteristics of the machines used. For this reason, the present work is to be considered as a preliminary work with the aim of verifying the level of operation and production in two different sites.

References

Brzózko, J., Szereszewiec, B., Szereszewiec, E. (2009). Productivity of machine timber harvesting at the wind-damaged site. *Agricultural and Forest Engineering*, *54*(54), 41–49.

Brzózko, J., Zychowicz, W., Bartosiewicz, M. (2012). The Influence of Operator Experience on Productivity of Mechanized Timber Harvesting From Windfall Stands. Proceeding of FORMEC 2012, October 8-12, Dubronik, Croatia

Chirici, G., Bottalico, F., Giannetti, F., Del Perugia, B., Travaglini, D., Nocentini, S., … Gozzini, B. (2018). Assessing forest windthrow damage using single-date, post-event airborne laser scanning data. *Forest@ - Rivista di Selvicoltura Ed Ecologia Forestale*, *91*(1), 27–37.

Ebner, G. (2018). A mountain of damages More than 50 M of meter cubic after storms, beetles and droughts in Central Europe. Timber-online (19.09.2018)

Enache, A., Stampfer, K. (2014). Machine utilization rates, energy requirements and greenhouse gas emissions of forest road construction and maintenance in romanian mountain forests. *Journal of Green Engineering*, *4*(4).

Fernandez-lacruz, R., Fulvio, F. Di, Bergström, D. (2013). Productivity and profitability of harvesting power line corridors for bioenergy, *47*(1), 1–23.

Gardiner, B., Andreas, S., Schelhaas, M.-J., Orazio, C., Blennow, K., Nicoll, B. (2013). Living with Storm Damage to Forests. Living with storm damage to forests. *What Science Can Tell* Us. 3. European Forest Institute. 132p.

Gerasimov, Y., Senkin, V., Väätäinen, K. (2012). Productivity of single-grip harvesters in clear-cutting operations in the northern European part of Russia. *European Journal of Forest Research*, *131*(3), 647–654.

Ghaffarian, M R, Stampfer, K., Sessions, J. (2007). Forwarding productivity in Southern Austria. *Croatian Journal of Forest Engineering*, *28*(2), 169–175.

Ghaffarian, Mohammad Reza, Stampfer, K., Sessions, J. (2007). Forwarding productivity in Southern Austria. *Croatian Journal of Forest Engineering*, *28*(2), 169–175.

Holzfeind, T., Stampfer, K., Holzleitner, F. (2018). Productivity, setup time and costs of a winch-assisted forwarder. *Journal of Forest Research*, *23*(4), 1–8.

Kärhä, K., Anttonen, T., Poikela, A., Palander, T., Laur, A. (2018). Evaluation of Salvage Logging Productivity and Costs in Windthrown Norway Spruce-Dominated Forests. *Forests*, *9*, 280.

Labelle, E. R. Breinig, L. Sycheva, K. (2018). Exploring the Use of Harvesters in Large-Diameter Hardwood-Dominated Stands. *Forests*, *9*, 424.

Mologni, O., Dyson, P., Amishev, D., Proto, A. R., Zimbalatti, G., Cavalli, R., Grigolato, S. (2018). Tensile force monitoring on large winch-assist forwarders operating in British Columbia. *Croatian Journal of Forest Engineering*, *39*(2), 193–204.

Motta, R., Ascoli, D., Corona, P., Marchetti, M., Vacchiano, G. (2018). Silviculture and wind damages. The storm "Vaia." *Forest@ - Rivista di Selvicoltura Ed Ecologia Forestale*, *15*(6), 94–98.

Nurminen T, Korpunen H, U. J. (2006). Time Consumption Analysis of of the Mechanized Cut-to-length Harvesting System. *Silva Fennica*, *40*, 335–363.

Proto, A. R., Macrì, G., Visser, R., Harrill, H., Russo, D., Zimbalatti, G. (2018). Factors affecting forwarder productivity. *European Journal of Forest Research*, *137*(2), 143–151.

Purfürst, F. T., Erler, J. (2011). The human influence on productivity in harvester operations. *International Journal of Forest Engineering*, *22*(2), 15–22.

Seidl, R., Schelhaas, M.-J., Rammer, W., Verkerk, P. J. (2014). Increasing forest disturbances in Europe and their impact on carbon storage. *Nature Climate Change*, *4*, 806.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

ANALYSIS OF THE BLACK LOCUST STANDS' BIOMASS PRODUCT IN HUNGARY

Tamás Major*, Richárd Iski, Tamás Pintér, Andrea Tünde Kiss, Imre Czupy
Institute of Forest and Environmental Techniques
Faculty of Forestry
University of Sopron
Bajcsy Zs. utca 4., H-9400 Sopron, Hungary
major.tamas@uni-sopron.hu

Abstract: *Nowadays, the black locust (Robinia pseudoacacia) is the most current and the most widely used tree species in Hungary. Due to its penetration and the wide variety of application it's worth to examine, what kind of assortment their with different origins, and in different environmental conditions growing stands offer.*
In our current article we compare the assortment composition of the black locust stands of seedling and coppice origin, and we analyse how the wood use income of the stands of different origins turns out (seed and root sucker).
We provided our research in the area of Nyírerdő Forestry Co. Ltd and SEFAG Forestry and Wood Industry Ltd. During the research we used the final harvest data for the 2010-2017 period.

Keywords: black locust, assortment composition

1. Introduction

Nowadays, the black locust (Robinia pseudoacacia) is the most current tree species in Hungary. No country in Europe has as many black locust forests as Hungary. More than 24% of our country's forest area is covered by black locust (Bartha, 2016; National Forest, 2015*)*. The most prominent black locust-producing districts are the Nyírség, Cserhát, hills of Gödöllő, the Bács-Kiskun, Somogy, Vas, Zala county, and the sandy area of the Little Hungarian Plain. Among them, the Nyírség, Bács-Kiskun county and the Northern Part of Somogy have high quality stands.

As the result of the climate change the annual average temperature increases and along with this the forest climate zones are also „migrating". Generally speaking, the area ratio of beech forest climate decreases and along with this the area of the forest steppe climate grows. This will lead to a change in the tree species composition, that will reduce the area ratio of beech (Fagus sylvatica) and the black locust can be emphasised, and the groups of poplar.

Thanks to the deep roots of the black locust, it can live on the sandy, salty areas, ties the loose running sand, and it can be used for the afforestation of the bad quality sandy areas (Járó, 1953; Rédei, 1997).

Its wood has a wide variety of recovery options. Its excellent physical properties and exceptional durability allow it to be widely used in the sawmill, furniture and carpentry industries. It's widely used in the land- and water building, it's durable as a fence post, vine pole and vine stake. The black locust can be used in the production of cellulose, wood-pulp board and chipboard as well. Recently, they also make glued-laminated holders of them. Half the weight of the produced black locust is used for energy purposes, so they make firewood of them (Major, 2016; Molnár, 1996).

Because of its penetration and its widespread use it is worth to examine what assortment the stands of different origins bring, and how they influence the use of the black locust.

2. Testing Methods

During the research, we sought to answer the question how the assortment composition of black locust stands of different forestry land changes in case of the same origin (seeds sprout, root sucker) and the same genetic soil type. We carried out our examinations in the area of the Nyírerdő Forestry Ltd. and the SEFAG Forestry and Wood Industry Ltd.

Black locust stands occur on 9 different genetic soil types. However, comparison can be made only on two soil types, because only these two occur on both forestry land. In case of „kovárvány" brown forest soil we could compare the seedling-and coppice stands, on humous sand we could compare the root sucker stands.

During our research, we used the end use data for the period 2010-2017 (Iski, 2017; Pintér, 2018).

Before starting the research, different filtering was performed on the data. The database contained 5-100% forest parts, only the forest parts with 90% or more black locust mixture ratio were taken in account during the evaluation.

During our research we compared the assortment composition and the timber utilisation income per ha as well. For this, we used the 2017 assortment prices.

3. The comparison of seedling black locust stands on "Kovárvány" brown forest soil

In the case of seedling stands the SEFAG Ltd. produced 152,7 m^3 per ha on „kovárvány" brown forest soil, the Nyírerdő Ltd. 170 m^3. In the Nyírség 21,67 m^3/ha were produced from sawlogs, in Somogy only the half of it, so 11,61 m^3/ha. The cuttings weren't in Somogy conversed into assortments, but in the Nyírség the cutting amounts to one-tenth of the total assortment in case of the seedlings. Both thick firewood and collected firewood were produced in Somogy more, approximately 10 m^3/ha (*Figure 1, Figure 2.*). The Nyírerdő Ltd. has an income of 3,86 million Ft/ha on „kovárvány" brown forest soil, in case of seedlings this amount is 1,26 million Ft more per ha than in case of the SEFAG Ltd. There are only a few from the high quality assortment , which are expensive, in the area of the SEFAG Ltd. but there are more from the cheaper ones, which effects the financial differences.

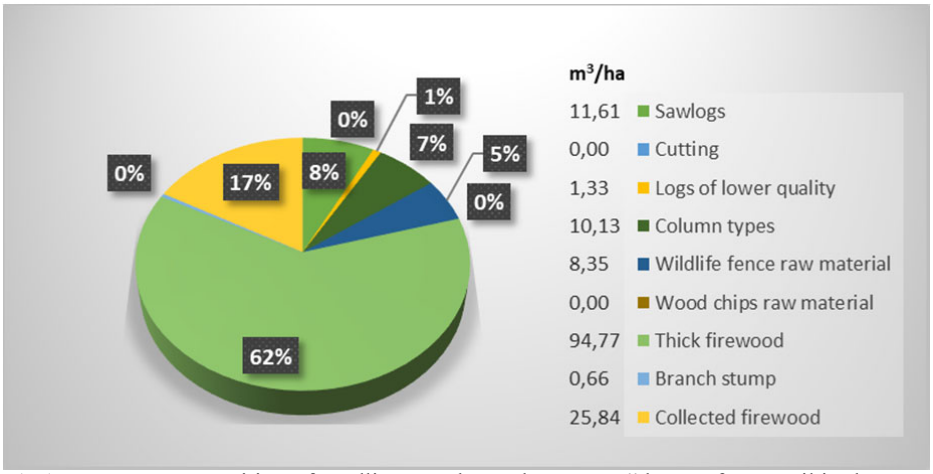


Figure 1: Assortment composition of seedling stands on „kovárvány" brown forest soil in the area of the SEFAG Ltd. *[m^3/ha; %]*

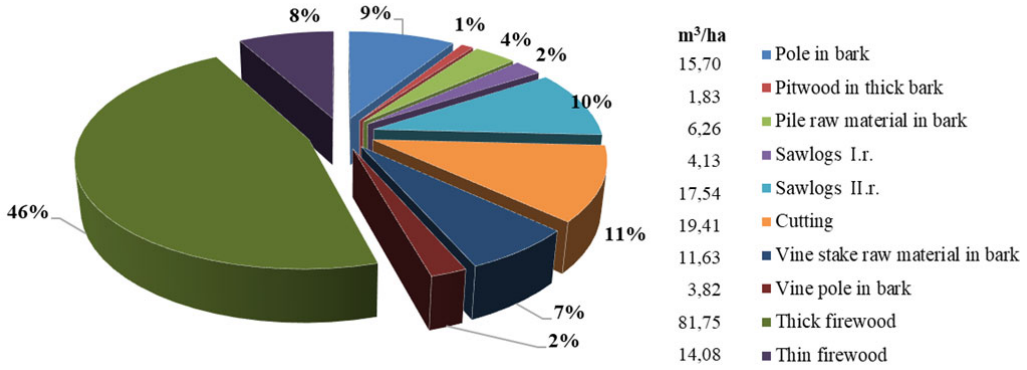


Figure 2: Assortment composition of seedling stands on „kovárvány" brown forest soil in the area of the Nyírerdő Ltd. *[m³/ha; %]*

4. The comparison of root sucker black locust stands on "Kovárvány" brown forest soil

In Somogy they produced 143,7 m³/ha timber from the root sucker stands on „kovárvány" brown forest soil, while in the Nyírség they produced only 110 m³/ha (*Figure 3, Figure 4.*). In case of root sucker stands the Nyírerdő Ltd. produced 2,20 million Ft/ha, while the SEFAG Ltd. produced 2,42 million Ft/ha. Off the three comparisons, this one was the only one, where the produced timber in the area the most valuable was.

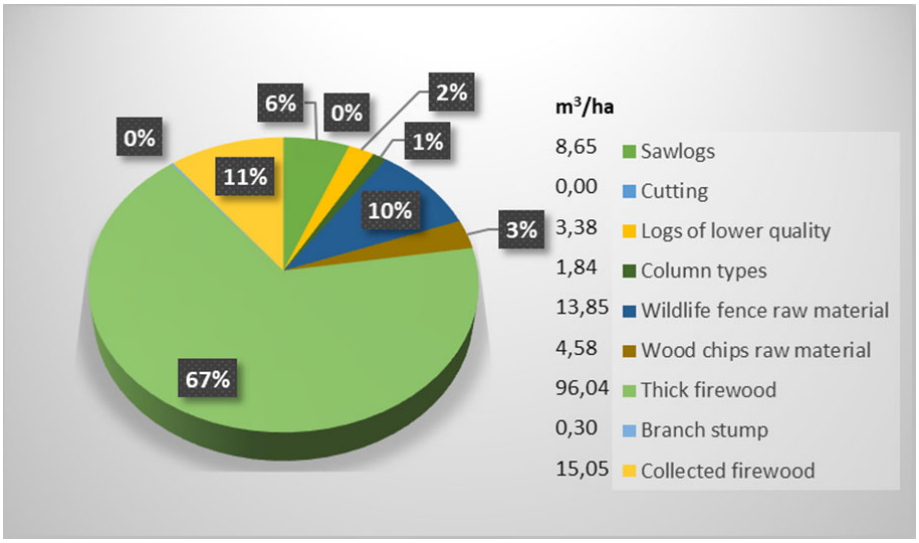


Figure 3: Assortment composition of root sucker stands on „kovárvány" brown forest soil in the area of the SEFAG Ltd. *[m³/ha; %]*

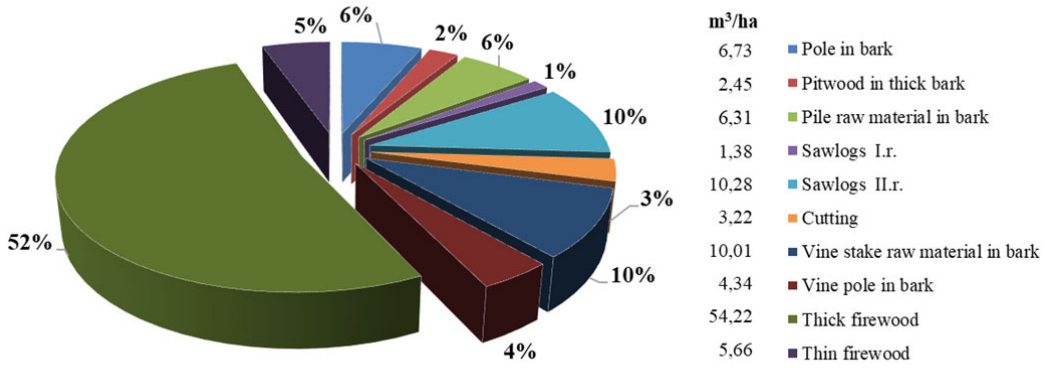


Figure 4: Assortment composition of root sucker stands on „kovárvány" brown forest soil in the area of the Nyírerdő Ltd. *[m³/ha; %]*

5. The comparison of root sucker black locust stands on humous sand

On the humous sand soils they exploited much less timber in the areas of Somogy (97,7 m³/ha), than in the Nyírség (130 m³/ha). As we have seen it in case of the „kovárvány" brown forest soil, the cutting production is really significant in the Nyírség, and on the other hand, they produced more from the sawlogs as well. The two forestries produced almost the same amount of the thick firewood. As we have seen it from the past two comparisons, they produced more from the collected firewood in the area of the SEFAG Ltd (*Figure 5, Figure 6.*). The differences between the assortments show up in the incomes as well. The Nyírerdő produced 2,77 million Ft/ha against the SEFAG Ltd., which produced only 1,56 million Ft/ha from their black locust stands on humous sand.

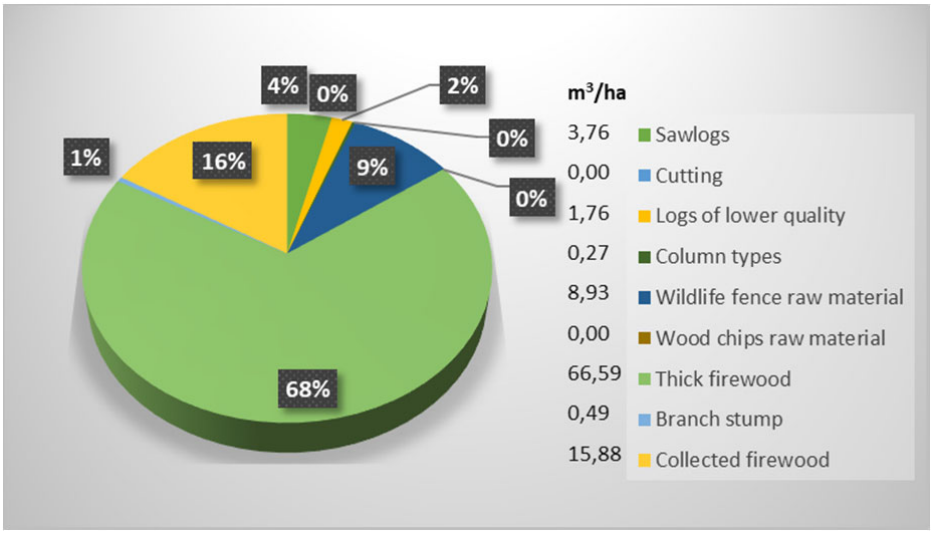


Figure 5: Assortment composition of root sucker black locust stands on humous sand in the area of the a SEFAG Ltd. *[m³/ha; %]*

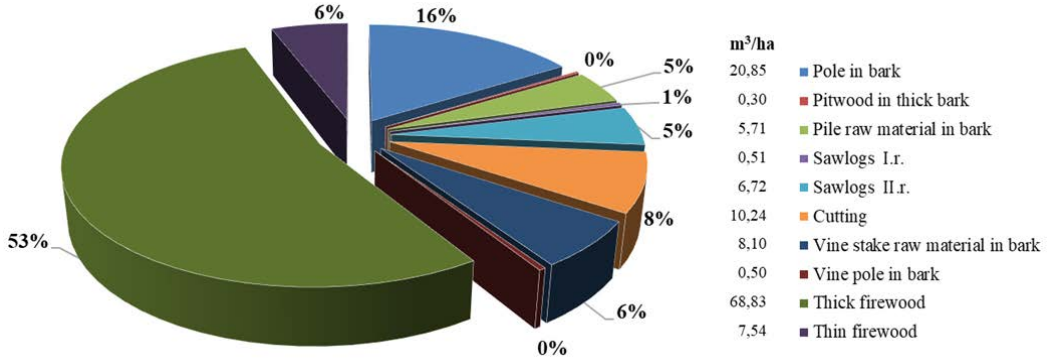


Figure 6: Assortment composition of root sucker black locust stands on humous sand in the area of the a Nyírerdő Ltd. *[m^3/ha; %]*

6. Summary

Table 1 summarizes the volume of timber harvested per ha and the timber utilisation income per ha in the area of the two forestries (forestry land).

Table 1: Summary of the differences between the two forestries

	Origin	Genetic soil type	SEFAG Ltd.	Nyírerdő Ltd.
Produced timber volume [m^3/ha]	Seed	„Kovárvány" brown forest soil	152,7	170,0
	Root sucker	„Kovárvány" brown forest soil	143,7	110,0
		Humous sand	97,7	130,0
Income [million Ft/ha]	Seed	„Kovárvány" brown forest soil	2,60	3,86
	Root sucker	„Kovárvány" brown forest soil	2,42	2,20
		Humous sand	1,56	2,77

There are significant differences between the assortment composition of the two areas and therefore in their timber utilisation's income too, because the position of the forestry influences the produced assortments significantly. In case of the Nyírerdő Ltd., the volume of the harvested timber is more evenly distributed among the various assortments.

7. Acknowledgements

The research work can come true as the part of the „Fenntartható Nyersanyag-gazdálkodási Tematikus Hálózat-RING 2017" EFOP-3.6.2-16-2017-00010 project based on the Szechenyi2020 programme with the support of the European Union, and with the co-financing of the European Social Fund.

8. References

Bartha D. (2016), Tények és tévhitek a fehér akác első európai megjelenéséről, Erdészeti lapok, CLI. évf. 292- 295.

Iski R. (2017), Akác faállományok választék-összetételének vizsgálata a Nyírerdő Zrt. területén, Diplomamunka, Sopron.

Járó Z. (1953), Az akác termőhelyi igénye, Az Erdő, 2.4/332-335.

Major T. (2016), A fahasználat irányítási műveletei, In. Rumpf J. szerk. Erdőhasználattan. Mezőgazda Kiadó, Budapest.

Molnár S. (1996), Az akácfa jelentősége, tulajdonságai és ipari felhasználása I-II., Bútor és Faipar, Budapest.

National Forest Data Repository, 2015

Pintér T. (2018), Akác faállományok választék-összetételének vizsgálata a SEFAG Erdészeti és Faipari Zrt. területén, Diplomamunka, Sopron.

Rédei K. (1997), Az akáctermesztés kézikönyve, Erdészeti Tudományos Intézet, Budapest.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

FORESTRY EDU TRAINER - COOPERATION FOR INNOVATION AND THE EXCHANGE OF GOOD PRACTICES

Andrea Teutenberg, Joachim Morat, Ute Seeling
KWF e.V. - Kuratorium für Waldarbeit und Forsttechnik e.V., Groß-Umstadt, Germany
ute.seeling@kwf-online.de

Abstract: *Forestry Edu Trainer - Cooperation for Innovation and the Exchange of Good Practices - is an ERASMUS+project supported by six project partners from France, Finland, Belgium, Spain, Italy and Germany. The aim of the project is the development of a competence standard for trainers and instructors in forestry, which refers to methodological, pedagogical and didactic competences of the trainers. Parallel to the standard of competence, a modern, modular qualification concept for trainers in forestry will be developed on blended learning.*

The background to this is that in most European countries, trainers employed in forestry trainings are highly skilled, but they generally lack sound pedagogical and learning methodological skills; a serious shortcoming, given the key role that trainers - also as rolemodel - have in education and training. Surveys in the partner countries among apprentices and coaches expressly prove the discrepancy between requirements and qualifications. The project Forestry Edu Trainer should help close this gap of non-sufficient pedagogical-methodical competences.

After developing the competence standard (general competence requirements for qualified trainers) and the training standard (modules derived from the competence standard and training content), the project is currently in the process of preparing the training material for the eight modules of the training standard, which in turn are in blended learning tools to be translated. At the end of the project, an e-learning training course will be available for forestry instructors, completing the European Certificate for Forestry Trainers (ECFT). The course covers the areas of manual harvesting, mechanized harvesting and skidding and will provide the necessary pedagogical-methodical skills and tools, taking into account the country-specific features.

The project is funded by the EU under the ERASMU + program.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

HOW CAN AGROFORESTRY IMPROVE THE SUCCESS OF AFFORESTATION AND CONTRIBUTE TO MEETING THE GROWING DEMAND FOR WOOD?

Klaudia Kovács, Andrea Vityi
Institute of Forest and Environmental Techniques
Faculty of Forestry
University of Sopron
Bajcsy-Zsilinszky street 4.
H-9400 Sopron, Hungary
klaudikovacs@gmail.com, vityi.andrea@uni-sopron.hu

Abstract: *The major part of the European green energy production accounts for biomass. In the decentralized energy production, the biomass used in combustion technologies is largely derived from woody biomass (dendromass). The steadily growing demand for wood in the industry, transport and energy production requires a change in land use and more intensive use of trees out of forests. Both the widespread introduction of agroforestry in agricultural areas and the re-introduction of intercropping in young forest plantations could make a significant contribution to meeting future needs of woody biomass. This paper discusses the results of a Hungarian experiment which confirms that the use of intercropping in reforestations can significantly reduce the climate sensitivity of the system, and thus improve the success of afforestation and thereby promote qualitative and quantitative growth in wood production.*

Keywords: agrofgorestry, reforestation, alley cropping, wood, microclimate

1. Introduction

Bioenergy is foreseen the largest source of growth in renewable consumption between 2018 and 2023, accounting for 30% of the growth in renewable consumption in this period. This is a result of the considerable use of bioenergy in heat and transport. Bioenergy growth in the industry, electricity and transport sectors combined could be as significant as that of other renewable energy sources in electric power production. (IEA 2017)

The use of biomass for energy purposes has many potential benefits, including lower GHG emissions and mitigate concerns as well as the security of domestic supply and a more limited reliance on fossil energy source imports. The growth of biomass-based energy production has the potential to stimulate development, especially in rural areas through local energy supply and creation of jobs. Recently biomass is the most important renewable source in the EU-28, accounting for about two thirds of primary renewables production in 2016. (Figure 1) (Eurostat, 2017)

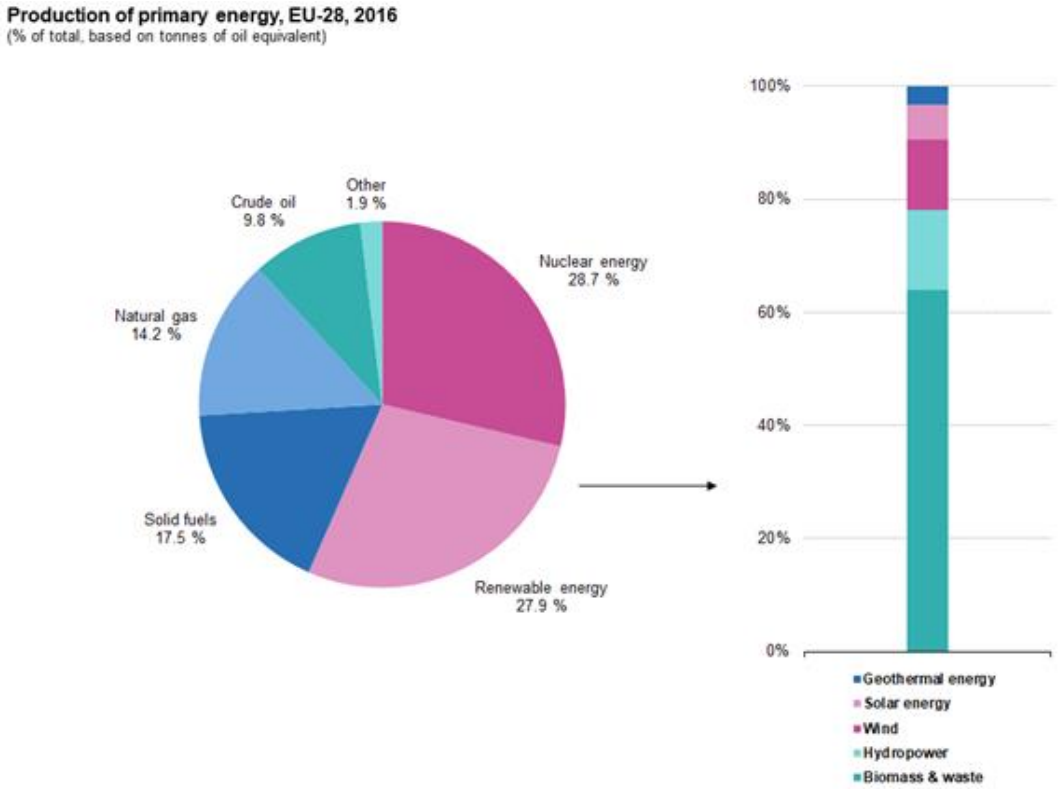


Figure 1: Share of biomass in EU-28 primary renewables production in 2016 (Eurostat, 2017)

With regard to solid biofuels, a considerable increase of demand is foreseen especially in the wood pellet market. In the past decade, the global production of wood pellets increased firmly, driven by constantly rising demand. As compared to the numbers communicated in the IEA report on wood pellets (IEA, 2011), wood pellet markets show development in all over the world and grow stable with about 14 % annually. (IEA, 2017) (Fig.2) Overall, trade in wood pellets in 2018 was estimated at around 23 million tonnes, a huge increase of 26% compared to 18.9 million tonnes in 2017. Imports to Denmark, South Korea and Japan each increased by 40% at minimum from their previous highs, and Japanese imports of wood pellets more than doubled. (Walker, Strauss, 2019)

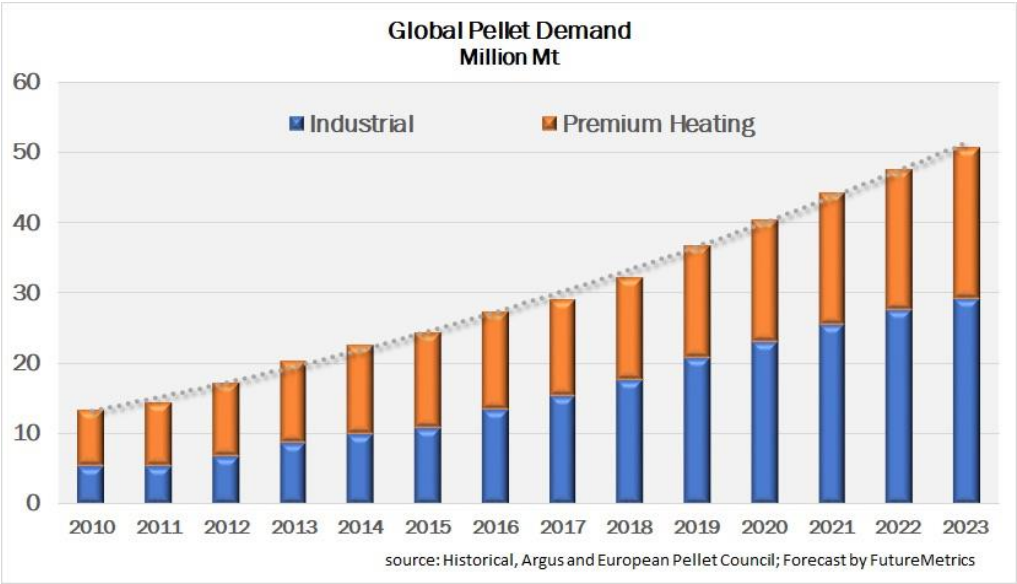


Figure 2: Market analysis forecasts continued strong growth over the next five years in global pellet demand. (Walker, Strauss, 2019)

However, increased pellet consumption increases the pressure on forests, leading in some countries to a significant reduction in forest cover which could severely deplete the region's forest carbon sinks, a major factor in reducing emissions.

Forest and tree plantation biomass has a significant role in the strive towards the policy targets established by the European Union within the "2020 climate and energy package" (Ferranti, 2014). With respect to woody biomass, different categories of resources can contribute to the supply of renewable energy, among which forestry residues, wood industry residues and short rotation energy crops are the most important energy sources (Karjalainen et al., 2004; EEA, 2007).

EU Member States expect to mobilize extra domestic biomass resources for heating and electricity generation and to increase the amount of biomass destined to these industries by 50% (from 76 Mtoe in 2006 to 113 Mtoe) by 2020. It is expected that forests will continue to be the predominant source of biomass supply, with an overall share of over 66% of total biomass as a renewable energy source by 2020 (rising from 62 Mtoe to 75 Mtoe) (EC, 2013). According to Johnsson et al., 2018, in a business-as-usual scenario, EU harvests increase seven percent by 2030 compared to past levels (485 million m3 on 2000-2012 average and 517 million m3 in 2030), corresponding to decreasing carbon-dioxide removal by the European forests. In a second, high mobilization scenario, based on the premise of full utilization of the potential wood supply and a doubling of EU wood pellets consumption, harvest increases by 55% (754 million m3 in 2030) compared to the business-as-usual scenario. Moreover, this increase in harvest level would significantly impair CO_2 sequestration by forests from the atmosphere in the medium term (-83% in 2030, compared to 2000-2012 average) (Johnsson, et al., 2018).
The above mentioned trends require a change in land use and more intensive use of trees out of forests, taking that recent increase of EU forest areas cannot compensate for this process because of the limited possibilities for upgrade afforestation (e.g. lack of areas available). One of the alternatives is the widespread introduction of agroforestry in agricultural areas that could make a significant contribution to meeting future needs of woody biomass and mitigate the loss of wooded areas.

2. Combination of agricultural practices and tree cultivation

Agroforestry system is a dynamic, ecologically based natural resource management system that integrates trees into farms and the agricultural landscape, thereby diversifying them and maintaining production for land users through enhanced social, economic and environmental benefits. In agro-forestry systems, the combination and structure of associated species or varieties can be very diverse. As agriculture has changed, intensive crop and livestock production has taken hold, reducing the occupation of small diverse production systems, such as agroforestry farms. Recently, agroforestry is spreading again, playing an increasingly important role in climate adaptation and safe production. (Vityi, Kovács, 2018) (Kovács, Vityi, 2017) Among its main types of landscape elements in Europe, green protective elements (e.g. riparian buffer strips, shelterbelts, windbreaks and hedgerows), tree plantations combined with crop production and alley cropping could play a greater role in agriculture. Introduction of woody components into livestock keeping systems (e.g. wood pastures and grazed tree plantations) is equally important.

3. The role of agroforestry in meeting the growing demand for wood from an agricultural perspective

It is a common feature of agroforestry systems that its elements interact with each other and can therefore lead to more ecologically and economically sustainable farming. (Leakey, 2012) A well-established and operated agroforestry system can produce up to 30-40% higher total biomass yield compared to the system with plant cultures grown separately. This is due to the use of woody vegetation, which provides protection to crop and livestock, a more favourable microclimate and diversity and at the same time produces wood that complements the yield of the agricultural crop. (Gál, 1963, Dupraz et al., 2005) A number of domestic and international practical examples confirm that the positive effect of trees present in the agricultural system is reflected in the improvement of both quantity and quality of production. (Suliman et al., 2012)(Daniel et al., 2017)(Abdul, 2013) The profitability of the production system can be increased through the introduction of trees in agricultural areas, such as combination of coppicing or timber tree plantations with agricultural crops, which can be supplemented with beekeeping if honey crops are included.

4. The role of agroforestry in meeting the growing demand for wood from the perspective of forest management: supporting afforestation through agroforestry

The application of agroforestry practices can play an important role in improving the quantitative and qualitative parameters of dendromass production from wooded areas in the future. In the history of the Carpathian Basin, intercropping in forest restocking was considered traditional. Observations and studies in Hungarian systems have shown that it has positive effect on the soil microclimate and the growth of saplings, thereby increasing the survival rate of trees. (Fig. 3)



Figure 3: Intercropped reforested area with a combination of a variety of tree species (*Quercus robur, Pyrus pyraster, Tilia tomentosa, Betula pendula*) and corn in a Hungarian experimental site. (Photo by K. Kovács)

Complex yield and site studies were performed in the experimental area and in the associated control area. Intercrop - typically corn in Hungary - if well-chosen (e.g. crop variety with below average growth), creates a competitive and partial shade, thus stimulating the growth of young trees. Examination of the growth parameter revealed that the saplings in the intercropped area brought stronger growth, with the same characteristics of the two areas. (Vityi, Kovács, 2018)

In the agroforestry area, soil temperature and water balance were much more balanced than in the control. The positive effect was particularly strong in drought periods; the drought damage loss was significant in the control area, while no loss was observed in the intercropped forest plantation. The daily average temperatures of the intermediate area during the arid period were significantly lower than the values of the control area. (Vityi, Kovács, 2016) (Fig 4,5)

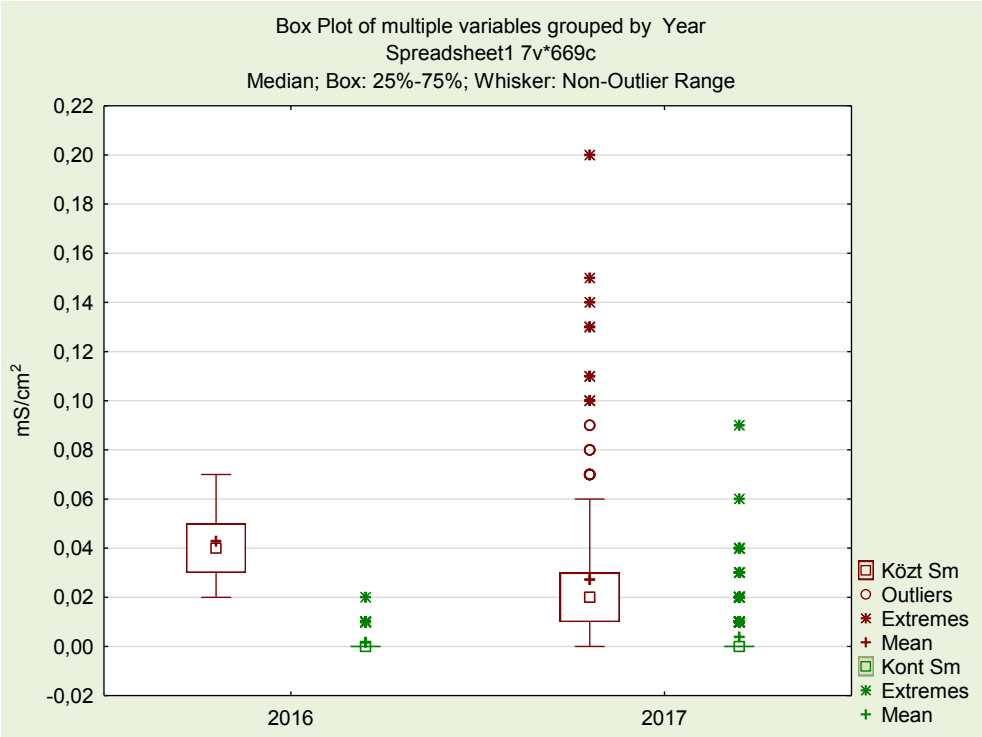


Figure 4: Observations on better plant conditions in the AF plot are confirmed by the box chart showing significant difference between the two afforestation systems in both years.

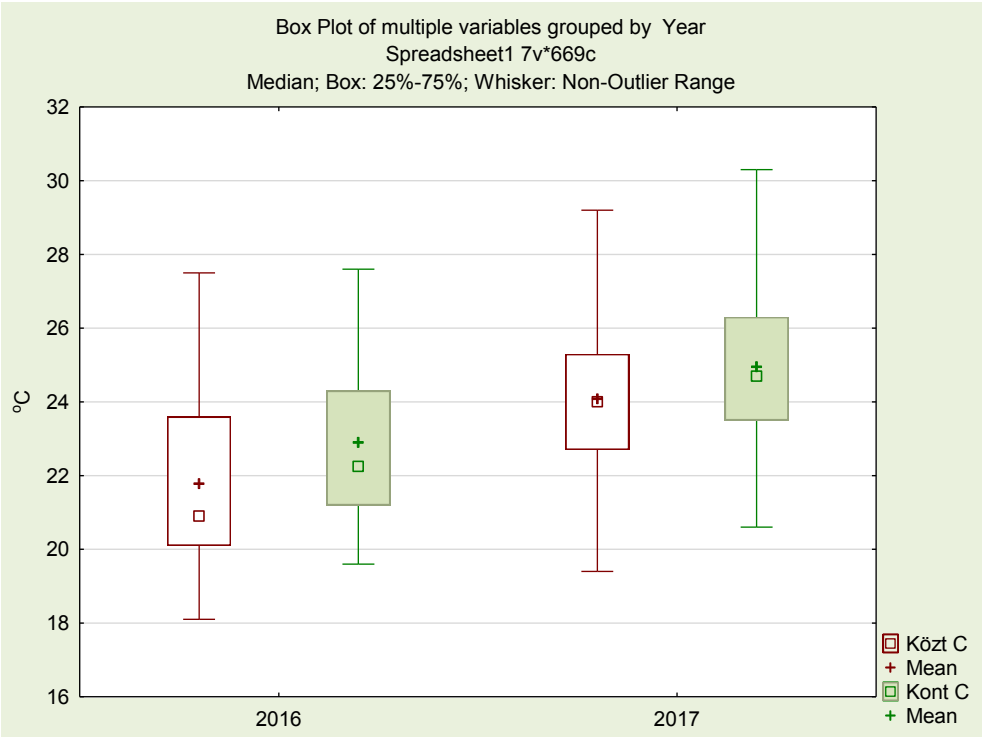


Figure 5: The soil daily average temperatures of alley cropping system were consistently and significantly lower than the values of the control area in the driest period (August) of 2016 and 2017.

Experimental areas are affected by wildlife damage. Experience shows that wild tended to damage the intermediate culture, leaving the trees intact. (Vityi, Kovács, 2018, Kovács, Vityi, 2017)

5. Summary

The steadily growing demand for wood requires a change in land use and more intensive use of trees out of forests. Both the widespread introduction of agroforestry in agricultural areas and the re-introduction of intercropping in young forest plantations in their first few years could make a significant contribution to meeting future needs of woody biomass and mitigate the loss of wooded areas. The results of a Hungarian experiment confirm that the use of intercropping in reforestations can significantly reduce the climate sensitivity of the system, and thus improve the success of afforestation. Greater supportive government measures for a more widespread use of both practices (introduction trees to agricultural crop systems and introduction of crops in forest cultivation) can be recommended, which in the long run may result in improved qualitative and quantitative parameters of wood production.

6. Acknowledgement

This research was supported by EFOP-3.6.2 – 16 -2017 – 00010 - Ring 2017 project and EFOP-3.6.2 – 16 -2017 – 00018 – Termeljünk együtt a természettel – Az agrárerdészet, mint kitörési lehetőség" project.

7. References

Abdul, K. (2013), Comparative study of different densities of poplar in wheat based agroforestry system in central punjab,From:https://www.researchgate.net/publication/28346983_comparative_study_of_different_densities_of_poplar_in_wheat_based_agroforestry_system_in_central_punjab

Daniel, N. and Patrick, N. (2017), Assessing the land equivalent ratio (LER) of maize (Zea mays L.) intercropped with Rhizobium inoculated soybean (Glycine max [L.] Merr.) at various P and K levels, ISSN: 2220-6655, From: https://www.researchgate.net/publication/315834117_Assessing_the_land_equivalent_ratio_LER_of_maize_Zea_mays_L_intercropped_with_Rhizobium_inoculated_soybean_Glycine_max_L_Merr_at_various_P_and_K_levels

Dupraz, C., Burgess, P.J., Gavaland, A., Graves, A.R., Herzog, F., Incoll L. D., Jackson, N., Keesman, K., Lawson, G., Lecomte, I., Mantzanas, K., Mayus, M., Palma, J., Papanastasis, V., Paris, P., Pilbeam, D.J., Reisner, Y., van Noordwijk, M., Vincent, G., van der Werf, W. (2005), SAFE, Silvoarable Agroforestry for Europe: Synthesis Report. http://www1.montpellier.inra.fr/safe/english/index.htm.

European Commission (2013), Commission Staff Working Document. Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A new EU Forest Strategy: for forests and the forest-based sector. Retrieved on 26 June 2016 from: http://ec.europa.eu/agriculture/forest/strategy/staff-working-doc_en.pdf
European Environmental Agency, EEA (2007), Environmentally compatible bio-energy potential from European forests, Retrieved on 22 August 2012, Retrieved on 26 June from: http://www.efi.int/files/attachments/eea_bio_energy_10-01-2007_low.pdf

Eurostat (2015), Renewable Energy Statistics. Retrieved on 26 June 2016 from: http://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics

Ferranti, F. (2014), Energy wood: A challenge for European forests. Potentials, environmental implications, policy integration and related conflicts, EFI Technical Report 95., European Forest Institute

Gál, J. et al. (1963), A mezőgazdasági terméshozamok növekedése az erdősávok védelmében. The increase of agricultural yields in protection zone of forest belts. Scientific Publications of the University of Forestry and Timber Industry. 1963/1-2: 43-81.

International Energy Agency (2011), IEA Bioenergy annual report, http://task32.ieabioenergy.com/wp-content/uploads/2017/03/IEA-Bioenergy-2011-Annual-Report.pdf

International Energy Agency (2017), Global Wood Pellet Industry and Trade Study 2017 Executive Summary, Summary Series, IEA Bioenergy: Task 40: 11 2017., http://task40.ieabioenergy.com/wp-content/uploads/2013/09/IEA-Wood-Pellet-Study_final-2017-06.pdf

Jonsson, K., Blujdea, V., Fiorese, G., Pilli, R., Rinaldi, F., Baranzelli, C. and Camia, A. (2018). Outlook Of The European Forest-Based Sector: Forest Growth, Harvest Demand, Wood-Product Markets And Carbon Dynamics Implications. Sisef-Soc Italiana Selvicoltura Ecol Forestale, From: ttps://ec.europa.eu/jrc/en/publication/outlook-european-forest-based-sector-forest-growth-harvest-demand-wood-product-markets-and-carbon

Karjalainen, T., Asikainen, A., Ilavsky, J., Zamboni, R., Hotari, K. E. and Röser, D. (2004), Estimation of Energy Wood Potential in Europe, Natural Resources Institute Finland, Helsinki

Kovács, K. and Vityi, A. (2017), Erdőtelepítés támogatása agroerdészeti rendszerekkel, In: Bidló, A; Facskó, F (szerk.), Soproni Egyetem Erdőmérnöki Kar VI. Kari Tudományos Konferencia: a konferencia előadásainak és posztereinek kivonatai, Sopron, Magyarország: Soproni Egyetem Kiadó, 81-84.

Leakey, R. R. B. (2012), Multifunctional agriculture and opportunities for agroforestry: implications of IAASTD. In: Nair PKR, Garrity D (eds) Agroforestry-the future of global land use, Advances in agroforestry, vol 9. Springer, Dordrecht, pp 203–216

Suliman, A. and Ahmed, M. (2012), Assessing the Land Equivalent Ratio (LER) of Two Leguminous Pastures (Clitoria and Siratro) Intercropping at Various Cultural Practices and Fencing at Zalingei, Western Darfur State - Sudan, ISSN 2225-7217, From: https://www.researchgate.net/publication/285538108_Assessing_the_Land_Equivalent_Ratio_LER_of_Two_Leguminous_Pastures_CLITORIA_and_SIRATRO_Intercropping_at_Various_Cultural_Practices_and_Fencing_at_ZALINGEI_-Western_Darfur_State_-Sudan

Vityi, A. and Kovács, K. (2018), Improve the efficiency of afforestation by the use of alley cropping system, 5 p. In: Proceedings of the 4th European Agroforestry Conference: Agroforestry as Sustainable Land Use (Ed.: Nuria, Ferreiro-Domínguez; María, Rosa Mosquera-Losada) 457-461., Nijmegen, Hollandia: European Agroforestry Federation

Vityi, A., Kovács, K., Dufla, F., Bácsmegi, L. and Nagy, I. (2016), Improve the efficiency of afforestation by the use of agroforestry practices, In: Marie, Gosme; Paulo, JA; Borek, R; Burgess, PJ; Dupraz, C; Domínguez, NF; Freese, D; González-Fernández, P; Hartel, T; Lamersdorf, N; Lawson, G; Lojka, B; Méziére, D; Moreno, G; Mosquera-Losada, M; Palma, J; Pantera, A; Paris, P; Pisanelli, A; Plieninger, T; Reubens, B; Rois, M; Rosati, A; Smith, J; Vityi, A (szerk.),3rd European Agroforestry Conference, Montpellier, France: European Agroforestry Federation, (2016) pp. 144-145. , 2 p.

Walker, S. and Strauss, W. (2019), 2019 global wood pellet markets outlook, Canadian Biomass, Retrieved Jan. 7, 2019 from: https://www.canadianbiomassmagazine.ca/2019-wood-pellet-markets-outlook-7190/

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

Calculating the cost of integrated harvesting of small-diameter trees dominated stand using various apportioning methods

Libin T. Louis[1] & Anil Raj Kizha[2]
School of Forest Resources
University of Maine Orono
5755 Nutting Hall, Orono, Maine, United States
[1]libin.thaikkattil@maine.edu
[2]anil.kizha@maine.edu

Abstract: *Multifaceted use of woody biomass including soil reclamation and energy production utilizing wood chips, pellet wood, and briquets is gaining global attention. Despite the diverse combinations of silvicultural prescriptions and harvesting methods present in the northeast US, better understanding the cost of extracting non-merchantable woody biomass such as, small diameter trees (SDT, diameter at breast height less than 15 cm), tree-tops and branches is crucial in efficient utilization and sustainable forest management. The primary objective was to examine the cost and factors that influence the productivity of two major timber harvesting methods, which were, hybrid cut-to-length (CTL) and whole-tree (WT). The second objective was to analyze the cost of harvesting SDT along with other harvest residues. The third objective was to compare the cost of harvesting SDT and biomass under various cost apportioning methods. The study was conducted on an industrial timberland property in Northern Maine, USA during the summer of 2018. SDT and other woody biomass (not meeting sawlog standards) generated from the WT treatment was sorted at the landing and comminuted to pulpwood quality chips. All prescriptions were carried out in adjacent harvest units comprising to a total of 60 ha. Detailed time and motion studies was conducted for all in-wood operational phases for both treatments. Machine rates and other related information were gathered from the logging contractors and timberland managing company. Regression models were developed for determining the influence of dependent variables over the cycle times for each operational phase. The total cost of harvesting was higher in CTL (US$ 14.33 m^{-3}) compared to the WT (US$ 13.06 m^{-3}), without considering the cost of chipping which added an additional US$ 3.12 m^{-3} to the later. The proportion of SDT in the stand was a deciding factor influencing the cost of harvest because of the higher operational time involved while dealing with SDT. The cost of SDT as by-product was (US$ 3.12m^3) half of the cost calculated using joint products (US$ 7.73 m^3). This study will provide techniques that can enable timberland managers and operational foresters to evaluate the cost of harvesting woody biomass thereby help them in taking better managerial decisions regarding silvicultural prescription and efficiently manage stands having large proportions of SDT.*

Keywords: cut-to-length, by-product, joint product allocation, timber harvesting, whole-tree

1. Introduction

Harvest residue is an inevitable part of all timber harvesting operations and plays a crucial role in bio-energy production and future management of the stand (Thiffault et al., 2015; Kizha and Han, 2016). Integrated harvesting simultaneously generates both sawlog and wood chips from harvest residues such as, dead branches, treetops, non-merchantable tree species, and small-diameter trees (SDT, diameter at breast height less than 15 cm). If these harvest residues were not to be utilized, they could potentially increase the cost of stand management and pose significant forest fires threat (Hartsough et al., 1997; Han et al., 2004). However, currently a wide range of bio-energy and other wood products are generated from these residues (FAO, 2015; Spinelli et al., 2019). The amount of harvest residue from a particular stand varies depending on the stand characteristics, silvicultural treatments, and harvesting method

(Kizha and Han, 2015a; Spinelli et al., 2019). Major portion of the harvest residue (by volume) is constituted by non-merchantable stems such as small diameter trees and branches (Ghaffariyan et al., 2015; Kizha and Han, 2015b; Spinelli et al., 2019).

Harvesting SDT in the stand had been found to increase the total cost of operation although in contrast the benefits are, it decreases the management costs, increases future stand productivity as well as decreases the risks of forest fire (Hartsough et al., 1997; Han et al., 2004). Products from harvest residues such as wood chips, pellet wood, and briquets in energy production has great demands in the global markets (Barrett et al., 2014; Spinelli et al., 2019), and are renewable resources that can be used to offset non-renewable energy production thereby aid in greenhouse gas emission reductions (Jones et al., 2010; Hanzelka et al., 2016). Production of high quality low cost biomass feedstock requires careful planning and implementation to avoid contamination until the chipping phase (Sahoo et al., 2019). After chipping, transportation of biomass to processing facility is an expensive part of the whole process hence, proximity to markets is a crucial factor in determining the cost of harvesting and processing biomass feedstock (Becker et al., 2009; Kizha et al., 2015; Paulson et al., 2019).

Additionally, the cost of harvesting SDT and sawlog can be calculated using various cost apportioning methods and could yield different costs for the same case under different scenarios (Hudson et al., 1990; Puttock, 1995). This is primarily due to the harvesting conditions and contracts prevailing for the specific harvest. For example, the harvest residues are hypothesized to receive a "free-ride" along with the sawlog component in by-product allocation method (until chipping), however, in joint product allocation the cost is split between sawlogs and harvest residues for the various operational phases.

In the global harvest scenario of round wood production, cut-to-length (CTL), whole-tree (WT) and other harvesting methods accounted for 35, 37 and 29%, respectively (Nordfjell et al., 2019). Different variations of WT, CTL, and tree-length are practiced in the state of Maine (Germain et al., 2019), of which 80% of timber harvest is accounted by WT (Leon and Benjamin, 2012). Even though the cost and productivity of two harvesting methods vary dramatically in different studies, but the methods are comparable (Lanford and Stokes, 1996).

The main objectives of this study were to compare and examine the operational efficiency and cost of harvesting small-diameter trees. The specific objectives were to: 1) examine the cost and factors that influence the productivity of two major timber harvesting methods, hybrid CTL and WT; 2) evaluate the cost of harvesting small-diameter trees (SDT, DBH < 15 cm) and harvest residues; 3) compare the cost of harvesting SDT under different apportion techniques.

2. Methodology

2.1 Study area

The study was conducted on an industrial timberland property in Northern Maine, USA (47 2' 7.54"N and 68 44' 10.95"W) (Figure 1) during July and August of 2018. Stand was harvested during summer months to allow for soil exposure. All the prescriptions were carried out in harvest units adjacent to each other. Hardwood pulpwood trees dominated the stand: red spruce (*Picea rubens* Sarg.), sugar maple (*Acer saccharum* Marsh.), striped maple (*Acer pensylvanicum* L.), black spruce (*Picea mariana* Mill.), yellow birch (*Betula alleghaniensis* Britt.), and American beech (*Fagus grandifolia* Ehrh.). The area was previously harvested in the 1950s, which indicates the age of the stand was about 70 years. The study area had an undulating terrain with a mixture of slopes that ranged from 3–35%. The major soil type were Chesuncook-Elliottsville association (23%), Telos-Chesuncook-Ragmuff association (27%), and Ragmuff-Monson complex (38%) (USDA, 2018).

2.2 Silvicultural prescriptions

Clear-cut (CC) and partial harvest (PH) were the two silvicultural treatments in the study. Clear-cut removed the entire trees from the stand while partial harvest in general retained some residual trees in the stand. Clear-cut prescription resulted in the harvesting of all merchantable timber from the stand and compressed the existing regeneration as part of site preparation and planting. In partial harvest treatment units, 50–70% of Basal Area was harvested and quality growing stock was retained according to a pecking order. Residual stand resulted in quality growing stock trees across all diameter size classes (regeneration, pole, mature, and immature). A control stand intended to serve as future reference was maintained where no harvest was done.

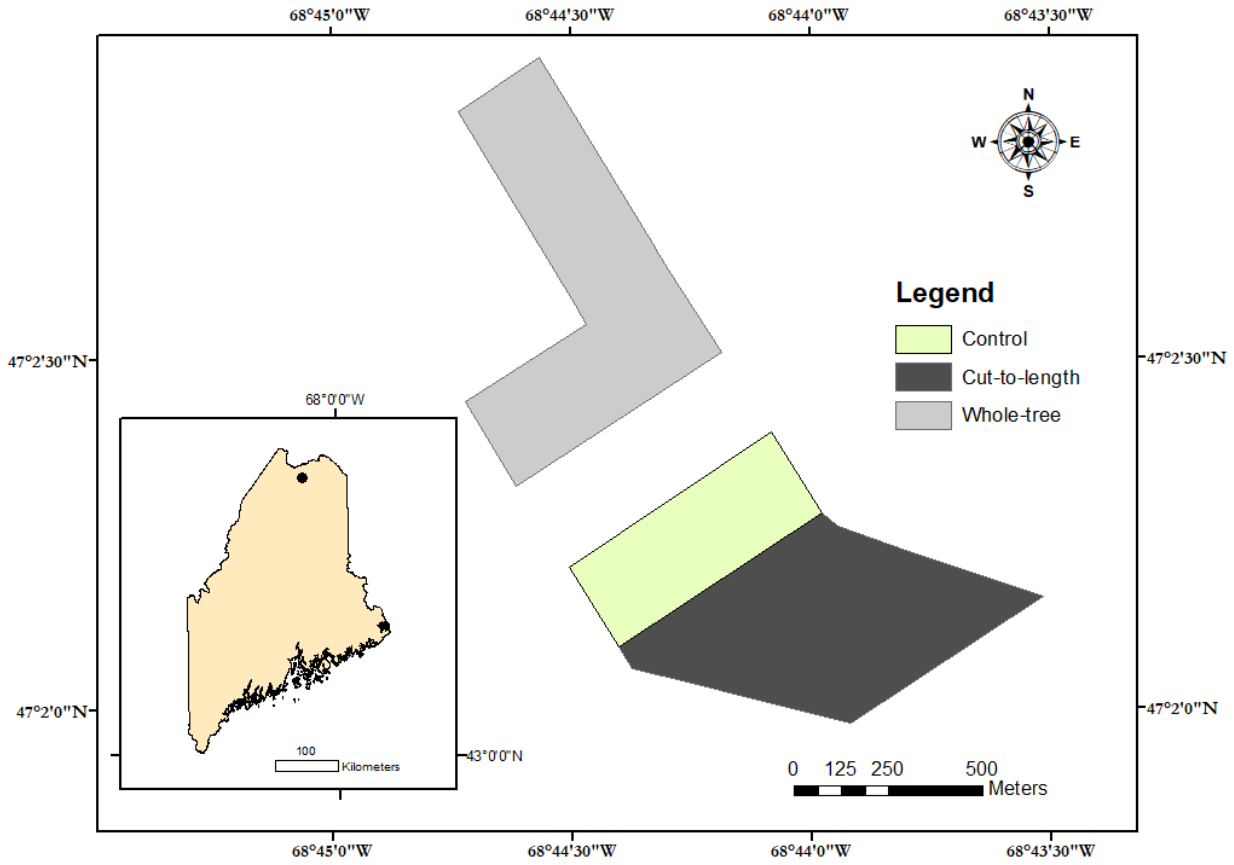


Figure 1. Map Showing the location of study site in the state of Maine (bottom left) and the treatment units that are included in the study such as Whole-tree and Cut-to-length along with control.

2.3 Stand inventory

The total area of the study site was 60 ha which was almost equally divided into two treatments (29.5 ha for WT and 30.6 ha under hybrid CTL). Pre-harvest inventory data was collected for both treatment units at 20% sampling intensity; 40 variable radius plots were inventoried prior to harvesting using 20 Basal Area Factor (BAF) prism. Parameters measured include species, diameter at breast height, and geographical location of the plot center.

2.4 Log Scaling

Small- and large-end diameter of random logs were measured, along with the log length to calculate the average volume of sawlogs. Scaling data were obtained from both treatments (WT and CTL) separately; but as scaling was done at the landing and was restricted to sawlogs, SDT from WT method were not accounted.

2.5 Harvesting operations

WT harvesting method was utilized for the clear-cut treatment units and a hybrid CTL operation was used in partial harvest treatment units (Fig. 1). Machines used and operators were the same throughout the respective treatments.

2.5.1 Whole-tree treatment

The machine combination used in WT treatment included, feller-buncher (John Deree 853), grapple skidder (John Deree 848H) and processor (John Deree 753). Delay-free cycle (DFC) of feller-buncher included time taken to travel to a tree followed by felling and bunching. Then the feller-buncher moved to a new tree initiating the next DFC. While

harvesting SDT, feller-buncher felled and bunched multiple trees in a single cycle. DFC of skidder began when the skidder travelled from the landing to the unit, extracting the tree bunch and moving back to the landing. Distance moved by machine was visually estimated with the aid of distance markers placed at regular intervals prior to the beginning of the operation. DFC of processor at the landing was the time taken to reach out, grab, process tree/s, and followed by decking. Self-loading trucks were used for loading merchantable logs at the landing. SDT and harvest residues generated from the WT treatment were chipped for biomass energy plants and maple trees (not meeting sawlog standards) from all units were sorted at the landing and comminuted to pulpwood quality chips.

2.5.2 Hybrid cut-to-length method (Hyb CTL)

Similar to WT, in the Hyb CTL treatments, the trees were felled using the same feller-buncher which made the two treatments comparable. Felled trees are processed within the unit by the processor (same machine used for the WT treatment) and then a forwarder (John Deree 1910) carried the processed logs to the landing. As a harvester was not employed for felling and processing, this treatment was considered to be a hybrid CTL. Hyb CTL methods are common to northeastern US and is believed to have better productivity than a conventional CTL (utilizing a harvester). Chipping was not done in the hybrid treatment, as the SDT and slash materials were not extracted to the landing. DFC of the processor in woods was the time taken to travel to a tree, reach out to the tree, grab, process, and decking. In Hyb CTL, processing of logs happened in the woods and a forwarder was used to carry the logs to the landing. Forwarder DFC initiated when the machine started from the landing, pick up the processed logs from the trails, travelled back to the landing, and until it finishes the unloading of logs to the respective piles back at the landing. Similar to WT treatment, self-loading trucks were used for loading.

2.6 Machine rate calculations

Detailed time and motion study was conducted for all operational phases for both treatments and DFC times were calculated for each machine separately. The DFCs for all machines were recorded using an analog stopwatch. Followed by which, machine rates were calculated (Miyata 1980). Delays were separately recorded to further understand other factors that could influence productivity. The delays were classified into mechanical, operational, and personal (Kizha and Han, 2016; Soman et al., 2019a).

Salvage value of machines, economic life, and utilization rates was obtained from the logging company and the purchase price of machines was obtained from the local dealer. Hourly machine costs (US$ PMH^{-1}) were calculated using standard machine rate calculation methods. Average sawlog volume was determined for both methods from 202 scaled sawlogs chosen from random sawlog decks.

2.7 Cost apportioning

In this study, different apportioning methods such as joint product allocation (JPA), and by-product allocation (BPA) (Hudson et al., 1990), were compared to calculate the cost of harvesting SDT and sawlog separately. JPA assumes that, simultaneously produced products shares the cost until the point where the products are separately identifiable. For example, in JPA, woodchip product from SDT will be an apportioned sum of the cost of felling, extraction and the whole chipping cost. SDT are not processed; therefore, sawlog processing was not included. However, processing cost will be included if the tree-tops and branches are also chipped, as it is a product of sawlog processing. Cost sharing in different stages of operation that produced both SDT and sawlogs apportioned their costs based on the proportion of each to the total harvest volume in the WT (Puttock, 1995; Harrill and Han, 2012).

BPA considers outputs as products (sawlogs) and by-products (chips). Therefore, only the cost related to specific operational component involved in producing the by-product is included in the production cost. That is, the cost of producing woodchips is restricted to only the cost of chipping SDT and all other operational components (such as felling, extraction and processing) are solely borne by the main product (sawlog) (Hudson et al., 1990).

2.8 Statistical analysis

Statistical analysis was performed using R software (version 3.5.2). All the dependent variables followed normal distribution and natural logarithm transformation was used for some dependent variables to attain normality. Linear regression models were fitted for each machine within each harvesting method separately with DFC as response variable and other non-time elements as predictor variables. Backward/forward model selection with lower AIC values were used for model selection and validation using MASS package (Venables et al., 2002). Standardized comparisons were performed to determine the cost of operations irrespective of the site and stand conditions such as; species, stand

density, terrain, and forwarding/skidding distance. ANOVA was used for testing the differences between SDT and sawlog volume and DFC in WT treatment.

3. Results and Discussion

3.1 Stand inventory

A total of 259 trees (102 in PH and 157 in CC) were measured from 40 plots. The inventory data showed that the Basal Area per Hectare was 27.26 for WT and 31.48 in Hyb CTL. The tree density was 1732 trees ha^{-1} and 1509 trees ha^{-1} for CTL and WT respectively. Scale tickets showed a total of 5613 m^3 of wood was extracted from both treatment units included in the study, of which, 2415 m^3 was from CTL and 3198 m^3 from WT. The scaling data showed that the average volume of trees in Hyb CTL (0.30 m^3) and WT (0.32 m^3) treatment units were not significantly different ($p = 0.32$); showing both treatments were comparable in terms of unit volume of trees harvested. In WT treatment, out of the total volume harvested, 2000 m^3 were hardwood pulp (63%) and 1198 m^3 were the volume from softwood and hardwood sawlog (37%).

3.2 Cost of treatment

The total cost of harvesting was higher in Hyb CTL (US$ 14.33 m^{-3}) compared to WT (US$ 13.06 m^{-3}), without considering the cost of chipping which adds an additional US$ 3.12 m^{-3} to the total cost of WT harvesting (Table 1). Harvesting cost of each machines were highly variable (Bolding et al., 2009; Hiesl and Benjamin, 2013; Han et al., 2018; Soman, 2019) and was influenced by various stand and site factors. To produce same volume of wood in WT, the time required would be considerably less to that of CTL. The total volume of wood produced was higher in WT because of the clear-cut prescription. The productivity was found to be lower in CTL compared to conventional CTL, as an additional machine was used in the felling phase contributing an extra US$ 4.71 m^{-3}.

Table 1. Cost of each operational phases in whole-tree (WT) and hybrid cut-to-length (HyB CTL) in US$ m^{-3}.

Phase	WT	Hyb CTL
Felling	4.14	4.71
Processing	3.17	3.46
Extraction*	5.09	5.50
Loading	0.66	0.66
Total	**13.06**	**14.33**
Chipping	3.12	N/A

*Extraction for WT and HyB CTL operations were skidding and forwarding, respectively.

3.2.1 Felling

The average distance travelled by the feller-buncher between the trees was 11 m (13 m for Hyb CTL and 10 m for WT) which significantly influenced the DFC ($p < 0.001$) (Table 2). The cost of felling for WT and for Hyb CTL treatments was US$ 4.14 m^{-3} and US$ 4.71 m^{-3}, respectively (Table 1). The turn size (volume per DFC) was higher for WT (0.84 m^3) than Hyb CTL (0.63 m^3). The average DBH of trees felled were not found to be significantly affecting the DFC. Average cutting time was the highest (14 sec) in DFC of feller-buncher followed by time to travel to the tree (11 sec) and the bunching time. The average cutting in WT (9 sec) was half to that of Hyb CTL (17 sec) which could be because in CTL larger sized trees were felled. On average, 2.5 trees were cut per cycle by the feller-buncher which also significantly affected the DFC ($p < 0.001$) and the average number of trees cut in WT (2.6 trees) was higher than Hyb CTL (2.1 trees).

Table 2. Showing the selected regression models in whole-tree (WT) and Hybrid cut-to-length (Hyb CTL) for each of the phases of operation, adjusted R^2 values, and number of observations.

Phases	Treatment	N	Adjusted R^2	Standardized models predicting DFC
Feller-buncher	WT	390	0.34	DFC = 13.86 + 0.20 (distance between trees) + 9.26 (number of trees cut/cycle)
	Hyb CTL	160	0.18	DFC = 17.70 + 0.34 (distance to bunch) + 4.40 (number of trees cut/cycle)
Processor	WT	100	0.43	DFC = 2.19 + 0.07 (diameter of logs) + 0.69 (softwood)
	Hyb CTL	160	0.29	DFC = 2.94 - 0.18 (softwood) + 0.23 (number of logs)
Extraction	WT (skidder)	102	0.75	Log DFC = 4.08 + 0.03 (diameter) + 0.002 (travel loaded distance) + 0.04 (number of pieces) + 0.005 (positioning distance)
	Hyb CTL (forwarder)	104	Negative value	Model not significant
Chipper	WT	179	0.27	DFC = 3.71 + 1.26 (diameter) + 3.79 (number of trees)
Self-loading truck	WT and Hyb CTL	63	0.32	Log DFC = 2.76 + 0.07 (diameter)

The difference in cost of WT and Hyb CTL have been found to be varying. Adebayo et al. (2006) reported the cost was higher for CTL compared to WT, while Benjamin et al. (2013) found that there was no significant differences between the two. In another study, Soman et al., (2019) reported Hyb Tree Length was less costlier than WH, however, claimed that the higher cost of operation was due to a snow storm event during the WT operation. This highlights that the cost of operation is subjected to stand and operational conditions. The study was conducted in an industrial level set-up and more volume of wood was harvested from the WT due to the clear-cut prescription (approximately 750 m^3 more than the Hyb CTL treatment). The results from the study showed that, Hyb CTL was costlier than WT (without chipping cost included). This could be because of the abundance of SDT which were harvested only in WT increased the number of logs per turn there by reducing the cost of WT harvesting. Even though an additional machine, feller-buncher, was used to fell the trees in Hyb CTL method instead of conventional CTL where harvester and forwarder, the cost surge of the former would be uncertain because the cost of harvester could have been reduced and the time required for the total harvest could also be reduced.

Feller-buncher harvested a greater number of SDT in WT hence increased the felling productivity. However, the average volume of logs calculated from the scaling data were ustilizing sawlogs which could be the reason for increased productivity of felling even though there was higher proportion of SDT harvested from WT. In Hyb CTL treatment, the distance to bunch influenced the DFC of feller-buncher. More time was required for the feller to sort the trees for facilitating in-wood processing compared to bunching for the skidder (in WT). Average bunching time in WT was 0.17 min whereas in Hyb CTL was 0.13 min. In general, the distance moved by the feller-buncher in both method of harvesting influenced the DFC (Adebayo et al., 2006).

3.2.2 Extraction

In WT, the loaded distance (89 m) travelled by the skidder was the most significant factor ($p < 0.001$) (Table 2). The average payload constituted 5 trees per trip, with an average diameter of 19 cm per tree. Travel loaded time contributed most (79 sec) to the average DFC, followed by unloaded travelling time (58 sec). In Hyb CTL, regression models for forwarder DFC was not significant and had a negative value for the adjusted R^2. Skidding the logs in WT costed US$ 5.09 m^{-3} and forwarding in Hyb CTL costed US$ 5.50 m^{-3}. Even though the estimated DFC of skidder (3 minutes)

was significantly smaller compared to that of the forwarder (77 minutes), the turn size was much higher in forwarder (26 m^3 per cycle) compared to skidder (2 m^3 per cycle).

In both WT and Hyb CTL, extraction accounted for highest cost among all different harvesting phases 39 and 38% respectively. Even though the forwarder carried considerably higher volume of wood per DFC, the skidder (28 m^3 hr^{-1}) was more productive than the forwarder (18 m^3 hr^{-1}) and can be attributed to faster turn-around time. The DFC of skidder varied from 0.45 min to12.5 min and depended on distance to the bunch, which led to considerable variation.

3.2.3 Processing

The average DFC of Harvester at landing (WT) was 0.53 min, in which processing time (0.32 min) constituted more than half of the DFC cycle. In WT, harvester's DFC increased as the diameter of the logs increased ($p < 0.001$) (Table 2). Number of logs produced per cycle was not significant. Whereas, in Hyb CTL, DFC was significantly influenced by number of logs ($p < 0.001$). The number of logs produced per DFC was less in Hyb CTL (2 logs) than the WT (3.5 logs) and can be attributed to stable conditions prevailing in the later compared to the in-wood conditions in Hyb CTL. Compared to the WT, in CTL the harvester had to travel in-woods from bunch to bunch and scatter the residues on to the skid-trail. The average DFC of harvester in-woods was 0.62 min out of which the average processing time of a tree was 0.35 min.

In general more time was required to process the larger logs and hardwoods species, which can be attributed to the weight of the wood piece and complex crown structures & branching pattern, respectively (Glade, 1999; Hiesl and Benjamin, 2013; Labelle et al., 2018, Kizha and Han 2016). In Hyb CTL method, processor processed the trees in-woods and the DFC was significantly influenced by the number of logs and species. Processing time has been found to be major influencing factor in the DFC of processor (Glade, 1999; Simões et al., 2008). Processor did not fell trees in Hyb CTL, and also the distance move constituted a minor portion of the DFC as felling trees was done by feller-buncher. This indicate that the "felling and processing" cost could increase if felling trees was also done by the processor.

3.2.4 Loading

Self-loading trucks were employed for transporting merchantable logs to the mill. The DFC of the self-loading trucks depended on the diameter ($p < 0.001$) of the logs (Table 2). The average DFC was 0.48 min. On an average the self-loading truck loaded 5 logs with an average diameter of 22 cm. Three self-loading trucks were used for hauling wood to the processing facility (93.3 km) which took 3.5 hrs. The average gross vehicle weight was 90 metric tons. The cost of loading was least among all the operational phases. Hauling wood to the processing facility is the most costly component among harvesting and delivering processes (Harrill and Han, 2012).

3.2.5 Chipping

Chipping operation was only done in whole-tree harvest and the DFC depended on diameter of the logs ($p < 0.001$) and number of trees ($p < 0.001$) fed into the chipper (Table 1). The cost of chipping SDT was estimated at US$ 3.12 m^{-3} (Table 1). The average DFC was 0.27 min in which the swinging empty time constituted 0.09 min and swinging loaded took 0.08 min for. Hardwoods were chipped during the operation because the stand was dominated by hardwood (SDT and pulpwood). Time to load a truck averaged to 35 min. The productivity of chipper was significantly influenced by the number and size of logs fed into the chipper. Larger logs reduced the time to load the truck. The utilization of chipper was 53% because of the regular changing of the blades. In this study, the chipper utilization was higher because the chipping was done once all the SDT are at the landing hence, the chipper didn't stop working because of the lack of trees to feed. The chipping cost increased the total cost of WT operation and hence the revenue from chips determines the economic feasibility to produce wood chips from SDT and other non-merchantable biomass.

3.3 Apportioning cost

Apportioning calculation was done only for WT treatment as there were no secondary products from the Hyb CTL. The total cost of harvesting SDT calculated using various apportioning methods showed US$ 3.12 and 7.73 m^{-3} for the BPA and JPA, respectively. In BPA, the cost for producing sawlog (US$ 13.06 m^{-3}) was the same as the total cost of the operations (Table 1), as the by-product (wood chips) is hypothesized to get a "free-ride" along with the main product (sawlogs).

The costs in JPA was shared for felling and skidding between the SDT and sawlog component. The cost of processing was not shared but only allocated for the sawlogs as SDT were not processed. Furthermore, the cost of chipping was allocated to the SDT. The SDT were left at the landing and naturally dried to remove the leaves. Since the SDT were not processed at the landing the total cost calculated for the producing wood chips are lower. In most cases if there are leaves retained or if softwoods are chipped, then processing of SDT would be necessary to produce better-quality pulpwood chips. In such cases if the processing cost of trees were to be shared with sawlog, it would decrease the to US$ 5.24 m^{-3} and woodchips cost would be US$ 10.93 m^{-3}. The total cost of producing wood chips depends on the proportion of the SDT in the stand. In this study the cost was calculated for up to loading the trucks, if the cost of trucking was included in the apportioning methods, both sawlog and wood chips would increase.

Table 1. Cost of harvesting (stump to truck) sawlog and SDT (small-diameter trees, with a diameter at breast height below 15 cm) calculated using two apportioning methods.

Apportioning method	Sawlog (US$ m^{-3})	SDT (US$ m^{-3})
Joint products allocation	8.45	7.73
By-product allocation	13.06	3.12

In integrated harvesting the primary objective is to produce multiple products. The two cost apportioning methods are used in different scenarios. JPA is generally used for calculating the cost of comminuted forest products when the woodchips have high market demands, the landowner want the residue out of the site because of the law and policy requirements or the processing facility is not far. In other words, JPA accounts treats the secondary product as an individual commodity. Harrill and Han (2012), found out that the cost of producing wood chips was seven times the cost of producing sawlogs. The results could vary depending on which all operational factors are considered in the calculation. The calculated cost of sawlogs and wood chips also depend on various factors such as size of trees, type of woods (hardwood or softwood), stand density, and machine configuration. BPA cost apportioning is used when the landowner objective does not involve production of wood chips but the SDT are harvested and extracted to the landing as a part of the silvicutltural prescription. Here the proportion of SDT is considerably low and the cost of production is not economically advantageous because of higher distance to the processing facility.

4. Conclusion

The total cost of WT was higher than that of CTL which was because of the additional cost incurred from chipping operation. When calculating the total cost of WT harvesting, the higher number of SDT in the stand could result in underestimation of the actual cost of sawlog. When studying SDT dominated stands, the scaling data and cost calculations need to be separate for both otherwise, the cost calculated will be less representative of the actual cost. The adoption of different approach based on the demand and price of wood chips in the harvest location is very crucial in determining the cost of producing wood chips. Cost of producing wood chips varies depending on the apportioning method used. If the wood chips get a free ride till the landing (by-product), the cost is dramatically less than the cost of producing sawlog. This apportioning us used to estimate the cost of producing wood chips if the landowner is legally accountable to remove the woody debris from the harvested site to reduce risk of fire. On the contrary, if there are no obligation to remove the woody debris but if the market demand is very high for wood chips, then the cost of production would be estimated such that the cost is almost comparable with that of producing sawlog.

5. Acknowledgement

We would like to express our gratitude to Harikrishnan Soman, Alex Kunnathu George, and Kevaughn for assisting in various aspects of data collection and editing. We would also like to thank Brian Edward Roth, Stephen Dunham and Jenna Zukswert and other faculty in the University of Maine, Orono for the support and help in various stages of the study. Our appreciation goes to all the foresters, contractors and machine operators associated with Irving Woodland LLC, Ashland, for their involvement in the operational aspect of the study.

6. Funding

This project was supported by U.S. Department of Agriculture /Agricultural Research Service, Forest Products Research Project #5407527 and the Cooperative Forestry Research Unit (CFRU).

7. References

Adebayo, A.B., Han, H.-S., Johnson, L., 2006. Productivity and cost of cut-to-length and whole-tree harvesting in mixed-conifer stand in northern Idaho. Conf. Proc. 10.

Barrett, S.M., Bolding, M.C., Aust, W.M., Munsell, J.F., 2014. Characteristics of Logging Businesses that Harvest Biomass for Energy Production. For. Prod. J. 64, 265–272. https://doi.org/10.13073/FPJ-D-14-00033

Becker, D.R., Larson, D., Lowell, E.C., 2009. Financial considerations of policy options to enhance biomass utilization for reducing wildfire hazards. For. Policy Econ. 11, 628–635. https://doi.org/10.1016/j.forpol.2009.08.007

Benjamin, J.G., Seymour, R.S., Meacham, E., Wilson, J., 2013. Impact of Whole-Tree and Cut-to-Length Harvesting on Postharvest Condition and Logging Costs for Early Commercial Thinning in Maine. North. J. Appl. For. 30, 149–155. https://doi.org/10.5849/njaf.13-016

Bolding, M.C., Kellogg, L.D., Davis, C.T., 2009. Productivity and costs of an integrated mechanical forest fuel reduction operation in southwest Oregon. For. Prod. J. 59, 12.

FAO, 2015. 2015 Global Forest Products Facts and Figures 16.

Germain, R., Regula, J., Bick, S., Zhang, L., 2019. Factors impacting logging costs: A case study in the Northeast, US. For. Chron. 95, 16–23. https://doi.org/10.5558/tfc2019-005

Ghaffariyan, M.R., Spinelli, R., Magagnotti, N., Brown, M., 2015. Integrated harvesting for conventional log and energy wood assortments: a case study in a pine plantation in Western Australia. South. For. J. For. Sci. 77, 249–254. https://doi.org/10.2989/20702620.2015.1052946

Glade, D., 1999. Single- and Double-Grip Harvesters – Productive Measurements in Final Cutting of Shelterwood. J. For. Eng. 10, 63–74. https://doi.org/10.1080/08435243.1999.10702736

Han, H., Chung, W., She, J., Anderson, N., Wells, L., 2018. Productivity and Costs of Two Beetle-Kill Salvage Harvesting Methods in Northern Colorado. Forests 9, 572. https://doi.org/10.3390/f9090572

Han, H.-S., Lee, H.W., Johnson, L.R., 2004. Economic feasibility of an integrated harvesting system for small-diameter trees in southwest Idaho. For. Prod. J. 54, 21–27.

Hanzelka, N.C., Bolding, M.C., Sullivan, J., Barrett, S.M., 2016. Productivity and costs of utilizing small-diameter stems in a biomass-only harvest. Int. J. For. Eng. 27, 43–52. https://doi.org/10.1080/14942119.2015.1135615

Harrill, H., Han, H.-S., 2012. Costs and productivity of woody biomass harvesting in integrated stand conversion and residue recovery operations 116.

Hartsough, B.R., Drews, E.S., McNeel, J.F., Durston, T.A., Storkes, B.J., 1997. Comparison of mechanized systems for thinning Ponderosa pine and mixed conifer stands. For. Prod. J. 47, 59–68.

Hiesl, P., Benjamin, J., 2013. Applicability of International Harvesting Equipment Productivity Studies in Maine, USA: A Literature Review. Forests 4, 898–921. https://doi.org/10.3390/f4040898

Hudson, J., Mitchell, C., Storry, P., 1990. Costing integrated harvesting systems. Proc. IEABA Task 6th Act. Integr. Harvest. Syst. 2, 46–52.

Jones, G., Loeffler, D., Calkin, D., Chung, W., 2010. Forest treatment residues for thermal energy compared with disposal by onsite burning: Emissions and energy return. Biomass Bioenergy 34, 737–746. https://doi.org/10.1016/j.biombioe.2010.01.016

Kizha, A., Han, H.S., Montgomery, T., Hohl, A., Bisson, J., 2015. Determining cost zones and hot spots for procuring feedstock for woody biomass-based power plants in northern California. Calif Agr 69, 184–190.

Kizha, A.R., Han, H., 2015a. Cost and productivity for processing and sorting forest residues 13.

Kizha, A.R., Han, H.-S., 2016. Processing and sorting forest residues: Cost, productivity and managerial impacts. Biomass Bioenergy 93, 97–106. https://doi.org/10.1016/j.biombioe.2016.06.021

Kizha, A.R., Han, H.-S., 2015b. Forest Residues Recovered from Whole-tree Timber Harvesting Operations. Eur J For. Eng 1, 46–55.

Labelle, E.R., Breinig, L., Sycheva, E., 2018. Exploring the Use of Harvesters in Large-Diameter Hardwood-Dominated Stands. Forests 9, 424. https://doi.org/10.3390/f9070424

Lanford, B.L., Stokes, B.J., 1996. Comparison of two thinning systems. Part 2. Productivity and costs. For. Prod. J. 46, 47.
Leon, B.H., Benjamin, J.G., 2012. A survey of business attributes, harvest capacity and equipment infrastructure of logging businesses in the northern forest. Sch. For. Resour. Univ. Maine Orono.
Miyata, E.S., 1980. Determining fixed and operation costs of logging equipment.
Nordfjell, T., Öhman, E., Lindroos, O., Ager, B., 2019. The technical development of forwarders in Sweden between 1962 and 2012 and of sales between 1975 and 2017. Int. J. For. Eng. 30, 1–13.
Paulson, J.S., Kizha, A.R., Han, H.-S., 2019. Integrating Biomass Conversion Technologies with Recovery Operations In-Woods: Modeling Supply Chain. Logistics 3, 16.
Puttock, G.D., 1995. Estimating cost for integrated harvesting and related forest management activities. Elsevier Sci. Ltd 8, 73–79.
Sahoo, K., Bilek, E., Bergman, R., Kizha, A.R., Mani, S., 2019. Economic analysis of forest residues supply chain options to produce enhanced-quality feedstocks. Biofuels Bioprod. Biorefining 13, 514–534. https://doi.org/10.1002/bbb.1958
Simões, D., Marcelino, F.A., Pletsch, T.A., Faria, L.R. de, Fenner, P.T., 2008. Technical and economical evaluation of Harvester in cut-to-length system in first cut eucalyptus forest. Cent. Theme Technol. Shar. Knowl. Dev. Proc. Int. Conf. Agric. Eng. XXXVII Braz. Congr. Agric. Eng. Int. Livest. Environ. Symp. - ILES VIII Iguassu Falls City Braz. 31st August 4th Sept. 2008.
Soman, H., 2019. Productivity, Costs, and Best Management Practices for Major Timber Harvesting Frameworks in Maine. The University of Maine.
Soman, H., Kizha, A.R., Roth, B.E., 2019a. Impacts of silvicultural prescriptions and implementation of best management practices on timber harvesting costs. Int. J. For. Eng. 30, 14–25. https://doi.org/10.1080/14942119.2019.1562691
Soman, H., Kizha, A.R., Roth, B.E., 2019b. Impacts of silvicultural prescriptions and implementation of best management practices on timber harvesting costs. Int. J. For. Eng. 30, 14–25. https://doi.org/10.1080/14942119.2019.1562691
Spinelli, R., Visser, R., Björheden, R., Röser, D., 2019. Recovering Energy Biomass in Conventional Forest Operations: a Review of Integrated Harvesting Systems. Curr. For. Rep. 5, 90–100. https://doi.org/10.1007/s40725-019-00089-0
Thiffault, E., Béchard, A., Paré, D., Allen, D., 2015. Recovery rate of harvest residues for bioenergy in boreal and temperate forests: A review. Wiley Interdiscip. Rev. Energy Environ. 4, 429–451. https://doi.org/10.1002/wene.157
USDA, N.R., 2018. Web Soil Survey [WWW Document]. Web Soil Surv. URL https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx (accessed 6.10.19).
Venables, W.N., Ripley, B.D., Venables, W.N., 2002. Modern applied statistics with S, 4th ed. ed, Statistics and computing. Springer, New York.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

PLANNING OF FOREST ROADS NETWORK: CASE STUDY IN THE MOUNTAIN NATURAL FORESTS AREA OF BOSNIA AND HERZEGOVINA

Vladimir Petković [1], Igor Potočnik [2], Dane Marčeta [1]
[1] University of Banja Luka, Faculty of Forestry, Bosnia and Herzegovina [2] University of Ljubljana, Biotechnical faculty, Department of Forestry and Renewable Forest Resources, Slovenia
vladimir.petkovic@sf.unibl.org

Abstract: *The natural forests are usually named high forests and they regenerate naturally from the seeds. A natural forest accessibility and overall forest accessibility are insufficient for sustainable forest management. It is a reason for research of planning of forest roads, actually planning of forest accessibility and designing of forest roads. This task requires quantity and quality analysis of actual forest roads network, determination of optimal density of forest roads, determination of suitability of forest area for construction of forest roads and designing of forest roads at the end. Planning of forest roads is carried out at strategic level. The tools of Geographic information system (GIS) allow complete spatial and statistical analysis and management of data which are collected from forest management plans, measured in the field and obtained from Digital terrain model (DTM). Planning of forest roads will be done in the Forest management unit (FMU) "Bobija-Ribnik" and Forest Administration "Oštrelj-Drinić", Petrovac municipality, Bosnia and Herzegovina. The total length of forest roads in natural forests is 64.14 km. According to that, actual accessibility of natural forests is 15.66 m/ha. Optimal average density of forest roads should be 26.5 m/ha. Length of new forest roads which are designed into FMU is around 22 km, and achieved natural forest accessibility is 21 m/ha.*

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

DISTRIBUTION OF DEAD WOOD AT DIFFERENT DISTANCES FROM FOREST ROADS

Mohsen Mostafa[1] * Aidin Parsakhoo[2] and Sima Mohtashami[3]
1- Assistant Professor, Mazandaran Agricultural and Natural Resources Research and Education Center, AREEO, Sari, Iran. Corresponding author (Mohsenmstf@gmail.com, M.Mostafa@areeo.ac.ir)
2- Assistant Professor, Department of forestry, Faculty of Forest Science, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. Aidinparsakhoo@yahoo.com.
3- The forestry research institute of Sweden (Skogforsk). sima.mohtashami@skogforsk.se

Abstract: *In current research, the effects of roads on dead wood (DW) distribution were studied in uneven-aged natural deciduous forest. District one of ShastKalate forestry plan, North of Iran (Golestan province) was selected with two zones around the road. Roads were randomly selected in two land units with the same site qualities and transects were established parallel with roads. Transects were divided into three zones of 15 m, 60 m and 100 m from the road edge. Data including dimensions (diameter, height or length), species, level of decay for standing dead trees, snags and lying deadwood were measured in a strip plot with a width of 20 m on transects. Results show a higher volume of standing dead trees belong to Carpinus betulus L. and Parrotia persica C.A.M ($P < 0.05$). Five decay levels were used to facilitate describing tree decays in studied zones: class A is trees with healthy trunk and without longitudinal fracture with crown decay, class B consists of trees that have lost approximately 50% of branches with diameters less than 10 cm, class C consists of trees that have lost approximately 50% of branches with diameters more than 10 cm, class D consists of trees that only their main trunk remains and class E includes trees with broken trunk beneath their crown. In the first zone of land unit I the higher volume of standing dead trees had decay level of B while standing dead trees with decay level of C and A were the highest in the second and third zones, respectively. The total volume of DW were in the form of trees with healthy trunk and without fracture but with decaying crown and with 50% fallen thin branches was the lowest in the first zone (road edge), with approximately 28 m3 ha-1. The majority of standing dead trees.*

Keywords: Dead trees; Snag; Felled limbs and logs; ShastKalate

1. Introduction

Road construction in a forest area might affect forest ecosystems through several ways, for instance, by decreasing the forest productive areas, disturbing hydrology, increasing soil erosion, habitat and biodiversity loss (Hui et al. 2003; Delgado et al. 2007; Demir 2007; Beyer et al. 2013; Bil 2015). Forest roads are the most important infrastructure in a forest ecosystem that require forest management practices to supply all functions of forest resources (Çoban and Eker 2010; Lotfalian and Parsakhoo, 2012; Mathisen 2018).

Smit and Asner (2012), Akay et al. (2012), Tampekis et al. (2015), showed that roads impact forest at multiple levels: first, individual, species and population level and second, ecosystem processes and landscape level. Forest roads, together with logging roads, may increase runoff and erosion at landscape level. Forest roads affect trees health and growth by creating gaps and altering environmental conditions such as light availability, soil moisture and bulk density (Lotfalian et al. 2019). Butler et al. (2004), demonstrated that the road network density negatively affected DW amounts in forests in Switzerland. The degree to which roads affect DW distribution depends upon both direction of the roads and width of roadbed (Potocnik et al. 2008). Larrieu et al. (2013), have been shown the construction of a forest road first created bark losses in trees then contribute to increase of DW in forest stand.

When green canopies of trees are removed by forest road construction, the gaps are enlarged and exposure to solar radiation and Albedo increases (Chunyu and Xiuhai 2007). These conditions may provide a situation for gradual decaying of trees. Rate of tree decays depends on numerous parameters such as topography, stand density, windward edge, tree species, soil parameters, and proximity to road corridors (Dupont and Brunet 2008; Lin et al. 2014).

DW consists of standing dead trees, snags and lying deadwood (Pasher and King 2009; Stokland et al. 2012; Jonsson et al. 2016) in forest. DW are one of the main components of forest ecosystems that affects

biodiversity, long-term forest productivity, carbon sequestration, and the structure and dynamics of riparian ecosystems (Lindenmayer and Franklin 2002; Kennedy et al. 2008). It provides essential elements to conserve wildlife and support ecological processes (Bluhm et al. 2015; Gundersen et al. 2017). DW provide habitat and nest to numerous animal and bird communities and can increase macronutrients of soil such as nitrogen (N), phosphorus (P), potassium (K), Calcium (Ca) and Magnesium (Mg) (Kopra and James 2005; Mäkipää et al. 2017). Nowadays, deadwoods are under varies researches bring about number of different issues including nature conservation, forest certification, sustainable forest management, carbon sequestration (Rondeux and Sanchez 2009). The relationship between diversity and decomposition stage showed the impact of DW on soil transition zone (Sefidi and Etemad 2015). Nowadays, timber and fuel wood production and post-disturbance salvage logging are main factors that create DW in natural forests (Seiboldi and Thorn 2018). The basic parameters include tree species, dimensions (diameter, height or length), and decay stage are developed to assessment of DW in forest stand (Rondeux and Sanchez 2009). Tree species is determining the decay rate of deadwood (Rondeux and Sanchez 2009; Blaser et al. 2013; Jonsson et al. 2016) and the habitat qualities for microorganisms (Lassauce et al. 2011; Seibold et al. 2015). Dimensions are using in order to calculate approximate volume of deadwood (Rosenvald et al. 2018), distinguish between individual types of deadwood coarse (Padari et al. 2009). In Decomposition process organic material broken down into simpler forms of matter (Lassauce et al. 2011) and can be occurred by physical and chemical processes (Barrette et al. 2014).

Ranius et al. (2005), Jonsson et al. (2016) indicated that the amount of woody debris depends on tree species, site index and distance to logging roads. Moreover, decaying logs retain moisture and nutrients that aid in new plant growth (Ferreira and Laurance1997; Santiago and Rodewald 2012; Rajala et al. 2012). Ranius et al. (2014), Herrero et al. (2016) presented the amounts of DW in managed forests are much lower than unmanaged forest. In managed forests, the quantity of DW, play important crucial in rate of biodiversity, while its reduced by forest management operation (Bölöni et al. 2017), as result of (Paletto et al. 2014) forest management affect the quantitative and qualitative deadwood and the road consecution is one of main element in forest management (Mostafa et al. 2017), although topographic factors are important in distribution woody debris in the forest (Sefidi et al. 2015; Johansson et al. 2017).

Hodge and Peterken (1998), recommended to leave 40-100 m3ha-1of deadwood with diameter ≥20 cm in high productive forests during the time and at least 20-40 m3ha-1of deadwood with diameter ≥20 cm in low productive forests. In a managed semi-natural broad-leaved high forest of Britain, 50-100 years old, it was recommended leaving 4-12 m3 ha-1of fallen wood and 20-31 m3 ha-1of all types of deadwood (Kirby et al. 1991; Hodege and Peterken 1998).

This study aims to investigate the volume and level of DW decay at different distances from forest roads. The two of distance units are located in high productivity and topography and the other is in low productivity and topography area. The findings of this research could improve DW management practices in Hyrcanian forests.

2 Materials and methods

2.1 Study area

District one in ShastKalate forests, with an area of 1713 hectares, is located in Golestan province (36˚43´27˝ to 36˚48´6˝ N and 54˚21´26˝ to 54˚24´57˝ E). The forest is mixed deciduous which has been established on brown forest soil with mostly sandstone as bedrock, Clay-loam-silty texture, and worn stones are spread around the region. The elevation ranges between 100 and 1000 m. The mean forest stock growth in the study area is 247 m3 ha-1. The climate of the region is Mediterranean, warm and humid, with mean annual precipitation of about 562 mm and the lowest amount in July and August.

The unit I with high productivity and hard topography is located in a part of the forest that has a steep slope with trees with a high volume of wood, this unit is currently underutilization, unit Ⅱ, with low productivity and gentle topography had been utilized in the past and the forest is younger.

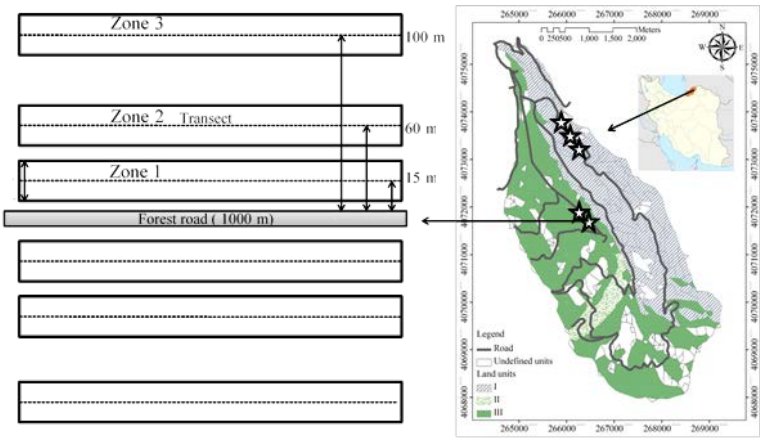


Figure 1. Sampling design in land units of study area

2.3 Sampling design and field survey

Five roads were randomly selected in two land units in an uneven- aged deciduous natural forest with similar site qualities. Land unit maps were investigated to evaluate variation of effective factors such as geology, slope direction, slope gradient and stock growth in DW distribution in the study area (Table 1). Transects were established parallel with the roads at three zones on each side of the roads with 15 m, 60 m and 100 m distances from the edge of the roads (in cut slope and fill slope side). Width and length of the strips were 20 meters and 1000 meter, respectively (Figure1). Data tree species, dimensions (diameter, height or length), and decay stage were collected in strip plots on transects. All DWs were classified according to the observed level of decay: class A is trees with healthy trunk and without longitudinal fracture with crown decay, class B consists of trees that have lost approximately 50% of branches with diameters less than 10 cm, class C is consists of trees that have lost approximately 50% of branches with diameters more than 10 cm, class D consists of trees that only their main trunk remains, and class E includes trees with broken trunk beneath their crown (Sefidi and Eetemad 2009),(Figure 2). The diameter and height of DWs were measured using a caliper, taped meter and clinometer.

Table 1. Features of land units in study area

Land Units	Geology	Slope direction	Slope Steepness (%)	Stock growth (m^3 ha^{-1})
I	Conglomerate sand stone	West	10-25	>300
II	current age stream deposits	North	0-10	100-200

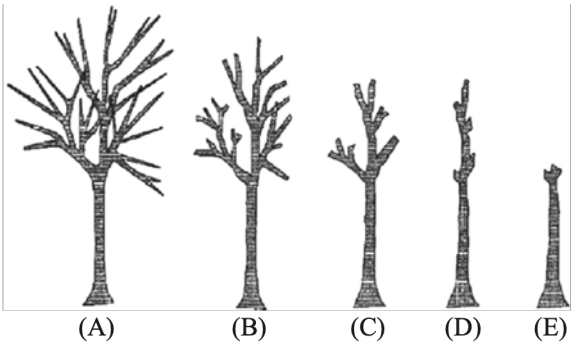


Figure 2. Tree appearances in different levels of decay

2.4 Statistical analysis

Data were statistically analyzed using the GLM procedure in SAS v 9.2 software. SNK test (Student Newman Keuls) at a probability level of 0.05 was used to compare means of DW volume and their level of decay for different species at studied distances from the roads.

3. Results

3.1 Distribution of DW volume for different species in land units

Results of this study in unit I show that higher volume of standing dead trees belong to Carpinus betulus L. in the first and second zone ($P < 0.05$). In the third zone, a higher volume of standing dead trees was recorded for Parrotia persica C.A.M ($P < 0.05$; Figure 3 Table, 2). Besides, no significant difference was found among the different species in terms of felled dead limbs and logs volume in the first zone ($P > 0.05$), whereas in the second and the third zone higher volume of felled dead limbs and logs significantly belonged to Carpinus betulus L. and Parrotia persica C.A.M, respectively ($P<0.05$; Figure 4, Table,3). The result of ANOVA for the effects of decay status and species on volume of DW is shown in table 4.

Table 2. Distribution of the volume of standing dead trees Carpinus betulus L in unit I

Distances (m) / Volume (m^3 ha^{-1})	Species	20	60	100
Standing dead trees	*Carpinusbetulus L.*	4.51^b	15.13^a	6.13^a
	Total	4.51	15.13	6.13

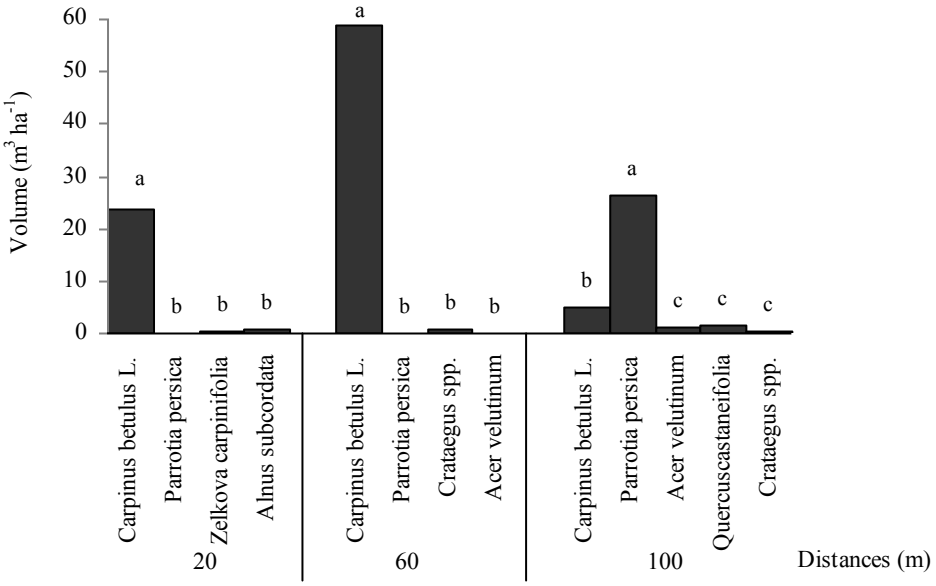


Figure 3. Distribution of the volume of standing dead trees for different species in land unit I

Table 3. Distribution of the volume of standing dead trees and felled dead limbs and logs for different species in unit II

Distances (m) / Volume (m^3 ha^{-1})	Species	20	60	100
Standing dead trees	*Parrotiapersica C.A.M*	4.82^{a}	8.12^{b}	1.39^{b}
	Carpinusbetulus L.	0^{b}	15.11^{a}	7.13^{a}
	Total	4.82	23.23	8.52
Felled dead limbs and logs	*Parrotiapersica C.A.M*	0.85^{a}	0.09^{a}	0.37^{a}
	Acer velutinumBoiss.	0^{a}	0.08^{a}	0^{a}
	Total	0.85	0.17	0.37

Table 4. The result of ANOVA for the effects of decay status and species on volume of DW

DW	Species	Zone	DF	SS	Mean Square	F Value	Pr > F
Standing dead trees	*Carpinus betulus L*	1,3	6	748.71	124.78	5.27	0.03
	Parrotia persica C.A.M	3	2	761.64	380.82	8.79	0.01
Felled dead limbs and logs	*Carpinus betulus L.* and *Parrotia persica*	2,3	6	12.72	2.12	7.12	0.01
	All species	1	2	41.43	20.71	2.86	0.06

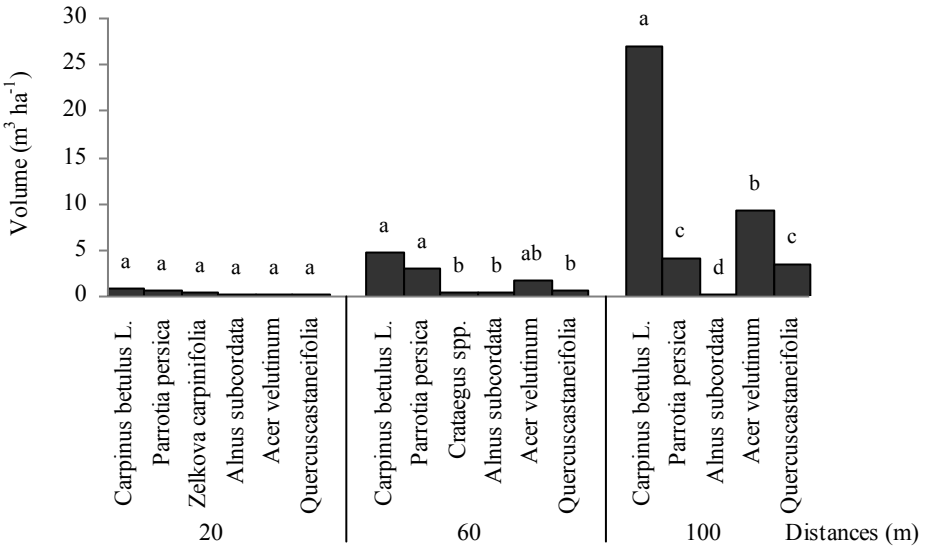


Figure 4. Distribution of felled dead limbs and logs volume for different species in land unit II

3.2 Distribution of DW volume in different levels of decay in land units

In the first zone of land unit I higher volume of standing dead trees belongs to class B. In the first zone of land unit II, higher volume of standing dead trees belongs to class A. In the second zone the higher volume of dead trees was categorized in class A and B, and in the third zone higher volume was recorded in class B (Figure 5). In the second zone the higher volume of dead trees was in class A and C, and in the third zone higher volume was recorded in class A (Figure 6).

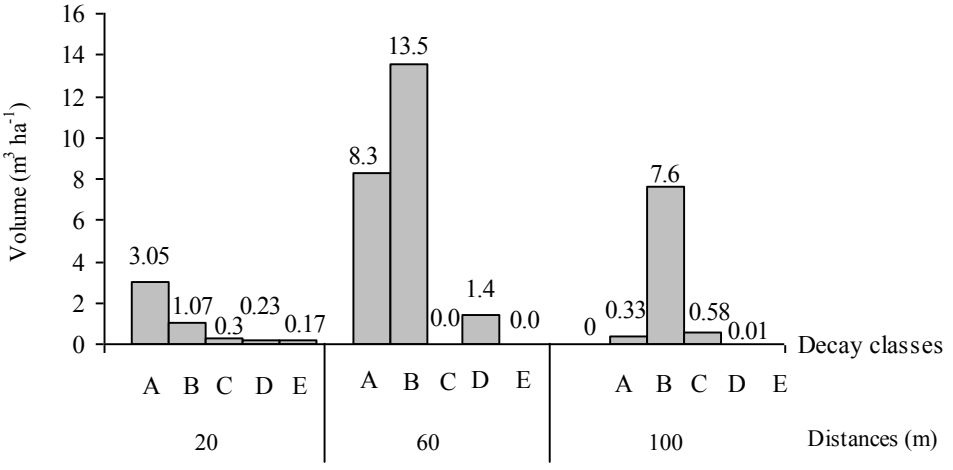


Figure 5. Distribution of standing dead trees volume in different levels of decay in land unit II

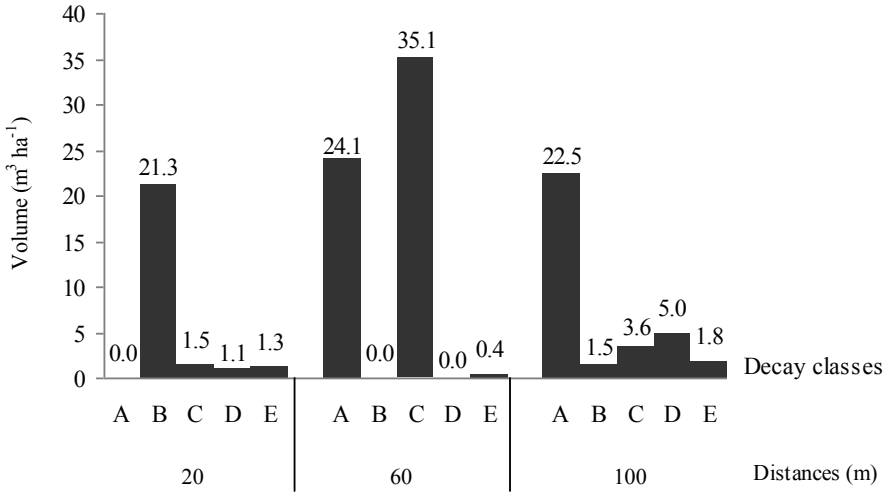
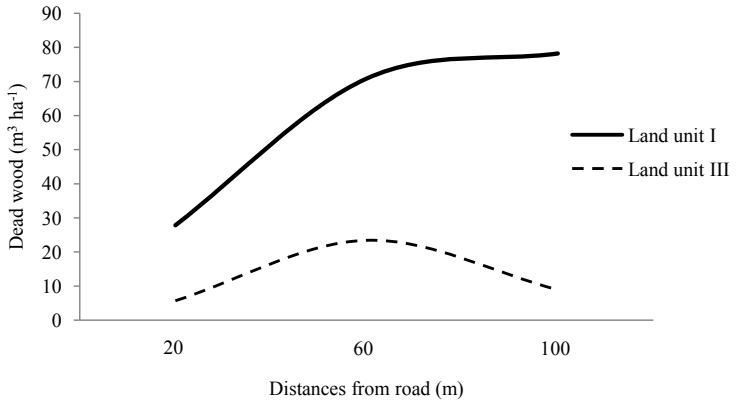


Figure 6. Distribution of standing dead trees volume in different levels of decay in land unit

3.3 Distribution of DW volume at different distances from road edge

In the first zone of land unit I, the total volume of DW was the lowest at the road edge, with approximately 28 m3 ha-1. There was an obvious change in total volume of DW with distance. DW volume increased to about 71 m3 ha-1 in the second zone, but it did not change significantly in the third zone (78 m3 ha-1). This pattern was also detected in different zones of unit II except the third zone, in which DW volume declined (Figure 7).



4 Discussion

Several researches have documented the important of DW in forest ecosystem (Rondeux and Sanchez 2009; Bluhm et al. 2015; Gundersen et al. 2018; Seiboldi and Thorn. 2018). The result of this study suggests that topography condition affects the volume of DW. Which is in line with what has been stated by Kennedy et al. (2008), Sefidi et al. (2015) also showed the complex relationship between topographic gradient and coarse woody debris in the forest. However, this result is not in agreement with the results of Herault et al. (2010) that found local topography had no effect on wood decay rates. Moreover, in this research it is also revealed that standing dead trees decomposed faster than downed dead trees. Bowering et al. (2006) in a study in an area near Williams Lake, British Columbia found fewer dead standing trees in the nearest distance of the road edge. Laurance et al. (2009) reported that narrow (<20m width) clearing of the road is less harmful for edge desiccation stress than wider clearings.

Our results confirmed that DW volume in west and in steeper slope was higher than north and gentle slope. The findings of the current study show that DW volume increased in the second zone from the road due to interior forest conditions and selective silvicultural operations, which are also more likely to achievement of (Travaglini et al. 2007; Jonsson et al. 2010; Lohmus et al. 2013), DW amount can be depending on harvesting intensities and silvicultural systems (Rosenvald et al. 2018).
Selective logging creates gaps in the canopy cover and boosts penetration of solar radiation in the stand, and consequently increases soil temperature (Rock et al. 2008), These conditions may increase wood decay volume in the second zone and this is in accordance with the results of Carlson et al. (2016) that estimated the volume of DW in selective system twice higher then unlogged forest.
In this study, the DW volume in the second and third zone is about 71 m3 ha-1and 78 m3 ha-1, respectively. Christensen et al. (2005) reported that the highest abundance of dead trees is in the mixed beech stands of Montane forests with severe protection for more than 50 years, whereas lower values are observed in stands under protection for a shorter time while, without silvicultural operation the increase dead wood volumes might be happen directly (Bauhus et al. 2009).
Retention trees, DW, and woodland key habitats contain many particular species. Tree species composition and density affect the DW quantitative and qualitative properties which in turn are correlated with the number of insect species (Norén et al. 2002; Johansson et al. 2013). Many species depend on standing dead trees for persistence. Moreover, it was detected that snag density is lower in areas of intensive timber harvest and increased human access (Wisdom and Bate 2008). A key element of forest management is the maintenance of sufficient densities of snags (standing dead trees) to support associated wildlife. Management factors that influence snag densities, however, are numerous and complex (Bate et al. 2007). Damage to cambium, the growth layer of trees that lies between the bark and the wood of the trunk which is most active in a woody plant, can weaken or kill a tree which may consequently decay the wood since new phloem and xylem will not be produced. Common forms of damage are caused in the form of wounds by road construction and human activities, storm, freezing of soil and compaction (Butler et al. 2005). Light availability, soil fertility and creation of heat islands around the corridor may cause DW volume decrease at the edge of road. This is evident through the many processes within a forest ecosystem that are influenced by the quality and quantity of DWs. Specifically, studies on snags evaluate the DW quantity and nutrient content to determine energy fluxes and productivity. This is largely because DW, and its subsequent decomposition, strongly influence primary production and regulates energy flow and nutrient cycling in forest ecosystems. Thus, standing and felled DWs is a major participant in the transfer of energy and nutrients in the forest ecosystem. The proportion of snags and fallen DWs increased with stand age.

5. Conclusions

The results of this study suggests that light availability, establishing a young stand, soil fertility and creating a suitable microclimate around the road corridor decrease the amount of dead wood at the edge of roads. Besides, an increase in DW volume in forest interior may be due to the intensity of competition and/or pest and diseases. Plan to allow a variety of trees to age and die naturally in order to provide a continuous source of replacement snags and nurse logs. This study also shows that the number of DWs increased with increasing distance from the roads. However, this result is not able to represent the effect of the road on DW abundance completely, thus more studies would be required to investigate the relationship between roads and DW abundance

6. References

Akay, A. E., Wing, M.G., Sivrikaya, F., and Sakar, D. (2012), "A GIS-based decision support system for determining the shortest and safest route to forest fires: a case study in Mediterranean Region of Turkey", Environ Monit Assess, 184:1391–1407.
Barrette, J. and Pothier, D., Duchesne, I. (2014), "Lumber and wood chips properties of dead and sound black spruce trees grown in the boreal forest of Canada," Inte J Forest Research, 88: 108–120.
Bate, L.J., Wisdom, M.J. and Wales, B.C. (2007), "Snag densities in relation to human access and associated management factors in forests of Northeastern Oregon, USA," Landscape and Urban Planning, 80 (3): 278–291.
Bauhus, J., Puettmann, K. and Messier, C. (2009), "Silviculture for old-growth attributes," For Ecol Manage, 258: 525–537.

Beyer, H.L., Ung, R., Murray, D.L. and Fortin, M.J (2013), "Functional responses, seasonal variation and thresholds in behavioral responses of moose to road density," J Applied Ecol, 50: 286–294.
Bil, M., Vodak, R., Kubecek, J., Bilova, M. and Sedonik, J. (2015), "Evaluating road network damage caused by natural disasters in the Czech Republic between 1997 and 2010," Trans Res Part A, 80: 90–103.
Blaser, S., Prati, D., Senn-Irlet, B. and Fischer, M. (2013), "Effects of forest management on the diversity of deadwood-inhabiting fungi in Central European forests," For Ecol Manage, 304: 42–48.
Bluhm, C., Scheu, S., and Maraun, M. (2015), "Orbited mite communities on the bark of dead wood vary with log type, surrounding forest and regional factors," Applied Soil Eco, 89:102–112.
Bölöni, J., Ódor, P., Ádám, R., Keeton, W., Aszalós, R. (2017), "Quantity and dynamics of dead wood in managed and unmanaged dry-mesic oak forests in the Hungarian Carpathians," For Eco Manage, 399: 120–131.
Bowering, M., Lemay, V. and Marshall, P. (2006), "Effects of forest roads on the growth of adjacent lodgepole pine trees," Can J Forest Res, 36(4)**:** 919-929.
Butler, B.W., Webb, B.W., Jimenez, D., Reardon, J.A. and Jones, J.L. (2005), "Thermally induced bark swelling in four North American tree species," Can J Forest Res, 35(2): 452-460.
Butler, R., Angelstam, P., Ekelund, P. and Schlaepfer, R. (2004), "Dead wood threshold values for the three-toed woodpecker presence in boreal and sub-Alpine forest," Biological Conservation, 119: 305–318
Carlson, B., Koerner, S., Medjibe, V., White, L. and Poulsen, J.R. (2016), "Deadwood stocks increase with selective logging and large tree frequency in Gabon. https:// doi: 10.1111/gcb.13453.
Christensen, M., Hahn, K., Mountford, E.P., Ódor, P., Standovár, T., Rozenbergar, D., Diaci, J., Wijdeven, S., Meyer, P., Winter, S. and Vrska T. (2005), "Dead wood in European beech (*Fagus sylvatica*) forest reserves," For Eco Manage, 210: 267-282.
Chunyu, Z. and Xiuhai, Z. (2007), "Soil properties in forest gaps and under canopy in broad-leaved Pinuskoraiensis forests in Changbai Mountainous Region, China," Frontiers of Forestry in China, 2: 60-65.
Coban, H. O. and Eker. M. (2010), "Analysis of forest road network conditions before and after forest fire," FORMEC 2010 Forest engineering: Meeting the Needs of the Society and the Environment July 11 – 14, 2010, Padova – Italy11p.
Delgado, J.D., Arevalo, J.R. and Fernandez-Palacios, J.M. (2007), "Road Edge Effect on the Abundance of the Lizard Gallotia galloti (Sauria: Lacertidae) in Two Canary Islands Forests," Biodiversity and Conservation, 16: 2949–2963.
Demir, M. (2007), "Impacts, Management and Functional Planning Criterion of Forest Road Network System in Turkey," Transportation Research. A-Pol, 41: 56–68.
Dupont, S. and Brunet, Y. (2008), "Impact of forest edge shape on tree stability: a large-eddy simulation study," Forestry Inte J For Res. 81: 299-316.
Ferreira, L.V., Laurance, W.F. (1997), "Effects of Forest Fragmentation on Mortality and Damage of Selected Trees in Central Amazonia," Conservation Biology. 11: 797-801.
Gundersen, V., Stange, E. E., Kaltenborn, B.P. and Vistad, O.I. (2018), "Public visual preferences for dead wood in natural boreal forests: The effects of added information," Landscape and Urban Planning, 15:12-24.
Herault, B., Beauchene, J., Muller, F., Wagner, F., Baraloto, C., Blanc, L., and Martin, J.M. (2010), "Modeling decay rates of dead wood in a neotropical forest. Oecologia," 164: 243-251.
Herrero, C., Monleon, V.J., Gómez, N. and Bravo, F. (2016), "Distribution of dead wood volume and mass in Mediterranean *Fagus sylvatica* L. forests in Northern Iberian Peninsula,"Implications for field sampling inventory. Forest Syst, 25(3): e069.
Hodge, S .J. and Peterken, G. F. (1998), "Deadwood in British forests: priorities and a strategy," 71(2): 99–112.
Hui, C., Shuang-cheng, L. and Yi-li, Z. (2003), "Impact of Road Construction on Vegetation alongside Qinghal-Xizang Highway and Railway," Chinese Geographical Science, 13 (4): 340-346.
Johansson, T., Gibbb, H., Hjältén, J. and Dynesius M, (2017), "Soil humidity, potential solar radiation and altitude affect boreal beetle assemblages in dead wood," Biological Conservation, 209: 107-118.
Johansson, T., Hjaltén, J., Jong, J. and Stedingk H. (2013), "Environmental considerations from legislation and certification in managed forest stands: A review of their importance for biodiversity," For Eco Manage303: 98–112.
Jonsson, B.G., Ekström, M., Esseen, P.A., Grafström, A., Ståhl, G. and Westerlund, B. (2016) Dead wood availability in managed Swedish forests – Policy outcomes and implications for biodiversity," For Ecol Manage, 376(15): 174-182.

Jonsson, M., Ranius, T., Ekvall, H. and Bostedt, G. (2010), "Cost-effectiveness of silvicultural measures to increase substrate availability for wood-dwelling. species: a comparison among boreal tree species," Scan J For Res, 132: 335-349.
Kennedy, R. S., Spies, T. A. and Gregory, M. J. (2008), "Relationships of dead wood patterns with biophysical characteristics and ownership according to scale in Coastal Oregon, USA," Land Ecol, 23:55–68.
Kirby, K. J., Webster, S.D. and Antczak, A. (1991), "Effects of forest management on stand structure and the quantity of fallen dead wood: some British and Polish examples," For Ecol Manage. 43: 167-174.
Kopra, K., Fyles, J. (2005), "Woody Debris and Nutrient Cycling: should we care???," SFMN Research Note Series, 8:1-4.
Larrieu, L., Cabanettes, A. and Delarue, A. (2013), "Impact of silviculture on dead wood and on the distribution and frequency of tree microhabitats in montane beech-fir forests of the Pyrenees," Eur J For Res, 131:773–786.
Lassauce, A., Paillet, Y., Jactel, H. and Bouget, C. (2011), "Deadwood as a surrogate for forest biodiversity: Meta- analysis of correlations between deadwood volume and species richness of saproxylic organisms," Ecol. Ind. 11: 1027–1039.
Laurance, W. F., Goosem, M. and Laurance, S. G. (2009), "Impacts of roads and linear clearing son tropical forests," Trends Ecol Evol. 24: 659-669.
Lin, N., Bartsch, N. and Vor, T. (2014), "Long-term effects of gap creation and liming on understory vegetation with a focus on tree regeneration in a European beech (Fagussylvatica L.) forest," Annals For Res, 57(2): 233-246.
Lindenmayer, D. B. and Franklin J.F. (2002), "Conserving forest biodiversity: a comprehensive multi scaled approach," Island Press, Washington, DC, 352pp.
Lohmus, A., Kraut, A. and Rosenvald, R. (2013), "Dead wood in clear cuts of semi-natural forests in Estonia: site type variation, degradation, and the influences of tree retention and slash harvest," Eur J For Res, 132:335–349.
Lotfalian M. and Parsakhoo A. (2012), "Forest Roads Network Planning. Aiizh Press,"Tehran, 153 pp. (In Persian).
Lotfalian, M., Yousefi Babadi, T. and Akbari, H. (2019), "Impacts of soil stabilization treatments on reducing soil loss and runoff in cutslope of forest roads in Hyrcanian forests,"Catena, (172): 158–162.
Mäkipää, R., Rajala, T., Schigel, D., Rinne, K. T., Pennanen, T., Abrego, N. and Ovaskainen, O. (2017), "Interactions between soil- and dead wood-inhabiting fungal communities during the decay of Norway spruce logs," The ISME Journal, 11: 1964–1974.
Mathisen, K. M., Wójcicki, A. and Borowski, Z. (2018), "Effects of forest roads on oak trees via cervid habitat use and browsing," For Ecol Manage, 424: 378–386.
Mostafa, M., Shataee Joybari, Sh., Lotfalian, M. and Sadoddin, A. (2017), "Watershed road network analysis with an emphasis on firefighting management," Journal of Environmental Engineering and Landscape Management, 25(4): 342–353.
Norén, M., Nitare, J., Larsson, A., Hultgren, B. and Bergengren, I. (2002), "Handbok för inventorying av nyckelbiotoper. Skogsstyrelsen," Jönköping,108pp.
Padari, A., Muiste, P., Mitt, R. and Pärn. L. (2009), "Estimation of Estonian wood fuel resources," Baltic Forest, 15: 77–85.
Paletto, A., De Meo, I., Cantiani, P., and Feretti, F. (2014), "Effects of forest management on the amount of DW in Mediterranean oak ecosystems," Ann For Sci, 71: 791–800.
Pasher, J., King, D. J. (2009), "Mapping dead wood distribution in a temperate hardwood forest using high resolution airborne imagery," For Ecol Manage, 258: 1536–1548.
Potocnik, I., Pentek, T., Pičman, D. Papa, I. and Poje, A. (2008), "Filling in the clearance of a forest road cross-section in Beech forest," Croat J For Eng, 29: 53-62.
Rajala, T., Tuomivirta, T., Pennanen, T., and Mäkipää, R. (2015), "Habitat models of wood-inhabiting fungi along a decay gradient of Norway spruce logs," Fungal Ecol, 18: 48–55.
Ranius, T., Caruso, A., Jonsell, M., Juutinen, A., Thor, G., and Rudolphi, J. (2014), "Dead wood creation to compensate for habitat loss from intensive forestry," Biological Conservation, 169: 277–284.
Ranius, T., Ekvall, H., Jonsson, M. and Bostedt, G. (2005), "Cost-efficiency of measures to increase the amount of coarse woody debris in managed Norway spruce forests," For Ecol Management, 206: 119–133.
Rock, J., Badeck, F. W. and Harmon, M. E. (2008), "Estimating decomposition rate constants for European tree species from literature sources," Euro J Fore Res, 127:301–313.

Rondeux, J. and Sanchez C. (2009), "Review of indicators and field methods for monitoring biodiversity within national forest inventories. Core variable: Deadwood," Environmental Environ Monit Assess., (164)1-4: 617-630.
Rosenvalda, R., Tullusa, H. and Lõhmusb, A. (2018), "Is shelter wood harvesting preferable over clear-cutting for sustaining deadwood pools? The case of Estonian conifer forests," For Ecol Manage, 429: 375–383.
Sefidi, K. and Etemad, V. (2009), "Standing dead trees (snags) component of the close to nature silviculture in a mixed beech forest in north of Iran," Pajouhesh and Sazandegi, 81: 50-58. (In Persian).
Sefidi, K. and Etemadm V. (2015), "Dead wood characteristics influencing macro fungi species abundance and diversity in Caspian natural beech (Fagus orientalis Lipsky) forests," Forest Syst, 24(2): eSC03.
Seibold, S. and Thorn, S. (2018), "The Importance of Dead-Wood Amount for Saproxylic Insects and How It Interacts with Dead-Wood Diversity and Other Habitat Factors. Saproxylic Insects," 1: 607-637.
Smit, I. P. J. and Asner, G. P. (2012), "Roads increase woody cover under varying geological, rainfall and fire regimes in African savanna," J Arid Enviro, 80:74-80.
Stokland, J., Siitonen, J. and Jonsson, B. G. (2012), "Biodiversity in Dead Wood," Cambridge University Press, Cambridge, UK, 495pp.
Tampekis S, Sakellariou S, Samara F, Sfougaris A, Jaeger D, Christopoulou O. (2015), "Mapping the optimal forest road network based on the multicriteria evaluation technique: the case study of Mediterranean Island of Thassos in Greece," Environ Monit Assess, 187: 687.
Travaglini, D., Barbati, A., Chirici, G., Lombardi, F., Marchetti, M., and Corona, P. (2007), "Forest BIOTA data on dead wood monitoring in Europe," Plant Biosyst, 141:222–230.
Wisdom, M. J., and Bate, L. J. (2008), "Snag density varies with intensity of timber harvest and human access," Fort Ecol Manage, 255(7): 2085-2093.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

A QGIS PLUGIN FOR OPTIMIZED CABLE ROAD LAYOUT PLANNING

Leo Bont [1], Patricia Moll [2], Laura Ramstein [1], Hans Rudolf Heinimann [3]
[1] WSL, Birmensdorf, Switzerland; [2] Patricia Moll, Zurich, Switzerland, [3] ETH, Zurich, Switzerland
leo.bont@wsl.ch

Abstract: *Cable-based technologies have been a backbone for harvesting on steep slopes. The planning of a cable road is a complex task. It essentially comprises the definition of the start and end points of a cable road, as well as the intermediate supports. It must be ensured that the permissible forces (in particular skyline tensile forces) are not exceeded, that there is a sufficient clearance between the load path and the ground, that suitable anchor trees are found and that at the same time the number of intermediate supports is minimised as far as possible. On the other hand, for ergonomic and silvicultural reasons (work safety, damages to the forest), the suspension rope should be as high as possible. In practice, the search for a solution is often iterative; especially with long lines, several attempts may be necessary until a good line is found. The presented QGIS plugin searches automatically for the optimal cable road layout, so the planning process can be considerably simplified and obtained solutions are more cost-efficient.*

The plugin is designed for Central European conditions and assumes a standing skyline (fixed anchored skyline at both ends). For the calculation of the mechanical properties of the skyline a close to catenary method is used (Zweifel 1960). When testing the feasibility of the cable line, care is taken that 1) the maximum permissible stresses in the skyline are not exceeded, 2) there is a minimum distance between the load path and the ground and 3) when using a gravitational system, there is a minimum inclination in the load path. The newly developed method calculates the load path curve and the forces occurring in it more accurately than other tools available on the market.

We further present a method to identify potential support and anchor trees directly from remote sensing data, which is as well integrated in the plugin. This ensures that there are effectively trees at the proposed intermediate positions and that the solution can be implemented in practice. Results of tests which will be carried out in forest enterprises in Austria and Switzerland will also be discussed.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October, 2019 - Sopron, Hungary

COPPICE AFTER 3 DIFFERENT CUTTING SYSTEMS: GROWTH CAPACITY AND MORTALITY

Carolina Lombardini
CNR IVALSA, Sesto Fiorentino, Italy
lombardini@ivalsa.cnr.it

Raffaele Spinelli
CNR IVALSA, Sesto Fiorentino, Italy
spinelli@ivalsa.cnr.it

Abstract: *In coppice forests the means to modernize its management lie in mechanized harvesting, so that it can grow along with the dynamic new bioeconomy. Anyway foresters are concerned that mechanized cutting may result in higher stump damage levels, which may cause increased mortality and lower growth rates.*
Nevertheless, stumps cut with mechanized systems do not cause higher mortality rates than do stumps manually cut using chainsaw.
The present study want to compare manual and mechanized cutting in terms of cut quality, stump damage levels, stump mortality, re-sprouting vigor and shoot growth. This study was conducted in a coppice stand placed in central Italy, with typical Mediterranean coppice species. The coppice was cut using 3 different systems: was cut manually with a chainsaw, than mechanically with a disk saw and a shear. About 350 stumps were selected, tagged and monitored over the first growing season after the cutting operations. The characteristics of stumps size, cutting level, cutting damage were recorded right after cutting and then at the end of the first growing season other characteristics have been determined. The same parameters have been recorded at the end of the second and the third growing season. The experiment is a long-period study, so that it can show the trend of the damages, mortality, re-sprouting vigor also in the time. Moreover samples were collected in order to determine the content of C, N, starch, soluble sugar and C/N ratio. The conclusion is that while it may result in higher stump damage levels, mechanized cutting does not seem to have any effects on coppice regeneration and growth. The experiment will be continued to know more information and to have more confirmation.

Abstract: Coppice; Mortality; Regeneration; Felling

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

A COMPARATIVE LIFE CYCLE ASSESSMENT (LCA) OF FOSSIL OIL AND A NEW INNOVATIVE SOLID BIOMASS CHAINS FOR SMALL-SCALE SPACE HEATING SYSTEM

Raghu KC*, Jarno Föhr, Tapio Ranta
Laboratory of Bioenergy
School of Energy system
Lappeenranta-Lahti University of Technology LUT
Lönnrotinkatu 7, 50100 Mikkeli
Raghu.kc@lut.fi, tel: +358 50 4647457

Abstract: *Decentralization of renewable energy resource is one of the keys as the quest for a carbon-neutral energy system intensifies. However, one of the major obstacles is to eliminate a small-sized oil-fired heating system in rural Finland. Fortunately, Finland is rich in biomass resource, which has the potential to replace oil in the heating sector. However, one of the obstacles for the small and decentralized energy system is logistics. In this research, a potential and innovative solution for underlying problem were investigated. The purpose of this research was to assess the environmental impact of alternative energy system where biomass (pellets and chips) replace the light fuel oil for space heating purpose. According to the results, converting from light fuel oil to wood chips, the GHG emissions would be reduced by about 96%. However, if wood pellets were to replace the light fuel oil, the GHG emission reduction would be about 89%. In addition, use of biomass instead of imported fossil fuel, cities, and small towns have the possibility to be energy independent, at least in case of heating sector.*

Keywords: Biomass, Heating, Oil, Logistics, LCA, Environment

1. Introduction

The European Union (EU) has mandated to increase the share of renewable energy from 20% to 27% by 2030 and similarly Finnish national energy and climate strategy has stated that that share of renewable energy in final energy consumption to go beyond 50% by 2030 and 80% by 2050. With that spirit, many cities and towns in Finland have been proactive to decarbonize their energy system (Karhunen, Laihanen, Föhr and Ranta, 2019).

Due to the cold climate and long winter, heat demand is high in Finland. In 2017, the consumption of energy in space heating was approximately 80 TWh, which is about 26% of the total energy consumption. (Statistics Finland, 2017). Consequently, space heating is also one of the major GHG emission contributors. On the other hand, heating constituted about 66% of the total residential energy demand in 2013, which was fulfilled by district heat (33%), wood (26%) and electricity (24%). The share of oil for the heating purpose was about 8%. The light fuel oil (LFO) is commonly used in single-family dwellings which apartment buildings and row-houses are mostly heated by district heating and electricity. According to Hast et al., there are about 200,000 houses in Finland that use oil for heating and those consume about 460m liters (l) of oil annually (Hast, Ekholm and Syri 2016).

South-Savo region is one of many regions in Finland that has been proactive on decarbonizing its energy system and eliminating oil-fired heating system has been one of the focuses. According to Karhunen et al., there are about 9,000 residences and buildings that use LFO for heating purposes which consume about 620 GWh of LFO. The majority of the LFO consumers in this region are detached and semi-detached houses (75%). The dwellings in South-Savo with oil-fired heating systems are illustrated in Figure 1. The figure

suggests that the dwellings that use oil for heating are sparsely scattered in the region and decentralized solution such as biomass could be the potential replacement.

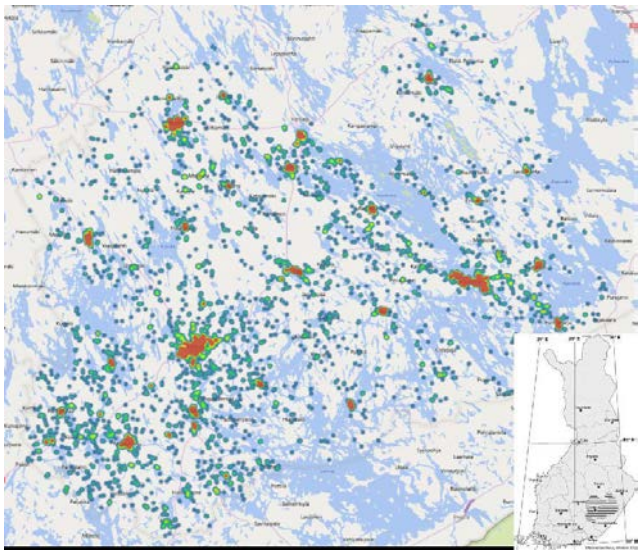


Figure 1: Dwellings with the oil-fired heating system in South-Savo region of Finland (Karhunen, Laihanen, Föhr and Ranta, 2019)

The purpose of this study is to assess new and innovative biomass (wood chips and pellets) delivery solution to a small-sized biomass heat plants and analyze the potential environmental benefits as compared to LFO-fired heating system. The focus is on a patented technology where wood chips are blown directly from the delivery container to storage silos. The environmental performance of various energy system for a commercial building space heating that consumes 80,000 l of LFO in a year is considered as a business as usual (BAU) scenario. The building is assumed to be located in the vicinity of Mikkeli city. For the comparison, wood pellets and wood chips from different locations: Hirvensalmi (40km), Juva (75km) and Savonlinna (140km).

1.1 Blowing containers

A container truck of a size of 40m^3 with a blower attached can blow through the pipe up to 1.2 bulk-m^3 of wood chips in a minute and up to 40m in distance is patented by Romanet SARL (Romanet SARL, 2019). The technology has been subject of interest in the Finnish energy sector such as Lämpösi Ltd is licensed to use the technology. The reason for such interest is that there are multiple benefits such as the elimination of the need for ground handling of material with front loader, as compared to traditional delivery methods. The blower and container trucks are illustrated in Figure 2. Figure B illustrates blowing the wood chips in action.



(A) (B)

Figure 2: Small-sized blower (A) and container truck with a blower attached at the back (B) (Föhr, KC, Karhunen Laihanen and Ranta, 2019)

1.2 Life Cycle Assessment (LCA)

According to the ISO 14040 (SFS-EN ISO 14040, 2006), LCA is an environmental tool that helps identify the possible environmental impacts of a product or service along with their life cycle phases. It helps in recognizing the improvement possibilities and inform the decision-makers of industries as well as government organizations. The LCA includes four stages, namely,

- Goal and scope definition
- Life cycle inventory (LCI)
- Life cycle impact assessment (LCIA)
- Interpretation

The ISO 14040 framework of LCA is illustrated in Figure 3.

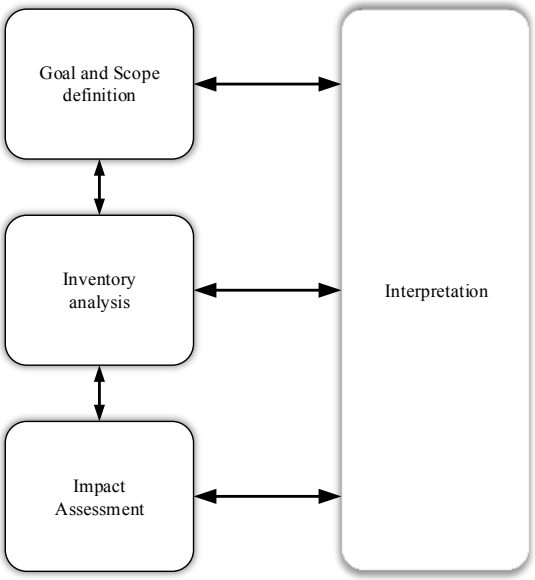


Figure 3: LCA framework (SFS-EN ISO 14040, 2006)

2. Material and Methods

2.1 Goal of the study

The purpose of this study is to analyze the comparative GHG emissions from different energy system for a small-scale industrial space heating. The BAU scenario refers to a heating system fueled by light fuel oil. The fuels in alternative scenarios include wood pellets originated in Vierumäki, Finland and wood chips originated from three different locations; Hirvensalmi, Juva, and Savonlinna. The impact assessment is done based on the CML 2001 (2016) methodology for Global warming potential (GWP) on 100 years of period. The functional units are *t $CO_{2\,eq}$ per year and kg $CO_{2\,eq}$ per MWh.* The assessment includes a typical cradle-to-grave system where fuel acquisition to the final use but excludes the ash management. In addition, infrastructures such as trucks, chippers/crushers, and wheel loaders as well as potential emissions from biomass storages are excluded from the assessment. The logistic scenarios are illustrated in Figure 4.

2.2 Logistics Scenarios

In a BAU scenario, light fuel oil is brought from a refinery located in Porvoo, Finland. For the case of wood pellets, they are produced in Vierumäki, Finland and brought on a truck of 27t of payload with 85% utilization. For the case of wood chips, after harvesting, logs are forwarded to the roadside storage and chipped with mobile drum chipper and blown directly into the container. The container directly takes the biomass to the destination. The capacity of the container is 40m^3 and 27t payload with 40% utilization. For the sensitivity case, logs are taken to the biomass terminal and chipped there directly into the container. It is assumed that the terminal is located 10km away from the heating plant but total distance from forest to heat plant is10km more than the corresponding direct delivery scenarios.

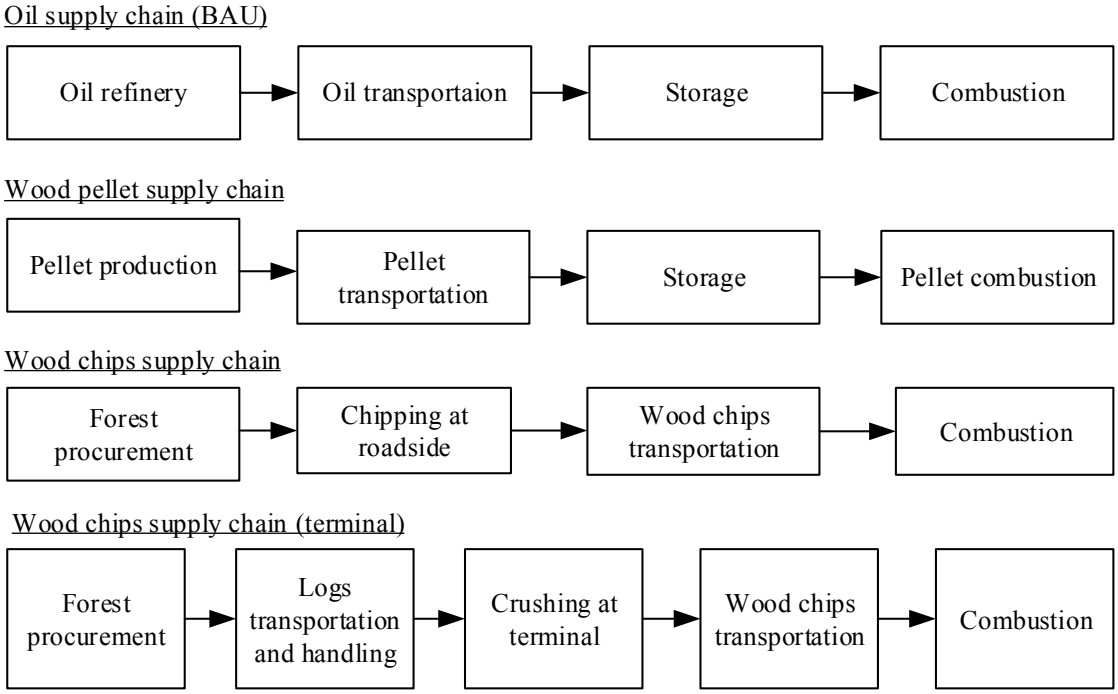


Figure 4: Illustration of supply chain phases for different scenarios including

2.3 LCI

In a BAU scenario where light fuel oil (LFO) is fired for space heating purpose and the idea is to replace with biomass. For the assessment, several assumptions were made regarding the feedstock. Further assumptions and inventory sources are presented in Table 1. The yearly LFO demand is assumed to be 80,000 l/year. The heating value and specific density of LFO are 42.5 MJ/kg and 860g/l, respectively. Furthermore, it is assumed that the heating system works with 90% efficiency.

For the same amount of energy demand, 169 t /year of wood pellets is required with a heating value of wood pellets is assumed to be 4.8 MWh/t. On the other hand, 337 t/year of wood chips is required to fulfill the same amount of energy demand and heating value of wood chips assumed to be 2.86 MWh/t.

Table 1: Unit processes, assumptions made and corresponding references

Unit processes	**Description**	**Reference**
LFO from refinery	Refinery located at Porvoo, Finland	(GaBi databases, 2011)
Heat from LFO	1 MW size	(Jungbluth, 2007)
Oil transportation trucks	EURO 6, 27t payload, 85% utilization	(GaBi databases, 2011)
Diesel from refinery		(GaBi databases, 2011)
Pellet transportation trucks	EURO 6, 27t payload, 85% utilization	(GaBi databases, 2011)
Log transportation trucks	EURO 6, 40t payload, 85% utilization	(GaBi databases, 2011)
Heat production from pellets	300 kW size	(Bauer, 2013a)
Wood pellet production		(Bauer, 2013b)
Wood harvesting	10.4 m^3/h productivity	(Werner, 2012a)
Forwarding	12.3 m^3/h productivity	(Werner, 2012b)
Handling	Wheel loader	(Jäppinen, Korpinen and Ranta, 2013)
Container transportation	EURO 6, 27t payload, 40m^3, 45% chips moisture	(GaBi databases, 2011; Lämpösi 2019)
Chipping	Roadside drum chipper: 475 kW	(Werner, 2013)
Crushing	9.38 kg CO_2/t dry biomass	(Prinz, Väätäinen, Laitila, Sikanen, and Asikainen, 2019)
Heat production from chips	1 MW size	(Bauer, 2007)

3. Results (LCIA)

3.1 Comparative GHG emissions

The comparative GHG emissions from different energy sources are presented in Figure 5. Evidently, heating with light fuel oil (BAU scenario), the GHG emissions is approximately 248 t $CO_{2\ eq.}$ per year or 339 kg $CO_{2\ eq.}$ per MWh. On the other hand, heating with wood chips would cut the GHG emissions down to about 9.5-13.6 t $CO_{2\ eq.}$ per year or 13-18.6 kg $CO_{2\ eq.}$ per MWh, depending on where the chips are originated. However, heating from wood pellets would slightly increase the GHG emissions to about 28 t $CO_{2\ eq.}$ per year or 38 kg $CO_{2\ eq.}$ per MWh.

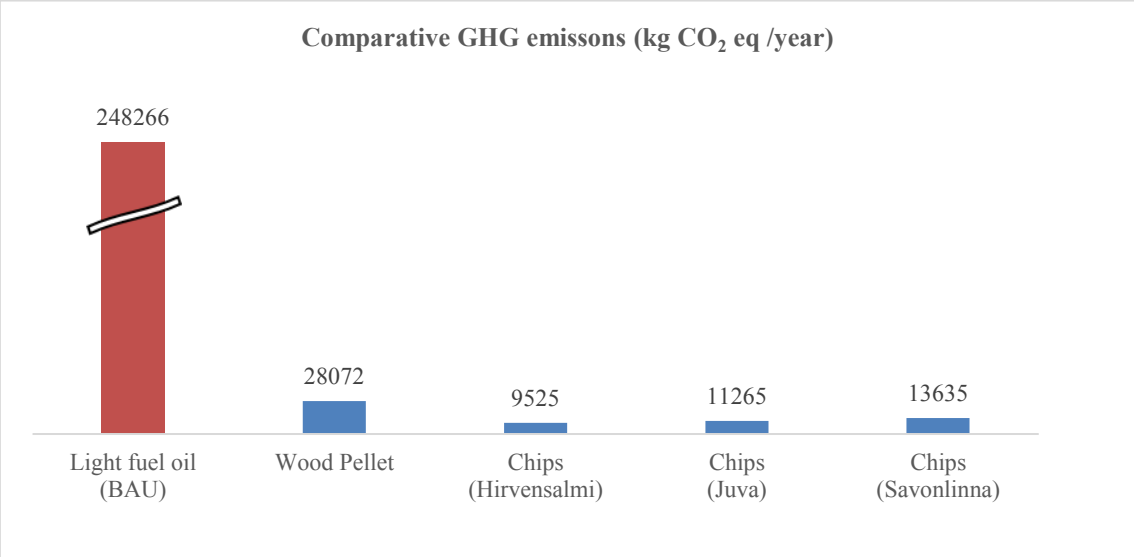


Figure 5: GHG emissions from various energy sources for heating purpose

3.2 GHG emissions contributions

The contributions of various phases of energy systems on GHG emissions are presented in Figure 6. According to the results, wood chipping is the biggest contributor (28-40%) followed by harvesting (17-24%) and combustion (18-25%), depending on the origin of the wood chips. Interestingly, transportation contributes about 10% of the total GHG emission in the case of wood chips originated from Hirvensalmi, whereas, the corresponding contribution raises to 37% in the case of wood chips from Savonlinna. Wood pellet production (includes upstream) contributes most of the GHG emissions (88%) in a pellet-fired heating system. In the case of oil-fired heating system, about 87% of the GHG emissions come from combustion and the rest of the emissions come from refinery activity.

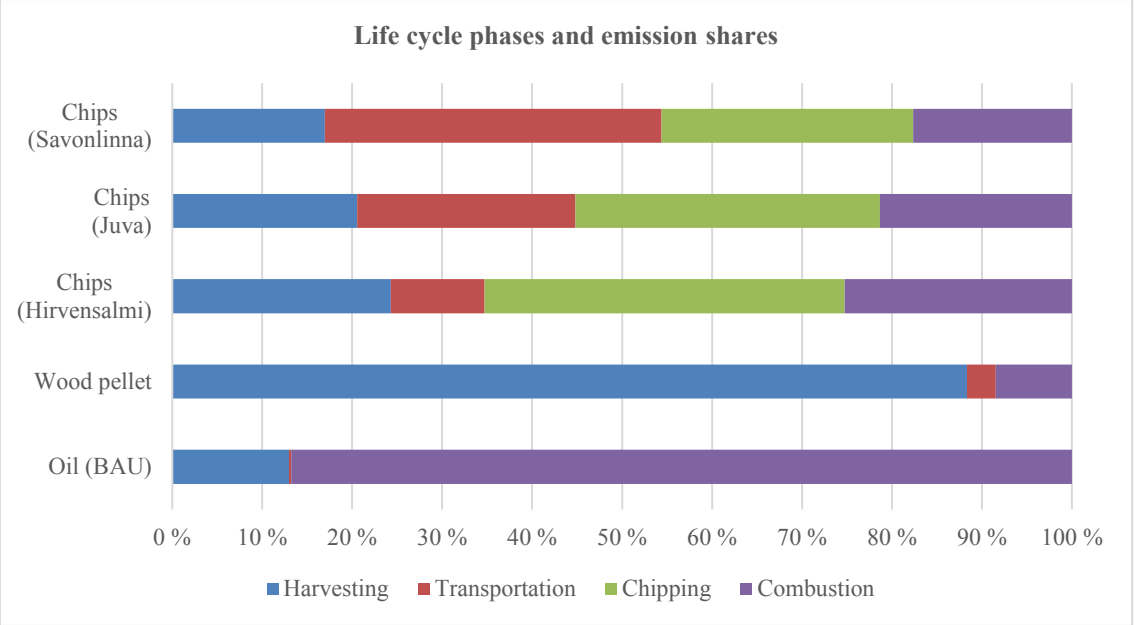


Figure 6: The share of GHG emissions among the life cycle phases of different scenarios.

3.3 Sensitivity results

The sensitivity analysis results are presented in Figure 7. According to the results, there is no significant difference in GHG emissions between two logistics scenario in case of wood chips from Hirvensalmi. However, as the wood chips delivery distance increases, the difference in GHG emissions between direct delivery and delivery via terminal also grows. The logistics via biomass terminal (chipping in terminal) is responsible for more GHG emission than direct delivery (chipping in forest roadside). The main reason for that is because the wood from the forest to the terminal is delivered on log trucks with 40t payload with 85% utilization. However, in the case of direct delivery, the payload capacity of container trucks is 27t and utilization is just 40%, which means container trucks need to make more trips as compared to log trucks.

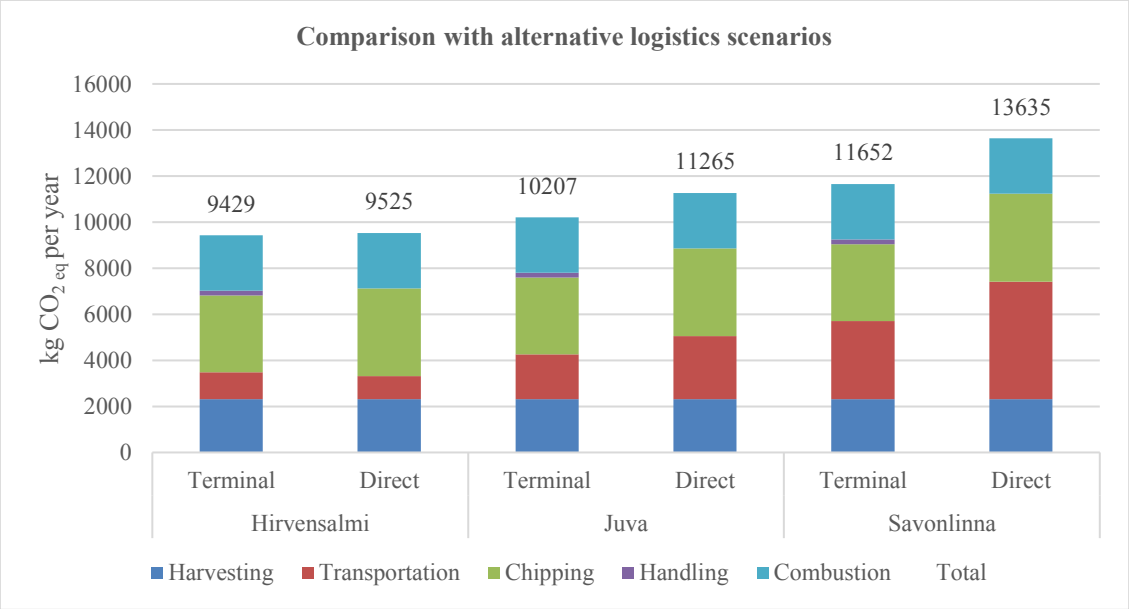


Figure 7: Comparative emissions from alternative logistics scenarios that include biomass delivery through terminals

4. Conclusion

The results show that the use of wood chips in a decentralized space heating systems helps cut down the GHG emissions by up to 96% as compared to LFO-fired heating system. The emissions are slightly higher (89% reduction) in case of wood pellets as compared to wood chips and that is largely due to the emissions attributed to pellet production. The sensitivity analysis results show that biomass chipping at the terminal causes slightly lower emissions despite additional delivery distance and material handling related emissions. The main reason is that the payload of log truck (40t) is higher than the blowing container (27t) and utilization of log truck is 85% as compared to 40% for container truck. On the other hand, the emissions from pellet-fired heating are up to three times as compared to chips but wood pellets offer other physio-chemical benefits such as uniformity in quality and higher heating value. Pellet production phase is one of the bottlenecks that can also offer an opportunity in minimizing its emissions.

The use of locally available biomass for heating instead of imported fossil fuel would mean the municipalities could be energy independent, at least in the case of the heating sector. However, according to Hast et al., replacing oil heaters with biomass including wood pellet is a challenging task in the Finnish case, especially when the price of oil is low. Even when the price of oil is low, replacing the oil heaters would have to be at the end of life and would need some sort of subsidy from the state.

Acknowledgments

This research is a part of the project: An innovative solution for solid biomass delivery and mobile heat containers to replace oil-fired heating (23B22076YT10). The project is mainly funded by the Regional Council of South Savo from the European Regional Development Fund. The project also received funding from the Energy Foundation of Suur-Savo.

References

Karhunen, A., Laihanen, M., Föhr, J. and Ranta, T. (2019) "Replacing Oil Based Heating by Domestic Biofuels", Proceedings of 27th European Biomass Conference and Exhibition, 1736-1738.

Statistics Finland, (2018) "Energy Supply and Consumption", Available: http://www.stat.fi/til/ehk/index_en.html, Accessed: 05.09.2019.

Hast, A., Ekholm, T. and Syri, S., (2016) "What is needed to phase out residential oil heating in Finnish single-family houses?," Sustainable cities and society, 22, 49-62.

Romanet SARL, (2019), "Blowing systems and blowing trucks", Available: http://www.romanet-sarl.com/, Accessed: 05.09.2019.

Föhr, J., KC, R., Karhunen, A., Laihanen, M. and Ranta, T., (2019), "An Innovative Solution for Solid Biomass Delivery and Mobile Heat Containers to Replace Oil-fired Heating", Proceedings of 27th European Biomass Conference and Exhibition, 1029-1031.

SFS-EN ISO 14040, (2006), "Ympäristöasioiden Hallinta. Elinkaariarviointi: Periaatteet Ja Pääpiirteet."

GaBi databases. Thinkstep AG; LBP-GaBi, University of Stuttgart: GaBi Software System, Leinfelden-493 Echterdingen / Germany (2011)

Jungbluth, N., (2007), "Heat production, light fuel oil, at industrial furnace 1MW", Ecoinvent database v3.1.

Bauer, C., (2013a), "Heat production, wood pellet, at furnace 300kW, state-of-the-art 2014", Ecoinvent database v3.1.

Bauer, C., (2013b), "Wood pellet production", Ecoinvent database v3.1.

Werner, F., (2012a), "Harvesting, forestry harvester". RER. Ecoinvent database v3.1

Werner, F., (2012b) "Wood chipping, mobile chipper at forest road". RER. Ecoinvent database v3.1.

Jäppinen, E., Korpinen, O.J., Ranta, T., (2013), "The effects of local biomass availability and possibilities for truck and train transportation on the greenhouse gas emissions of a small-diameter energy wood supply chain", BioEnergy Research, 6(1), 166-177.

Lämposi, (2019), "Chips blower container", Available: https://lamposi.fi/, Accessed: 05.09.2019.

Werner, F., (2013) "Wood chipping, mobile chipper, at forest road", Ecoinvent database v3.1.

Prinz, R., Väätäinen, K., Laitila, J., Sikanen, L. and Asikainen, A., (2019), "Analysis of energy efficiency of forest chip supply systems using discrete-event simulation", Applied Energy, 235, 1369-1380.

Bauer, C., (2007) "Heat production, softwood chips from forest, at furnace 1000kW, state-of-the-art 2014", Ecoinvent database v3.1.

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

MANUAL CULTIVATION OPERATIONS IN POPLAR STANDS: A CHARACTERIZATION OF JOB DIFFICULTY AND RISKS OF HEALTH IMPAIRMENT

Tiberiu Marogel-Popa [1], Marius Cheţa [1], Marina Viorela Marcu [1], Cristian Ionuţ Duţă [1], Florin Ioraş [2], Stelian Alexandru Borz [1]

[1] Department of Forest Engineering, Forest Management Planning and Terrestrial Measurements, Faculty of Silviculture and Forest Engineering, Transilvania University of Braşov, Romania [2] Buckinghamshire New University, Queen Alexandra Road, High Wycombe, Buckinghamshire, UK
stelian.borz@unitbv.ro

Abstract: *Abstract. Short rotation poplar forests are a viable alternative in producing high quality wood for industrial applications. Their success depends on timely and high-quality implementation of a series of operations. Weed control operations are implemented to favor the trees in their competition for soil resources, and cultivation is an option typically used in many European countries. For the moment, a complete mechanization of such operations is virtually impossible, and they still require an intensive use of manual labor. Since information on work difficulty and risks in manual cultivation operations is limited, this study aimed to characterize this job. Evaluation was made in terms of work efficiency, cardiovascular workload, work intensity and postural risks by implementing a time and motion study combined with heart rate measurements, accelerometry and whole-body postural analysis. Work efficiency was particularly low even if the share of effective work time was high (70% of the observation time). Job was characterized as moderate to high intensity, which resulted into a moderate to high cardiovascular strain. While the postural analysis indicated rather small risks, the main problem was found for the back postures assumed during the work. Improvements should aim to extend mechanization, train the workers and appropriately design rest breaks.*
Keywords: manual cultivation, job characterization, ergonomics, efficiency, cardiovascular workload, work intensity, risk of musculoskeletal disorders

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

OPERATIONAL PERFORMANCE OF PARTLY MECHANIZED PLANTING IN WILLOW SHORT ROTATION COPPICE

Nicolae Talagai [1], Marina Viorela Marcu [1], Andrea Rosario Proto [2], Stelian Alexandru Borz [1]
[1] Department of Forest Engineering, Forest Management Planning and Terrestrial Measurements, Faculty of Silviculture and Forest Engineering, Transilvania University of Braşov, Romania [2] Laboratory of Wood Technology and Forest Mechanization, Department of AGRARIA, University Mediterranea of Reggio Calabria, Italy
stelian.borz@unitbv.ro

Abstract: *Abstract. Biomass for energy use can be procured from various sources including willow short rotation crops (WSRC). The feasibility of such crops, especially in small scale applications is dependent on the costs incurred by plantation, maintenance, harvesting and transport. This often results in the use of low-cost equipment designed for general agricultural purposes in the operational management of WSRCs. However, to be able to plan and manage WSRCs, with the aim to ensure their profitability, research is needed to clarify how performant such operations could be and to what extent their performance may affect the operational costs. This study evaluated the planting performance of WSRCs when using regular farming tractors to propel a planting aggregate consisting of a wheel-drive steel-frame device designed to plant single twin rows, by the use of manual labor in pushing the cuttings into the soil.*

Planting aggregates consisting of different types of farming tractors equipped with willow planting devices were tested in 14 field experiments to be able to compute the main performance indicators such as the net and gross production rate. To this end, we combined GPS techniques to collect location and time consumption data with video recording of operations to extract the time consumption and production rates for the selected field experiments.

The main findings were as follows: total observed time accounted for cca. 120 hours out of which planting time accounted for more than 75%. Approximately 5% of the time was used as preparatory time and the rest (cca. 19%) consisted of row and headland delays. There was an evident variability between the time consumption categories at plot-level, and the planting time depended to a great extent on the operated area. The effective planting speed was evaluated at 1.15 km/h, and the headland returning speed was evaluated at 0.4 km/h. The gross production rate averaged cca. 0.15 ha/h while the net production rate was of 0.18 ha/h. Variability of the net production rate was explained largely by the ratio of the length of headland returning maneuvers to total length covered in a given plot.

Compared to the purpose-built equipment, the performance of planting operations in this study was rather low. Nevertheless, the studied equipment represents a flexible option for small-scale farmers which could increase the utilization rate of their tractors by using them in other agricultural operations when needed. In addition, the studied equipment may fit well to very narrow and small-sized plots as such situation is typical to Romania and other European countries.

Keywords: Willow, short rotation coppice, planting operations, performance

FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future
6-9 October 2019 - Sopron, Hungary

SIMULATION OF HARVESTER LOGGING PROCESSING AND DYNMIC DRIVING MOTION USING UNITY3D

Zhang Jianting, Huang Qingqing, Liu Jinhao, Cheng Bowen, Xie Danmu
Forest Engineering, Engineering Institute, Beijing Forestry University, China
huangqingqing@bjfu.edu.cn

Abstract: *Modern forestry equipment is characterized by high power and high energy consumption , and the working environment is in complex plantation areas , which makes it difficult to conduct production practice and cognition practice, as well as related teaching work of equipment machinery , hydraulic actuators and electronic control systems . The loggingg harvester simulator is an important infrastructure means for modern forestry characteristics of higher education. Through the demonstration and operation of the system , it can play a key role in professional cognitive teaching and mechanical , electronic and hydraulic integrated forestry equipment production internship . It is a multiplier effect for students to quickly master the advanced production methods and improve their practical ability of forestry machinery . The system is based on the actual multifunctional breeding machine control system , and is equipped with simulation visual software compatible with the input and output signals of the control system . With this system software , it can simulate mechanical operation , control system interface debugging, forest logging , hitting branches, making materials, etc. This paper focuses on the dynamic motion simulation platform sawing wood work and vehicles in Unity3D scene was simulated and experimental testing, through a single scene Unity3D wood sawing and dynamic simulation of the vehicle can be achieved anywhere, detailing for forestry equipment Key simulation techniques for job simulation and driving scene reproduction.*

Keywords:forestry felling&cultivation machine; virtual reality; unity3d; virtual cutting

AUTHOR INDEX

AALMO, Giovanna Ottaviani 21
ACKERMAN, Pierre 476
ACKERMAN, Simon 196
ACKERMAN, Simon 476
ACUNA, Mauricio 114
ACUNA, Mauricio 130
ACUNA, Mauricio 148
AMINTI, G 256
ANDERSON, Nathanial 105
ANDERSON, Nathaniel 112
ANDRIĆ, Ivan 559
ANTTILA, Perttu 119
ARNIČ, Domen 468
ARUGA, Kazuhiro 422
ARUNPRAPARUT, Wanchai 366
ASTRUP, Rasmus 19
ASTRUP, Rasmus 196
ASTRUP, Rasmus 214
ATZBERGER, Clement 3
AURENHAMMER, Peter 241
AUST, W Mike 37
BABICZKI, László 495
BAČIĆ, Marin 65
BARRETT, Scott M 37
BEAUDOIN, Daniel 198
BEMBENEK, Mariusz 313
BENNEMANN, Caroline 241
BERENDT, Ferréol 584
BERRY, Michael 148
BEZUIDENHOUT, Carel 137
BIELECKI, Chris 355
BILIGT, Battuvshin 422
BJÖRHEDEN, Rolf 375
BLADON, Kevin 18
BLINN, Charlie 231
BLUM, Uwe 320
BOJA, Florin 560
BOJA, Nicusor 560
BOLDING, Chad 3
BOLDING, M Chad 37
BOLDRINI, Chloé 410
BONT, Leo 284
BONT, Leo 635
BORCHERT, Herbert 35
BORCHERT, Herbert 88
BORCHERT, Herbert 151
BORCHERT, Herbert 320
BORCHERT, Herbert 330
BORZ, Stelian Alexandru 645
BORZ, Stelian Alexandru 646
BOWEN, Cheng 647
BRÄNNSTRÖM, Hanna 104
BREINIG, Lorenz 241
BREINIG, Lorenz 278
BRINK, Michal 300
BRITTO, Pedro C 24
BROWN, Mark 114
BROWN, Mark 220
BROWN, Mark 374
BYKOVSKIY, Maxsim A 546
CACOT, Emmanuel 410
CADE, Alberto 591
CALDECOTT, Tim 373
CAMBI, Martina 187
CARRETTE, Thomas 131
CATALDO, Maria Francesca 72
CAVALLI, Raffaele 72
CAVALLI, Raffaele 223
CAVALLI, Raffaele 225
CAVALLI, Raffaele 591
CHEŢA, Marius 645
CHIRWA, Paxie 300
CHRISTIANS, Ginny 137
CHUNG, Woodam 18
CHUNG, Woodam 112
CHUNG, Woodam 219
CLINTON, Peter 286
CONRAD, Joe 248
CORSANO, Michael 375
CZUPY, Imre 487
CZUPY, Imre 599
DA ROCHA, Kleydson Diego 199
DAIGNEAULT, Adam 317
DANMU, Xie 647
DE ARRUDA MOURA, Angelo Conrado 5
DE SANTA EULALIA, Luis 266
DETKONG, Narongdet 447
DIACI, Jurij 468
DIAN, Wang 74
DIEFENBACH, Lorenz 280
DIEFENBACH, Lorenz 571
DIETSCH, Patrick 280
DIETSCH, Patrick 378
DIETZ, Elke 88
DIETZ, Elke 320
DIETZ, Elke 330
DIETZ, Hans-Ulrich 302
DIETZ, Hans-Ulrich 475
DODSON, Elizabeth 105
DODSON, Elizabeth 112
DONG, Wang 74
DORREN, Luuk 280
DÖG, Markus 503
DREHER, Moritz 280
DREW, David 196
DUBEAU, Denise 266
ĐUKA, Andreja 304
ĐUKA, Andreja 486
DUMINS, Karlis 574
DUONG, Linh N K 294
DUPUZS, Edgars 527
DUŢĂ, Cristian Ionuţ 645
EISNER, Stephanie 19
ERBER, Gernot 21
ERBER, Gernot 528
FABIANO, Fabio 187
FANTINI, Alfredo C 24
FISCHER, Christoph 284
FODER, Cristiano 38
FODERI, Cristiano 187
FÖHR, Jarno 637
FRAFEL, Marielle 284
FRANJEVIĆ, Milivoj 486
FRITZ, Michael 439
FRUTIG, Fritz 284
FUJIMOTO, Kiyohiko 555
GALLAGHER, Thomas 199
GALLAGHER, Thomas 207
GARREN, Austin M 37
GAVRAN, Ivan 559
GEORGE, Alex K 36
GEORGE, Alex Kunnathu 379
GHAFFARIYAN, Mohammad Reza 220
GINET, Christophe 131
GÖßWEIN, Sebastian 151
GRÉDICS, Szilárd 495
GREEN, Preston 18
GRIESS, Holger 373
GRIGOLATO, Stefano 72
GRIGOLATO, Stefano 223

GRIGOLATO, Stefano 225
GRIGOLATO, Stefano 591
GRONALT, Manfred 120
GRUSHECKY, Shawn 103
GRÜNBERGER, Jochen 506
HAAVIKKO, Hanna 242
HÄGGSTRÖM, Carola 84
HÄGGSTRÖM, Carola 221
HALBROOK, Jeff 161
HALBROOK, Jeff 224
HÄMÄLÄINEN, Jarmo 197
HAMBERG, Leena 455
HAN, Han-Sup 161
HAN, Han-Sup 224
HARRILL, Hunter 6
HARRILL, Hunter 220
HARTMANN, Hans 93
HARTMANN, Hans 320
HARTSCH, Florian 278
HATTEN, Jeff 18
HAUCK, Andrea 503
HAUCK, Andrea 506
HEINIMANN, Hans R 214
HEINIMANN, Hans Rudolf 635
HEINRICH, Bernd 506
HEISKANEN, Jussi 293
HELLSTRÖM, Jarkko 104
HELMISAARI, Heljä-Sisko 277
HENNEK, Marcus 243
HEPPELMANN, Joachim B 314
HEPPELMANN, Joachim B 506
HEUBAUM, Felix 186
HILTY, Lorenz 283
HINTE, Bastian 182
HIROAKI, Shirasawa 547
HIRVELÄ, Hannu 86
HOCHBICHLER, Eduard 83
HOFER, Manfred 220
HOFFMANN, Stephan 21
HOFFMANN, Stephan 24
HOFFMANN, Stephan 528
HOFFMANN, Stephan 584
HOLM, Stefan 283
HOLOPAINEN, Markus 197
HOLZFEIND, Thomas 4
HOLZFEIND, Thomas 120
HOLZLEITNER, Franz 4
HOLZLEITNER, Franz 83
HOLZLEITNER, Franz 149
HOLZLEITNER, Franz 439
HOLZLEITNER, Franz 528
HOOPER, Brionny 286
HORVÁTH, Attila László 521
HORVÁTH, Attila László 529
HRAŠOVEC, Boris 486
HUBER, Christoph 55
HUNT, James 6
HYVÖNEN, Pekka 86
HYYPPÄ, Juha 197
IKAMI, Yuji 555
IORAŞ, Florin 645
IRDLA, Marek 573
ISKI, Richárd 599
IVANOVS, Janis 34
IVANOVS, Janis 438
IWAOKA, Masahiro 189
IWAOKA, Masahiro 585
JAEGER, Dirk 21
JAEGER, Dirk 24
JAEGER, Dirk 375
JAEGER, Dirk 528
JAEGER, Dirk 534
JAEGER, Dirk 584
JIANTING, Zhang 647
JINGHAO, Liu 74
JINHAO, Liu 647
KAAKKURIVAARA, Nopparat 226
KAAKKURIVAARA, Nopparat 366
KAAKKURIVAARA, Nopparat 447
KAAKKURIVAARA, Nopparat 458
KAAKKURIVAARA, Tomi 277
KÄÄRIÄINEN, Heikki 242
KAJBA, Davorin 559
KAMMERMEIER, Max 319
KANAZAWA, Yutaka 555
KANKARE, Ville 197
KANZIAN, Christian 4
KANZIAN, Christian 83
KANZIAN, Christian 120
KANZIAN, Christian 149
KANZIAN, Christian 439
KARASZEWSKI, Zbigniew 313
KÄRHÄ, Kalle 197
KÄRHÄ, Kalle 242
KASTENHOLZ, Edgar 47
KATO, Hideo 555
KAWASAKI, Akie 417
KC, Raghu 637
KEMMERER, Julia 278
KENEFIC, Laura 379
KIKULSKI, Jarosław 528
KISFALUDI, Balázs 279
KISS, Andrea Tünde 599
KIVINEN, Veli-Pekka 197
KIZHA, Anil Raj 36
KIZHA, Anil Raj 245
KIZHA, Anil Raj 317
KIZHA, Anil Raj 379
KIZHA, Anil Raj 613
KOGLER, Christoph 115
KOHROKI, Katsuhisa 417
KOLAR, Antonija 486
KOSZMAN, Colin 6
KOVÁCS, Klaudia 606
KRAJNC, Nike 570
KRČ, Janez 468
KRUMOV, Tihomir 535
KUCHLER, Carina 320
KUFFER, Georg 93
KUPTZ, Daniel 93
KUPTZ, Daniel 320
KÜHMAIER, Martin 214
KÜHMAIER, Martin 220
LABELLE, Eric R 35
LABELLE, Eric R 241
LABELLE, Eric R 278
LABELLE, Eric R 314
LABELLE, Eric R 319
LAINA, R 256
LAINE, Tiina 455
LAITILA, Juha 86
LAITILA, Juha 104
LAITILA, Juha 119
LANDEKIĆ, Matija 65
LANDEKIĆ, Matija 423
LANGMAIER, Magdalena 83
LASCHI, Andrea 38
LASCHI, Andrea 187
LAZDINA, Dagnija 527
LAZDINA, Dagnija 574
LAZDINS, Andis 34
LAZDINS, Andis 438
LAZDINS, Andis 574
LEBEL, Luc 198
LEBEL, Luc 266
LEMM, Renato 283
LENZ, Volker 93
LESCHE, Simon 93
LESHCHINSKY, Ben 18
LESLIE, Cameron 6
LEWARK, Siegfried 512
LEWARK, Siegfried 575

LIEPINS, Janis 574
LINDROOS, Antti-Jussi 277
LITTLE, Keith 300
LOMBARDINI, Carolina 636
LÓPEZ-VICENS, I 256
LOUIS, Libin T 317
LOUIS, Libin Thaikkattil 245
LOUIS, Libin Thaikkattil 613
LUNDBÄCK, Mikael 84
LUNDBÄCK, Mikael 221
LUPIKIS, Ainars 34
LYONS, C Kevin 223
MACK, Robert 320
MAGAGNOTTI, Natascia 82
MAGAGNOTTI, Natascia 374
MAGAGNOTTI, Natascia 394
MAGAGNOTTI, Natascia 520
MAJOR, Tamás 599
MAKOVSKIS, Kristaps 527
MAKOVSKIS, Kristaps 574
MALINEN, Jukka 293
MALINEN, Jukka 467
MARČETA, Dane 623
MARCHI, Enrico 38
MARCHI, Enrico 187
MARCHI, Luca 223
MARCHI, Luca 225
MARCU, Marina Viorela 645
MARCU, Marina Viorela 646
MAROGEL-POPA, Tiberiu 645
MARRA, Elena 38
MARRA, Elena 187
MARTINIĆ, Ivan 423
MARUYAMA, Yasufumi 40
MASTROLONARDO, Giovanni 38
MATSUDA, Yosuke 555
MATSUMOTO, Takeshi 189
MATSUMOTO, Takeshi 585
MATSUMURA, Tetsuya 40
MATSUMURA, Yukari 555
MATSUOKA, Yusuke 422
MÁTYÁS, Katalin Szakálosné 521
MÁTYÁS, Katalin Szakálosné 529
MAXEINER, René 503
MCDONALD, Timothy 199
MCDONALD, Timothy 207
MCEWAN, Andrew 374
MCEWAN, Andrew 394
MCNABB, D H 340
MEDERSKI, Piotr 82
MEDERSKI, Piotr S 313
MELKAS, Timo 197
MELNIKS, Raitis 438
MENK, Julia 280
MENNALA, Markus 467
MEYER-SCHULZ, Katharina 182
MIHELIČ, Matevž 407
MITCHELL, Dana 199
MITCHELL, Dana 207
MITCHELL, Rick 148
MITCHELL, Rick 247
MITCHELL, Rick 374
MOHTASHAMI, Sima 624
MOLL, Patricia 635
MOLOGNI, Omar 19
MOLOGNI, Omar 223
MOLOGNI, Omar 225
MOLOGNI, Omar 591
MORAT, Joachim 56
MORAT, Joachim 605
MORIN, François 266
MORRISSETTE, Brett 18
MOSTAFA, Mohsen 624
MOURA, Angelo 37
MOZUNA, Masahiro 469
MUISTE, Peeter 573
MUNEOKA, Hiroko 555
MURPHY, Glen 130
MURPHY, Glen 148
MÜHLENBERG, Jana 93
NAHOR, Evan Ross 245
NAKAZAWA, Masahiko 469
NAKAZAWA, Masahiko 555
NARANGAJAVANA, Payattipol 458
NEMESTÓTHY, Nikolaus 55
NERI, Francesco 38
NERI, Francesco 187
NERUDA, Jindřich 162
NITAMI, Toshio 40
NORDFJELL, Tomas 84
NORDFJELL, Tomas 183
NORDFJELL, Tomas 187
NORDFJELL, Tomas 221
NORDFJELL, Tomas 365
NUMMELIN, Tuomas 119
O'BRIEN, Obie 355
OBERMAYER, Bernhardt 83
OKADA, Ryotaro 454
ONO, Sho 189
OVASKAINEN, Heikki 197
PACKALEN, Tuula 86
PADARI, Allar 573
PALANDER, Teijo 242
PANDUR, Zdravko 65
PAPANDREA, Salvatore 72
PAPP, Viktória 495
PAPP, Viktória 540
PARKER, Richard 286
PARSAKHOO, Aidin 624
PENTEK, Tibor 304
PERSSON, Henrik 221
PÉTERFALVI, József 279
PETERSON, Rachel 231
PETKOVIĆ, Vladimir 623
PICA, Adrian 560
PINTÉR, Tamás 599
PLODCHUM, Nichmon 366
POIKELA, Asko 197
POJE, Anton 407
POLLEX, Anett 93
POOLSIRI, Roongreang 447
POPESCU, Ilie 560
PORŠINSKY, Tomislav 304
POTOČNIK, Igor 623
PRETTIN, Stephan 584
PRIMUS, Josef 3
PRIMUSZ, Péter 279
PROCHÁZKA, Petr 162
PROTO, Andrea R 72
PROTO, Andrea Rosario 646
PSZENNY, Dariusz 528
PUCHER, Christoph 21
QINGQING, Huang 74
QINGQING, Huang 647
RADICS, Robert I 137
RADICS, Robert I 294
RAMANTSWANA, Muedanyi 300
RAMANTSWANA, Muedanyi 394
RAMSTEIN, Laura 635
RANTA, Tapio 637
RÁTKY, Mihály 529
RAUCH, Peter 115
RIEBLER, Markus 88
RIEBLER, Markus 320
RIEBLER, Markus 330
RIEGLER, Markus 528
RINKENAUER, Gerhard 375
RIST, Elisabeth 320
ROBERT, Renato C G 24
ROESER, Dominik 6
ROESER, Dominik 223
ROESER, Dominik 373

ROININEN, Kimmo 242
ROSIŃSKA, Martyna 313
ROSIŃSKI, Krzysztof 313
ROUTA, Johanna 104
RUCH, Philippe 410
RYHTI, Kira 277
SAARINEN, Veli-Matti 455
SAITO, Masashi 477
SAITO, Masashi 547
SAKSA, Timo 455
SANTNER, Christoph 149
SANZ, Blanca 293
SCHALLER, Christoph 280
SCHÖN, Claudia 320
SCHÖNAUER, Marian 21
SCHÖNAUER, Marian 375
SCHÖNAUER, Marian 528
SCHÖNAUER, Marian 534
SCHUSSER, Marina 151
SCHWEGMAN, Kylle 394
SCHWEIER, Janine 584
SEELING, Ute 47
SEELING, Ute 56
SEELING, Ute 475
SEELING, Ute 506
SEELING, Ute 605
SEIFERT, Stefan 314
SEIFERT, Thomas 314
SERTIĆ, Mirna 304
SERVIN, Martin 365
SESSIONS, John 18
SHIRAI, Norio 555
SHIRAI, Yuko 442
SHIRAI, Yuko 454
SHIRASAWA, Hiroaki 422
SHIRASAWA, Hiroaki 477
SITANGGANG, Marisa 207
SKAGESTAD, Eva 375
SNYDER, Stephanie 231
SOKOL, Wolfgang 439
SOSA, Amanda 114
SPINELLI, Raffaele 5
SPINELLI, Raffaele 21
SPINELLI, Raffaele 82
SPINELLI, Raffaele 103
SPINELLI, Raffaele 256
SPINELLI, Raffaele 300
SPINELLI, Raffaele 374
SPINELLI, Raffaele 394
SPINELLI, Raffaele 520
SPINELLI, Raffaele 636
SPONG, Ben 244
ŠPORČIĆ, Mario 65
ŠPORČIĆ, Mario 423
STALS, Toms Arturs 574
STAMPFER, Karl 4
STAMPFER, Karl 21
STAMPFER, Karl 220
STARKE, Michael 186
STARKE, Michael 280
STARKE, Michael 378
STRANDGARD, Martin 247
SUDÁR, Ferenc János 521
SUK, Sooil 40
ŠUŠNJAR, Marijan 65
SUZUKI, Yasushi 316
SUZUKI, Yasushi 431
SZALAY, Dóra 495
SZALAY, Dóra 540
SZIGETI, Nóra 487
TAKEZAWA, Tokito 547
TAKI, Seishiro 555
TALAGAI, Nicolae 646
TALBOT, Bruce 19
TALBOT, Bruce 21
TALBOT, Bruce 375
TANAKA, Wataru 555
TERBLANCHE, Marius 476
TEUŞDEA, Alin 560
TEUTENBERG, Andrea 47
TEUTENBERG, Andrea 56
TEUTENBERG, Andrea 605
THEES, Oliver 283
THONGKAM, Angkana 458
TIKHOMIROV, Evgeny A 546
TOKOLA, Timo 293
TOLOSANA, E 256
TOMIĆ, Tin 559
TRIPLAT, Matevž 570
UEKI, Tatsuhito 477
UEKI, Tatsuhito 547
UEMURA, Takumi 469
UEMURA, Takumi 555
UENOHARA, Midori 189
UENOHARA, Midori 585
ULRICH, Radomír 162
UOTILA, Karri 350
USUI, Kengo 469
USUI, Kengo 555
UUSITALO, Jori 185
UUSITALO, Jori 277
VÄÄTÄINEN, Kari 86
VÄÄTÄINEN, Kari 119
VÁGVÖLGYI, Andrea 487
VAHTILA, Mika 197
VANCE, John 103
VIBRANS, Alexander C 24
VIDREAN, Dan 560
VISSER, Rien 6
VISSER, Rien 220
VÍTEK, Ondřej 162
VITYI, Andrea 606
VUSIĆ, Dinko 304
VUSIĆ, Dinko 559
VUSIĆ, Ivana Plišo 559
WAAS, Siegfried 35
WAGNER, Thilo 375
WANG, Jingxin 103
WATANABE, Masaru 477
WATANABE, Masaru 547
WHITAKER, Dylan 224
WIBERG, Viktor 365
WICTORSSON, Rasmus 183
WIEDEMANN, John 247
WITTKOPF, Stefan 314
WITTKOPF, Stefan 506
YAMAMOTO, Takahisa 422
YOSHIDA, Chikashi 555
YOSHIMURA, Tetsuhiko 316
YOSHIMURA, Tetsuhiko 431
ZEČIĆ, Željko 559
ZEMÁNEK, Tomáš 162
ZENG, Thomas 93
ZIESAK, Martin 186
ZIESAK, Martin 280
ZIESAK, Martin 378
ZIESAK, Martin 571
ZIMBALATTI, Giuseppe 72
ZIMMERMANN, David 320
ZOTT, Fritz 439
ZU HOHENLOHE, Felix 173