PROCEEDINGS

Proceedings of The Joint 43rd Annual Meeting of Council on Forest Engineering (COFE) & the 53rd International Symposium on Forest Mechanization (FORMEC)

Forest Engineering Family – Growing Forward Together

September 27-30, 2021

Corvallis, Oregon, U.S.A.

Editors

Woodam Chung

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COUNCIL ON FOREST ENGINEERING

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Message from the Chairs

On behalf of the COFE-FORMEC Organizing Committee, it is a great pleasure for us to welcome all the participants to the 43rd annual meeting of the Council on Forest Engineering (COFE) and the 53rd annual meeting of the International Symposium on Forest Mechanization (FORMEC). This year event is the second of the three consecutive annual joint meetings scheduled between COFE and FORMEC. This year joint meeting follows the historic first and in-person joint meeting held in Hungary/Austria in 2019, and is prior to the third COFE/FORMEC joint meeting to be held in-person in Corvallis, Oregon, October 2022.

As you know, the COVID-19 pandemic prevented this second joint meeting from taking place in 2020. While the pandemic still affects international travels and in-person gatherings, we have come together online this year to learn, share and network. Just like the event theme, 'Forest Engineering Family – Growing Forward Together', we hope our series of joint meetings will strengthen our One Big Family of Forest Engineering around the globe. Together, we will learn from each other, tackle present forest engineering challenges, map our future, and empower our next generations.

We hope you enjoy this exciting and engaging virtual joint meeting of COFE-FORMEC 2021, and look forward to seeing you again next year in Oregon, U.S.A.

Best regards,

Woodam Chung Karl Stampfer

COFE-FORMEC 2021 Chairs

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Digital learning as an opportunity for forestry qualification as a European task

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ABSTRACT

The global pandemic does not only bring along many restrictions but also many opportunities to promote blended and digital learning along the value chain in the forestry now and in the future. Moreover, forestry is one of the most accident-prone and dangerous industries in Germany. Digital qualification offers provide the opportunity to pass on the latest forestry knowledge on occupational safety and other forestry topics in practice quickly and time-efficiently.

Blended learning is a mixture of digital learning and face-to-face teaching and combines the advantages of both forms of learning while balancing the disadvantages. Since 2017, the KWF has been developing several blended learning courses on various topics in three Erasmus+ projects with strong European partners.

'Forestry EDUTrainer' (09/2017-08/2020) has dealt with the pedagogical-methodical competences of trainers in relation to the training and education of adult learners in the forestry sector. This grounds on the fact that exactly this methodological-pedagogical qualification of trainers and instructors in forestry tends to be rather the exception than the rule in most European countries. Considering the important role that trainers play - also with regard to the requirements of occupational safety and health protection - a training standard including a multi-module qualification concept based on an e-learning platform has been developed within the framework of the project.

'Blended European Forestry Training' (BLEFT) brings together 7 partners from five different countries (12/2018-08/2021) with the aim to jointly create online learning modules for forestry professionals. Amongst others, topics of the e-learning or blended learning course include prevention culture, soil protection or certification. The course can then be accessed on the project websites from around in the world. This does not only involve the creation of learning videos but also encompasses other online tools such as interactive pictures, surveys or quizzes.

The partners in the third Erasmus+ project 'Forests For Health' (11/20-10/23) are developing a blended or e-learning course leading to a 'certified Forests for Health coach' qualification. The coaches will build bridges between the health and forestry sectors and raise awareness about the multiple health and recreational functions of forests. At the same time, the acceptance and necessity of sustainable forest management is promoted in society.

Experience shows that the pandemic has opened a door for the future of digital learning in forestry.

How will COVID-19 Change Forestry Education? A Case Study of US Forest Operations Instructors

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ABSTRACT

The covid pandemic impacted nearly every aspect of higher education. It has been particularly disruptive to forest operations courses that rely heavily on field experiences. Dodson and Blinn (2021) surveyed US forest operations instructors at 4-year institutions granting SAF-accredited Forestry degrees to understand how they rapidly modified courses during spring 2020 to accommodate a move to fully-remote instruction. Through an online survey administered in March and April 2020, a follow up study was conducted to understand how courses were modified when instructors had time to prepare for the 2020/2021 academic year and what, if any, of those modifications are likely to be retained post covid. Thirteen instructors responded, providing reflections on 43 courses. Of those courses, 37% were classified as forest operations, 49% more general forestry, and 14% general education courses or courses otherwise targeted to non-majors. Over half (51%) of the courses were senior and/or graduate-level. Respondents used a variety of approaches to better prepare themselves for delivering their 2020/2021 courses online with 77% reporting that meeting with colleagues from other institutions and participating in small group discussions as being somewhat to very helpful. Most instructors (80%) report that at least some of the elements of the changes they made to their course(s) over the last year will be retained once a return to a post-covid "normal" is possible. Course delivery changes expected to be retained include: use of video conferencing platforms such as Zoom to allow students to attend remotely, record and post lectures for students to review, to bring in out-of-town guest speakers, and for small-group meetings; new assignments that expose students to forestry practices outside their own region, including interactions with students from other universities; increased use of online quizzes and exams; video labs created for remote delivery for use when a student needs a make-up assignment; and flipped classroom techniques such as recorded lectures students view before class meetings.

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The Economic Potential for Tele-extraction of Roundwood in Sweden

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ABSTRACT

Mechanization of harvest and extraction of roundwood in Sweden have historically cut costs rapidly as the need for manual labor steadily decreased. Ongoing efforts since the 90:s have continued to increase the work- and cost efficiency. However, harvester and forwarder machinery and work methods have basically stayed the same. Many believe that the next major technology leap will include automation, and that tele-operation, i.e. when a machine is operated remotely from long distance, might be a step along that way. This study aims to evaluate the economic potential of tele-extraction compared to standard forwarding work within the Nordic CTL two-machine harvesting system. The outset was an assumption of autonomous driving during terrain transportation with and without load, and tele-operation of loading and unloading. To assess the effects of such a setup, a Discrete Event Simulation-model was built and implemented in the AnyLogic simulation software. About 1 100 actual clear cut harvest sites from different parts of Sweden was used as input data for the model, with sizes ranging from 0.2 to 57 ha, an average volume of 1 700 m3, and 20 to 1 500 meters extraction distance. Scenarios with different numbers of tele-operators for a fleet of forwarders was tested, as well as different levels of costs, driving speeds, and extraction distances. With a decreasing number of operators for a fixed number of forwarders, productivity will also decrease; the idea in this study is that the lower productivity would be offset by even lower cost per m3. In the base scenario, with all parameters set at standard level, the optimal number of operators are 7 for 10 forwarders, resulting in a potential saving of 7% compared to standard forwarding. As the cost decrease with number of operators (less operator wages), a limitation arose as the machine waiting time increase and brought up the fixed machine cost per m3 to very high levels, thus increasing the total cost. Extraction distance was identified as the most important factor for potential savings and an extraction distance of >500 m provided higher operator utilization and lower machine waiting time for the tele-extraction concept, resulting in potential savings of up to 10%. The reason is that the relative time spent on autonomous drive increase with extraction distance, enabling the operator to work with other machines. This model creates significant possibilities for future evaluation of different scenarios of automation and tele-operation of forestry machines.

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Assistance System for an Automatic Loading Process

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Keywords: Automation, Assistance Systems, Artificial Intelligence, Control Systems

EXTENDED ABSTRACT

1. **Introduction**

One of the biggest challenges forestry contractors face today is high employee fluctuation, resulting in unexperienced operators with minor background in forestry. On the other hand, forwarding shows a huge potential towards automation. An assistance system which semi-automates the loading process during a cut-to-length logging process would increase the productivity significantly, in particular for new operators. Especially for them, positioning the grapple and gripping the log without ground penetration are the most challenging parts of loading phases due to a high number of simultaneous control tasks. The presented assistance system is able to execute these phases completely automatically. The assistance system consists of two essential components, a log detection algorithm and a control system for driving the forestry crane.

2. Log detection

The log detection is based on machine vision methods and uses rgb-images and point cloud data from a depth camera mounted on the forwarder. The neural network YOLACT++ as CNN-based single-stage instance segmentation architecture was trained via transfer learning to determine which pixels in an image belong to a log, achieving a high mean accuracy of 56.65 mAP. Combining this 2D-based object detection with the point cloud data of the depth camera results in a semantically segmented point cloud of the environment. The very points belonging to a log are further processed to estimate the log features like diameter, length and position, compare figure 1. The log position and accordingly its gripping point is transferred to the machine control of the forwarder.

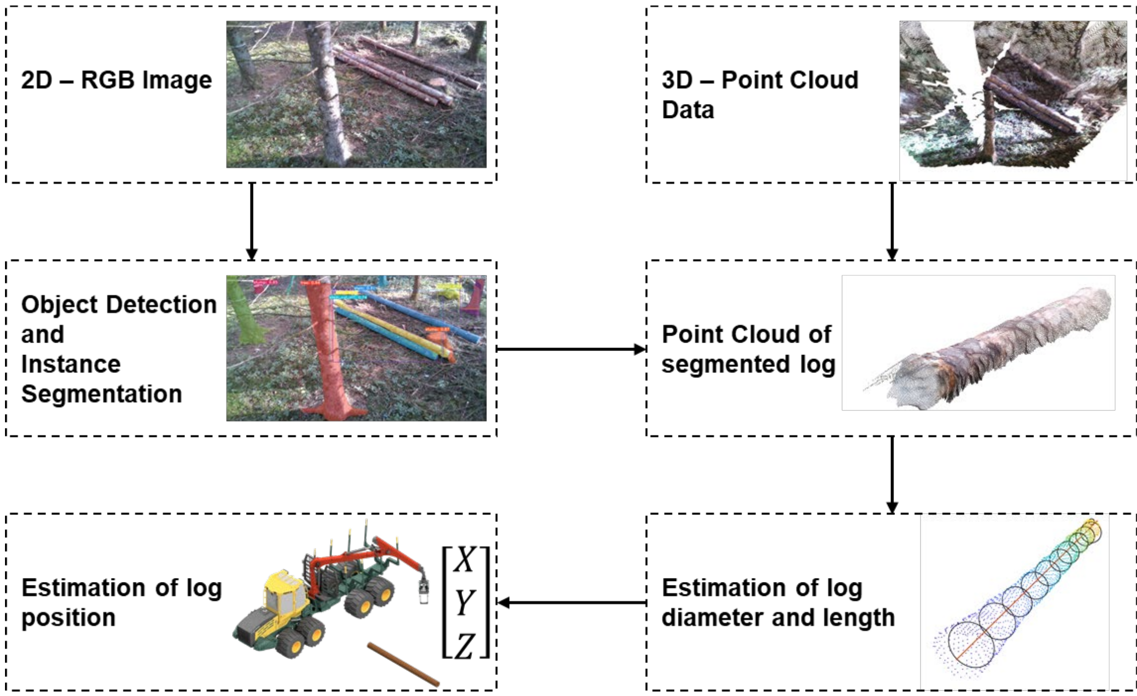

Figure 1: Object detection in logging sites

3. Assistance System 'AutoLoad'

The gripping point serves as target point for the automatic crane drive. When the operator steers the grapple into a sphere of 4 m around the gripping point, the machine control overtakes automatically the control of the crane and manoeuvres the grapple towards the target point. The accuracy of the crane control is below 5 cm. Reaching the target point, the log is gripped and lifted up, while the grapple tips are moving parallel to the underground avoiding its penetration. As basis for the automatic crane drive, a boom tip control resting on a weighted pseudoinverse of the crane kinematics Jacobian matrix was developed. It can be operated in different modes specialized for clearcut, thining or final felling.

The effect of the assistance system was measured with reproducible reference loading cycles. Therefore, 2 inexperienced operators fulfilled these reference cycle each 30 times with ('AutoLoad) and without ('Serie') the assistance system, compare figure 2. The cycle time is reduced up to 40% when operating with AutoLoad, verifying the effectiveness of the assistance system.

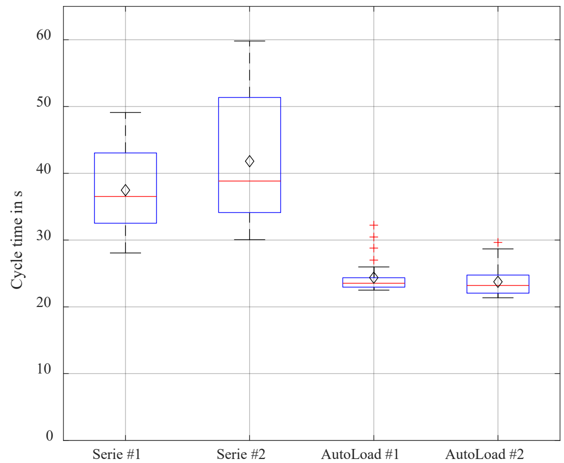

Figure 2: Cycle time during reference cycle for 2 inexperienced operators

4. Conclusion & Future Work

The presented assistance system was successfully tested with an 11-ton HSM-208f forwarder under laboratory conditions. Using the assistance system, the productivity of beginner operators is highly increased. The assistance system will be tested under real working conditions on a logging site during thinning in near future.

5. Acknowledgements

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The Role of Forest Engineering in Curbing Climate Change

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ABSTRACT

Forest and landscape restoration (FLR) across 350 million hectares under the Bonn Challenge and the UN Decade on Ecosystem Restoration can accelerate progress towards climate goals, create urgently-needed jobs in rural areas, and hasten economic recovery. Nature-based solutions, including FLR can deliver an estimated one-third of the climate mitigation needed by 2030 to keep warming below 2°C. Forests play an important role as carbon sinks but can also be a source of emissions due to deforestation. In the face of twin crises posed by climate change and the COVID-19 pandemic, Forest Engineering and operations have never been more relevant. The magnitude of national commitments, as well as the variety of interventions needed to restore lands, require the implementation of sustainable forest operations and innovation in engineering. Innovations in nurseries, site preparation, thinning, and harvesting of timber and nontimber products are becoming key areas to develop in the coming years. Forest engineering also will play a role in the ongoing discussion about timber plantations and their role in mitigation and how to balance between social and environmental objectives. In the climate change discussions, operations are often overlooked, and forest engineering is not receiving the attention needed. However, forest engineering is key to ensure the success of action implemented to protect, manage and restore our forests. In this presentation, we will discuss challenges ahead for forests and how Forest Engineering can play a role in important role in implementing innovative solutions. We will also discuss challenges ahead for forestry focused on competition between land for food and forest products and discussions around exotic versus native species in forestry.

Integrating Forest Biomass into Regional-scale Multi-feedstock Supply Chain Models

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ABSTRACT

Researchers and industry partners participating in the new Mid-Atlantic Sustainable Biomass for Value-added Products Consortium, also known as "MASBio", are working to deliver a sustainable and economically feasible industrial production system for innovative bio-adhesives, 3D printing resins, biochar and other bio-based products. The biomass supply chain for this system strategically leverages diverse feedstocks available in the Mid-Atlantic region of the United States, including biomass from willow and switchgrass cultivation that is suitable for restoration of over 4 million hectares of abandoned and reclaimed surface mined lands in the area. In addition to these purpose-grown feedstocks, 8 million dry tonnes of forest residues are available annually from timber harvest and other forest management activities. However, achieving the benefits of an expanding bioeconomy in this region will require a new generation of supply chain models that integrate techno-economic analysis and life cycle assessment into multi-feedstock, multi-process procurement planning to manage biomass supply risk as measured by cost, quality, timing, energy balance, greenhouse gas emissions and other metrics. We will present a framework for MASBio feedstock supply modeling that includes the use of new heuristics to solve large, complex problems using real-time production, logistics and procurement data from existing and new conversion facilities. These models explicitly incorporate uncertainty and spatial and temporal variability that can intensify risk, with the purpose of de-risking biomass supply and improving the design, performance and circular nature of bioproduct supply chains that include forest biomass from diverse sources.

Theme 1: Human Factors and Safety

Comparison of battery driven and gasoline driven brush cutters in terms of efficiency and ergonomic effects

Christoph Huber, Nikolaus Nemestóthy, Jürgen Richter

Promoting Occupational Safety and Health in Motor-Manual Tree Felling: A Postural Analyses

Efi Yuliati Yovi

Logging Practice in Indonesian Natural Forests: Adoption of Personal Protective Equipment Associated with Worker Safety

Hermudananto Hermudananto

Important considerations for using mobile and wearable device sensors to model worker productivity and develop digital health and safety applications for motor-manual operations

Robert F. Keefe, Eloise G. Zimbelman

An Ergonomics Risk Assessment of Manual and Motor-Manual Pruning of Pinus Patula at Two Different Lifts

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ABSTRACT

Mechanization and modernization in pruning operations for South Africa's forestry industry have advanced to keep abreast with best practices internationally. Commercially planted pine species in South Africa are not self-pruning, therefore, pruning activities are done extensively to produce clear wood, for fire protection or accessibility purposes. Although traditional handheld pruning tools have been used for decades, motor-manual pruning saws have recently been introduced to South African pruning operations. This has, however, raised the question what the ergonomic risks in manual and motor-manual pruning operations potentially expose workers to. Therefore, the study aimed to assess ergonomic risks that may be associated with the manual (M) and motor-manual (MM) pruning operations of Pinus patula stands in Kwa-Zulu Natal (KZN), Midlands.

Seven pruners were sampled to collect data on productivity, workload, awkward postures and body discomfort rating for ergonomic risks assessment. Statistical analyses were executed using Statistica 64 and Excel functions. Awkward postures were assessed for deviation from the neutral plane of body posture using the REBA tool to assess the risk level.

Results show that pruning operations fell under the "medium to heavy" workload classification. Manual operations yielding less productivity compared to motor-manual operations. Common postures adopted by workers were the shoulder and elbow abduction and extension, twisting and neck extension, ulnar deviation and bending of the back. High prevalence of discomfort was reported for manual (55 %) operations compared to MM (49 %) and 2.0 m pruning lift (61 %) and 3.5 m pruning lift (42 %). Pruning operations were rated as severe discomfort except for 3.5 m MM, which was rated as moderate discomfort. Some of the postures adopted by workers must be adjusted to avoid future health problems, such as high flexion of the back in the 2.0 m M and MM operations with a high prevalence of discomfort reported. Additionally, the duration of exposure to the operation and the repetitive nature

of pruning operations are additional ergonomic risks identified in this study.

These results show that pruning have associated ergonomic risks that and therefore should be considered for further mechanization interventions of pruning equipment. However, it is recommended for this study to be repeated with a larger sample and with gender as an additional factor to represent current pruning teams. Additionally, a thorough focus on musculoskeletal disorder since many workers have been working in the forestry industry for years.

A Question of Business Culture - Multi-Methodical Analysis of Forest Work Accidents

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ABSTRACT

Forestry work remains one of the occupations with the highest risk of accidents compared to other sectors: occupational accidents occur more frequently and are also often more serious than in other fields of work. Motor-manual timber harvesting is assessed as a particularly dangerous task in everyday forest work. As part of a study on occupational safety in forest work, a multi-method research design was carried out in Baden-Wuerttemberg between 2015 and 2019, providing new insights into this complex field of research (Sauter et al. 2020). Accident reports were statistically analyzed and additionally, guided interviews with occupational safety experts and group discussions with forest workers were conducted. The aim of the study was to find explanations for the particularly high accident rates in the investigated state forestry operation and to offer concepts for safety management.

The results show that the originally suspected hazards, such as the high average age of the forest workers or the high proportion of terrain with steep slopes, cannot be the causes of the high accident figures. Rather, in difficult terrain the level of concentration is extremely high, and accordingly there is an overall higher stress in the daily work, which leads to accidents in other places. The foresters themselves see the near-natural silviculture and especially the increase of natural forest regeneration in the area as a main danger for their work safety. They do not only criticize the changed forest cultivation per se, but also the operational processes and developments behind these changes and the related safety management. The analysis shows, when workers are not adequately involved in management processes that influence their everyday workplace to such an extent, this can cause an indirect safety hazard, e.g. because the resulting frustration can diminish the commitment to safety regulations and cause psychological stress.

Our results show that occupational safety is a cross-sectional issue that should be considered in all areas of organizational action. According to this understanding of occupational safety, methodological requirements for the investigation of occupational safety problems also arise.

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Decision-Making among Harvester Operators in Tree Selection and Need for Advanced Harvester Operator Assistant Systems (AHOASs) in Thinnings

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Abstract: The aim of this survey was to investigate the decision-making of harvester operators in tree selection during thinning and their views regarding what kind of advanced harvester operator assistant system (AHOAS) would be useful in cutting work on thinning sites. In total, 60 harvester operators with thinnings as their primary cutting sites were interviewed. The results of the survey revealed that the selection of trees for removal was most frequently affected by the diseases and quality defects of trees. The most important quality features for stems with automated identification that would support cutting work were corkscrew, resinous wounds and top breaks in trees. Of the operators, 88% said that they would utilize an assistant application that could monitor the thinning intensity during cutting work, while 51% found that the assistant system for tree selection would be useful. The choice between two trees with defects was regarded as the most noteworthy situation, one for which decision support would be needed. The operators estimated that a tree selection assistant system would have mainly positive effects on cutting work, including higher quality and productivity of cutting work and better well-being at work. In conclusion, rather than the AHOAS guiding the operator to leave or remove individual trees, it is more essential for it to provide information on the quality of individual trees and thinning intensity in the stand. Based on this information, the harvester operator could make the final tree selection decisions and produce a suitable thinning intensity for the stand. The operators interviewed had a positive attitude towards AHOASs in this survey, providing a solid basis on which to launch the new AHOASs for the operators. Technological development work on forest machines is needed to enable the introduction of semi-automated and fully automated machines equipped with advanced sensors in the future.

Keywords: cutting, thinning intensity, quality, productivity, forest machine automation

1. Introduction

The impact of a harvester operator on cutting performance (i.e., productivity and quality) is remarkable. Several studies have illustrated that there is a significant correlation between the work experience and skills of a harvester operator and their productivity in cutting work, particularly in thinning stands (e.g., Sirén, 1998; Kärhä et al., 2004; Ovaskainen, 2009; Purfürst, 2010; Palander et al., 2012). During the last few decades, forest machine manufacturers have actively improved their produced forest machines in many ways. Such development has led to a situation in which productivity is increasingly constrained by the forest machine operator and their skills rather than by the machine unit (Väätäinen et al., 2012). Additional information and guidance during the decision-making process for forest machine operators would improve the productivity and quality of harvesting work, as well as alleviate the mental workload of an operator and speed up on-the-job learning, especially with a beginner forest machine operator (cf., Ylimäki et al., 2012; Räsänen, 2020; Spinelli et al., 2020).

During thinning, the growth of a forest stand is encouraged by promoting the best and most vibrant trees of the highest quality. Thinning is challenging work, not least because the information received by the harvester operator about the trees and forest stand during cutting work is often incomplete and inaccurate (e.g., Ovaskainen, 2009; Kokkarinen, 2012). Therefore, many different types of guidance to provide the harvester operator with additional information on the tree stand to support their cutting work is vital for forest thinnings. Vahtila (2019) and Räsänen (2020), for instance, have shown that the productivity and quality of cutting work is higher when the harvester operator is assisted with prior tree-marked stems during thinning. Moreover, Räsänen (2020) has reported that the mental workload of the harvester operator is lower when they are supported in tree selection and control of thinning intensity on thinning sites. However, studies by Spinelli and Magagnotti (2013) and Holzleitner et al. (2019) have found that there is no significant effect on cutting productivity when the harvester operator is guided by prior tree marking for tree selection during thinning operations.

Studies by Väätäinen et al. (2011), Ylimäki et al. (2012) and Kauppinen et al. (2016) have highlighted the need for a harvester operator guidance during cutting work. Advanced harvester operator assistant systems (AHOASs) and decision support systems (DSSs) refer to electronic devices or systems based on the advanced sensor technology of mobile laser scanning (MLS), machine vision (MV) or a combination of these. They assist the harvester operator in their decision-making and facilitate the use of the harvester by guiding the harvester operator through various stages of work, for example by selecting removable trees on thinning sites and controlling the thinning intensity in forest thinnings, although they do not yet exist in field use.
The aim of this survey was to investigate the decision-making of harvester operators regarding tree selection during thinning and their views on what types of AHOASs would be useful in cutting work on thinning sites. The survey also examined harvester operators' current expectations of AHOASs. Moreover, the survey detected the effects of the age and thinning experience of the harvester operators on their decision-making, views and expectations of AHOASs.

2. Materials and Methods

2.1 Interviews and Questionnaire

The survey was conducted using telephone interviews. The forest machine entrepreneurs contracted to Stora Enso Wood Supply Finland were asked to name their harvester operators with solid experience in the cutting work of thinning stands. In total, 60 harvester operators whose cutting sites had been mainly thinnings were interviewed. Half of the interviews were conducted in 2018 (Kasper, 2019) and the rest of the interviews in 2019 (Inget, 2020).
A semi-structured questionnaire consisting of seven sections with ready-made answer options (including the options queried of "Other issue, what?") was drawn up. In the first section, the background variables of the respondents were investigated, i.e., the harvester operators' ages and educational backgrounds, experience in thinning work (in years) and total cutting volume in 2018, along with what proportion of the total cuts in 2018 came from thinning stands. Furthermore, the questionnaire clarified whether the harvester operators had any previous experience with working in pre-marked forest stands, and, if the respondent did have previous experience, what kind of cuttings they had made on the pre-marked harvesting sites.

The average age of the harvester operators interviewed was 43 years (std: 11.8 years), with a range from 18 to 68 years. The operators interviewed had strong experience in thinnings, with an average of 18 years (std: 8.3 years). A majority (55%) of the operators had the occupational education of a forest machine operator. In 2018, they had cut, on average, 31,000 m^3 (solid over bark)/operator (std: 19,000 m^3/operator). From thinning stands, the operators had felled 62% of their total wood quantity in 2018. Almost half (45%) of the operators interviewed had some type of experience with cuttings on pre-marked harvesting sites, including special fellings (e.g., property fellings, cuttings

from defective tree stands with pre-marked stems), trees marked for cutting by a forest landowner, or, in the case of older harvester operators working during the era of lumberjack cuts, pre-marking conducted by a forest company officer.
The second section of the questionnaire dealt with harvester operators' decision-making processes and the selection of trees to be removed. First, the respondents were asked to describe how they select trees for removal during the first and later thinnings. There were three answer options for this portion of the questionnaire: In the working sector, I select first the trees to remain, with the rest of the trees to be removed; I select first the trees to be removed in the working sector, with the rest of the trees to remain; and I alternate between removable and remaining trees. Afterward, an open question clarified during which cutting element(s) the harvester operator most commonly selects the removable trees in thinnings. Finally, respondents were asked how many trees to be removed or to remain the operator usually outlines on average at one time during thinning.

The third section of the questionnaire concentrated on the characteristics of the removable trees: What characteristics and issues most influence the harvester operator's selection of the trees to be removed during thinning? The evaluations were conducted using a five-level Likert scale: 1 = Not important at all; 2 = Of little importance; 3 = Moderately important; 4 = Important; and 5 = Extremely important. The characteristics and issues evaluated were quality defects (e.g., crook, corkscrew, top break, knottiness); proportion of the living canopy of tree; diseases in the tree (e.g., resinous wounds); tree species; uneven spatial distribution in stand; position of the tree in relation to the surrounding trees; position of the tree in relation to the harvester; wishes of the forest landowner; and tree stem size. Additionally, the respondents were asked to determine which part of the tree they usually focus on when selecting trees for removal during thinning. Respondents were asked to choose the most accurate option of three: Mainly to the butt of the stem; Mainly to the canopy of the stem; and To the entire length of the stem.

In the fourth section of the questionnaire, the harvester operators were asked to evaluate how different harvesting circumstances make tree selection more difficult during their cutting operations. Their evaluations of the success of tree selection were made using a five-level Likert scale (from 1 = Not important at all, to 5 = Extremely important). The harvesting circumstances evaluated were density of initial tree stand (e.g., delayed first-thinning stands); snow in trees; dense undergrowth; dazzling sunlight; high density of deciduous trees when the main tree species in the stand is Norway spruce (*Picea abies* (L.) Karst.) or Scots pine (*Pinus sylvestris* L.); and darkness and rainfall.

The fifth section of the questionnaire focused on any additional information required by the harvester operator. First, the questionnaire asked what kind of additional information the respondents consider the most useful in selecting the removable trees. The benefit evaluations were conducted on a five-level Likert scale (1 = No benefit at all; 2 = Of little benefit; 3 = Moderately beneficial; 4 = Beneficial; and 5 = Extremely beneficial) relating to additional information about the different parts of the tree (top; butt; and canopy) and tree species (Scots pine; Norway spruce; and birch (*Betula* spp. L.)). Second, the respondents were asked to choose the three most important quality features of trees which would automatically identify them as removable trees during thinning. The quality features of trees listed were resinous wounds; corkscrew; two-forked tree; top break; vertical branch; knottiness; decay; and crook.

In the sixth section, the questionnaire determined which different factors the respondents believed to have the most important effect on thinning intensity. The answer options were as follows: Target set for thinning removals (m^3/ha); Density of initial tree stand; Spatial distribution of initial tree stand; Low quality of initial tree stand; Harvesting machinery to be used; Capability of the harvester operator to estimate the number of remaining trees; and Difficult terrain. The evaluations were conducted on a five-level Likert scale (from 1 = Not important at all, to 5 = Extremely important). Moreover, the questionnaire asked whether an operator would utilize an assistant application for controlling the thinning intensity if they had one. The answer options were: Yes; No; and I cannot say.

The seventh section of the questionnaire concentrated on the visualization of the removable trees to the harvester operator. First, it clarified the views of the respondents on whether or not the tree selection assistant system would be of potential benefit to them. Second, it investigated which information about the trees would be most useful in decision-making situations: Choice between two trees of different tree species; Choice between two defective trees; Selection of remaining trees alongside strip road; and Selection of removable trees from the outer edge of work location. The evaluations were conducted applying a scale of Never; Rarely; Sometimes; and Often. Third, the questionnaire asked the interviewed operators' thoughts on the possible effects of an advanced tree selection assistant system. The effects queried were: Guidance on tree selection would increase the quality of cutting work; Guidance on tree selection would increase the productivity of cutting work; The use of a tree selection assistant system would improve my well-being at work during the workday; and Guidance on tree selection would hamper my normal cutting work. Finally, the questionnaire asked the respondents' views regarding for which cutting method the harvester operator tree selection assistant system would have the greatest potential: In first thinnings; In later thinnings; or The potential would be equal in both first and later thinnings.

2.2 Data Analysis

The variables of decision-making and AHOASs in the survey were analyzed using percentage shares and distributions, mean values and standard deviations (std). The differences between the harvester operators interviewed related to their ages and thinning experience were analyzed. The groups tested in relation to the ages and thinning experience of the harvester operators were created by applying upper and lower quartiles, i.e., about one quarter of the operators (n=14–16 interviewees), to the following groupings: harvester operators below 34 years of age were considered to be *Young* (n=15), 34–51 years was *Middle-aged* (n=29), and over 51 years was *Old* (n=16). Similarly, harvester operators who had thinning experience of less than 11 years were regarded as *Beginner* (n=16); thinning experience of 11–22 years was considered *Skilled operator* (n=28); and experience of more than 22 years was *Master* (n=16).

The survey data was initially tested for normal distribution assumption using a Kolmogorv-Smirnov test. Based on the results of the test, the survey data did not comply with normal distribution. Since the material was not distributed normally, non-parametrical tests—Mann-Whitney test (U) and Kruskal-Wallis one-way ANOVA test (χ^2)—were used in the statistical analysis of the survey. A significance level of 0.05 was applied. This paper reports only statistically significant differences between the groups tested in terms of the harvester operators' ages and thinning experience.

3. Results

3.1 Selection of Removable Trees

The harvester operators interviewed were asked to describe whether they choose first the trees to remain (i.e., trees to be saved) when thinning, first the trees to be removed, or whether they alternately select the trees. The responses were almost evenly distributed among the options of *Trees to be removed* and *Alternately*. Of the operators, 46% said that they select first the removable trees on the thinning site, while 47% of the operators said that they alternate selection of the trees. Only 7% of the respondents reported that they select first the trees to remain and then the trees to be removed. According to oral comments by the harvester operators interviewed, the procedure for tree selection at the level of one work location followed three steps:

1. Look at first the trees that are clearly different from other trees (i.e., diseased or faulty trees) and remove them.
2. Select the best quality trees for which thinning is conducted.
3. Remove trees around good quality trees so that the density and other thinning targets are met.

The interviewees emphasized that the main goal of thinning work is to produce a good quality tree stand with a uniform spatial distribution and height ratio. The operators interviewed reported that they most commonly make their tree selection decisions during the processing of the last log in the stem processing cycle. Another typical time to select the trees was during moving from one work location to another with the harvester, allowing the trees to be viewed from more than one direction. Tree selection decisions were also conducted when the harvester head was steered out and grabbed or felled a tree; however, most interviewees stated that these work elements require intense concentration and attention, making simultaneously reviewing standing trees out of the question.

The respondents were asked how many trees to be removed or to remain they perceive at a time during the cutting work of thinning stands. This question was found to depend strongly on the harvesting conditions of the forest stand and the tree species. For example, on the untreated Norway spruce thinning site, the progression may be from one tree to the next consecutively; on the other hand, when there is good visibility in a dry upland Scots pine thinning stand, more than five trees at a time may be perceived. It was most frequently estimated that 3–5 trees to be removed or to remain would be perceived at once.

The interviewees were also asked to name the part of the tree at which they look first when conducting tree selection. Most of the interviewees (75%) carried out selection of a tree based on the quality of the whole tree stem. The most common method was to evaluate first the living canopy of the tree, then the butt, and finally the entire tree stem. The initial tree stand influenced the method of observation: in a homogeneous Scots pine thinning stand, the aim was to take into account the removable trees on the basis of quality defects and diseases by first looking at the tree stem. In contrast, with a delayed thinning, attention was first paid to the condition and vitality of the tree canopy. In later thinnings, operators first focused on the butt of the stem to assess the quality of the butt log section.

Selection of removable trees was most frequently affected by the diseases and quality defects of trees (Fig. 1). The next most important selection criteria for the operators were the wishes of the forest landowners and the share of the living canopy from the total length of a tree. There was a significant difference according to thinning experience between the operator groups in terms of the wishes of the forest landowner (χ^2=10.6; p<0.01). The harvester operators with little thinning experience (*Beginners*; U=-10.5, p<0.05) and those with extensive experience (*Masters*; U=15.9, p<0.01) placed significantly less emphasis on the wishes of the forest landowners in the selection of the removable trees compared to the *Skilled operators* (those with thinning experience of 11–22 years).

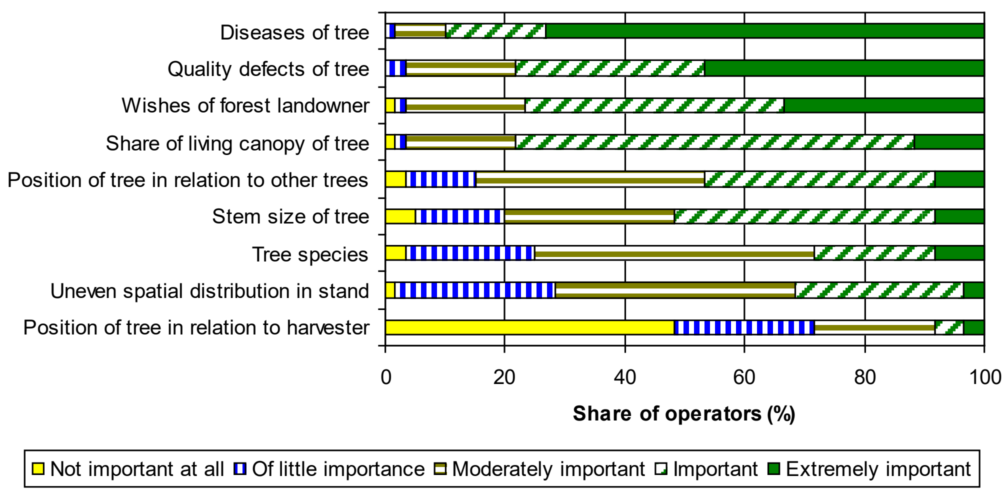

Figure 1. Operators' opinions on what characteristics and issues most influence the selection of the trees to be removed during thinning

The position of the tree in relation to the other trees in the stand, the stem size of trees, the tree species of the removable trees and the uneven spatial distribution were considered to be moderately essential criteria for the selection of removable trees (Fig. 1). There was a significant difference between the age groups of the operators regarding the selection option of the position of the tree in relation to the surrounding trees (χ^2=6.8; p<0.05). The *Young* harvester operators highlighted the position of the tree in relation to the other trees in the stand as a selection criterion less than the *Middle-aged* (U=-11.1, p<0.05) and *Old* (U=-14.6, p<0.05) harvester operators did.

The least meaningful factor was considered to be the position of the tree in relation to the harvester (Fig. 1). The operators interviewed emphasized that the machine can be moved in relation to the position of the tree; furthermore, according to the interviewees, the position of the tree is not a criterion for leaving the tree during their cutting work.

Among other factors to be assessed in the selection of a tree, the strip road network and the trees damaged by cutting were also mentioned as influencing the selection of the trees to be removed.

Dense undergrowth was estimated to be by far the most difficult environmental factor impacting successful tree selection (Fig. 2). Snow in trees was also found to cause challenges in detecting tree defects, as well as to create vision problems due to snow dusting during cutting. Darkness combined with rainfall was perceived as a challenging harvesting condition, as was dazzling sunlight. The density of the initial tree stand and the high density of deciduous trees in a coniferous-dominated thinning stand were not estimated to have a remarkable negative effect on tree selection. In fact, respondents felt the opposite; in other words, the high initial density was reported to provide more opportunities for tree selection. In addition to the previous options, a challenging terrain (i.e., steep terrain or soft and wet soil) was estimated to make cutting work more difficult and reduce the opportunities for tree selection.

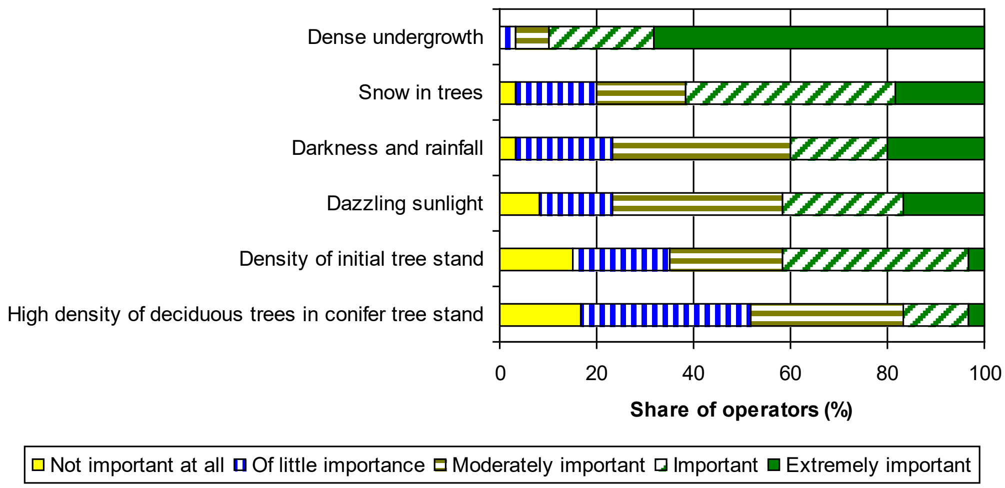

Figure 2. Operators' opinions on how the different harvesting circumstances make tree selection more difficult during thinning

3.2 Additional Information Required by the Operator

The harvester operators interviewed most frequently wanted additional information for their cutting work regarding the condition of the living canopy of trees and the top of the tree as a whole, since visibility to the top layer of the forest stand is usually weak. Sufficient information is usually obtained from the lower (butt) part of tree stem, because the lower part is sufficiently visible from the cabin of the harvester. Nevertheless, there was a high perceived need for more information on the invisible, shaded side of stems.

By tree species, the greatest benefit potential from additional information was reported in regard to the Norway spruce. The branches of Norway spruce trees cover almost the entire stem; therefore, exploring stem defects is challenging. Additionally, snow accumulation on Norway spruce branches in wintertime noticeably increases the visual barrier in the forest stand. For Scots pine and birch, the need for additional information was perceived to be the greatest regarding either very good or very poor quality thinnings, in which there are too many or too few obvious options.

The interviewees were further queried to name the three most important quality factors of stems, the automated identification of which would support their cutting work. In the oral comments given, assistance was sought to identify quality features that are difficult to detect in one direction from the strip road when viewed from the harvester cabin. The most important quality features listed by the interviewees were corkscrew, resinous wounds and top breaks in trees (Fig. 3). In addition, the interviewees underlined the need to identify decay in the stem; however, they also stated that it is almost impossible to identify decay in the tree solely on the basis of the external appearance of the stem.

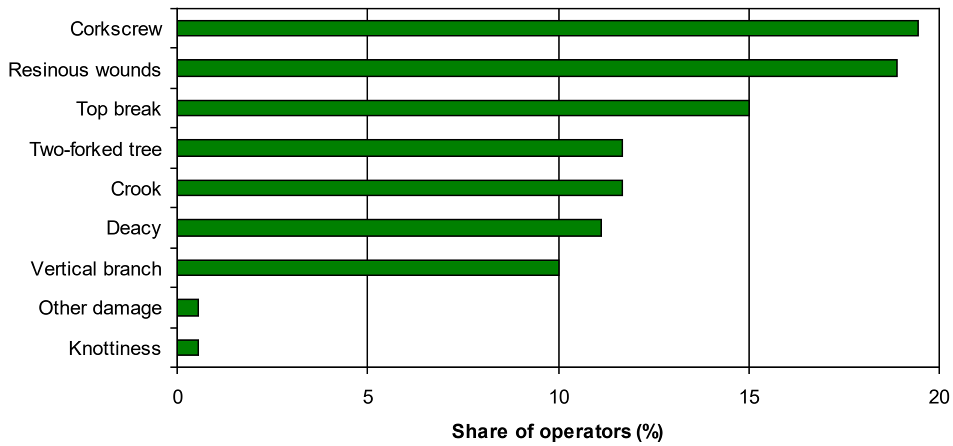

Figure 3. Operators' opinions on the most important quality features of stems which could automatically distinguish between the trees during thinning and hence support the cutting work of harvester operators

3.3 Thinning Intensity

The operators interviewed regarded the capability of the harvester operator to estimate the amount and density of remaining trees in the stand as the most important factor in controlling the thinning intensity (Fig. 4). The second most important factor was the terrain. The interviewees stated that there is no access to all parts of a thinning site with a forest machine. Hence, more stems can be taken from the easily accessible parts of a harvesting site, while more trees may be left in difficult ones, depending on the terrain.

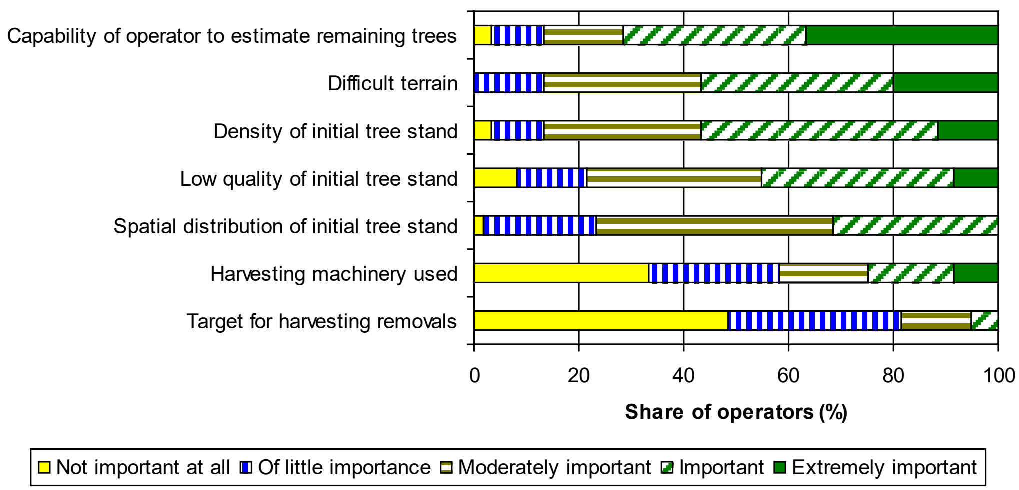

Figure 4. Operators' opinions on which different factors have the greatest effect on the thinning intensity of cutting operations

The respondents considered the density of the initial forest stand to be the third most important factor (Fig. 4). The operators interviewed underlined that a dense initial stand offers more choices in thinning, while the dense (unmanaged) stand can be left to remain slightly denser due to the potential risk of devastations. The operators also pointed out that it is very challenging to thin a cutting site with low-quality initial trees into a homogeneous tree stand; moreover, there are many tree stems that can be classified for removal. Thus, it is difficult to choose the trees to be left to grow. The interviewees underscored that the harvesting machinery used and the target set for harvesting removals have only minimal effect on the thinning intensity during practical cutting operations (Fig. 4).

Of the operators, 88% said that they would utilize an application that could monitor the thinning intensity during cutting work if such an assistant application were available. On the other hand, 7% of the operators stated that they would not be willing to use that kind of assistant application if it were available. The rest (5%) of the respondents did not want to comment on the issue.

3.4 Visualization of Removable Trees to the Operator

More than a half (51%) of the operators interviewed reported that the assistant system for tree selection would be useful if such a guidance system were available. Conversely, 42% of the harvester operators interviewed did not see the assistant system for guiding tree selection as necessary, and the rest (7%) of the interviewees did not want to comment on the matter of potential benefit. Regarding tree selection, the greatest benefit potential of the assistant system was felt to be for both cutting methods, i.e., both in first and later thinnings.

The choice between two defective trees was regarded as the most noteworthy situation for which decision support from the assistant system would be beneficial (Fig. 5). The selection of the removable trees from the outer edge of the work location was regarded as the second most beneficial situation. The choice between two trees of different tree species or the choice of leaving trees to remain alongside strip roads were not perceived as very difficult selection situations. Among the other tree selection situations, the interviewees emphasized the challenges of poor visibility and the difficulties of perceiving boundaries on harvesting sites.

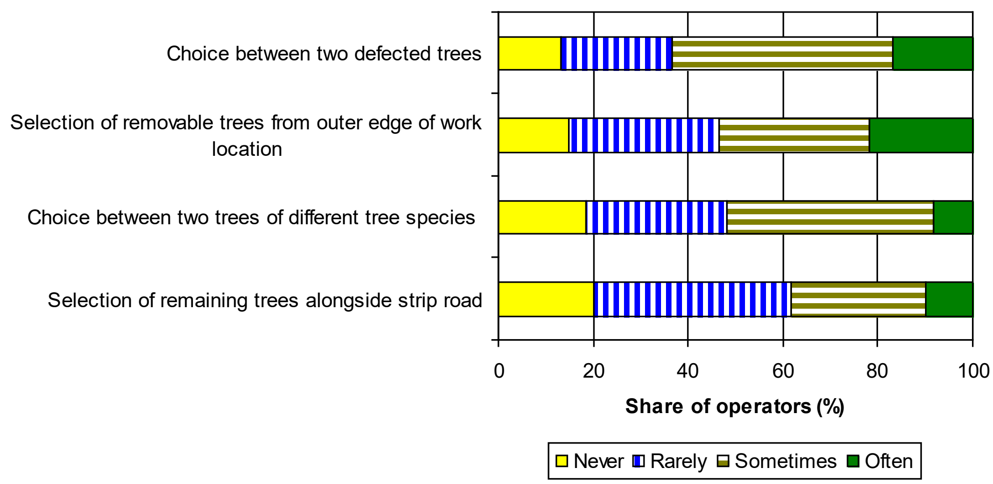

Figure 5. Operators' opinions on for which decision-making situations information about the trees would be useful during thinning

The operators estimated that the tree selection assistant system would have mainly positive effects on their cutting work. They posited that the system would increase the quality and productivity of cutting work and improve their well-being at work during a long work shift (Fig. 6). While the majority (69%) of the *Middle-aged* and *Old* harvester operators believed that a tree selection assistant system would not hamper their normal cutting work, only one third of the *Young* operators thought so (χ^2=7.7; p<0.05).

Based on the comments collected during the interviews, the tree selection assistant system should not cause conflicts between the harvester operator and the system (a situation likely to increase the harvester operator's mental workload and stress as well as the time consumption of cutting work).

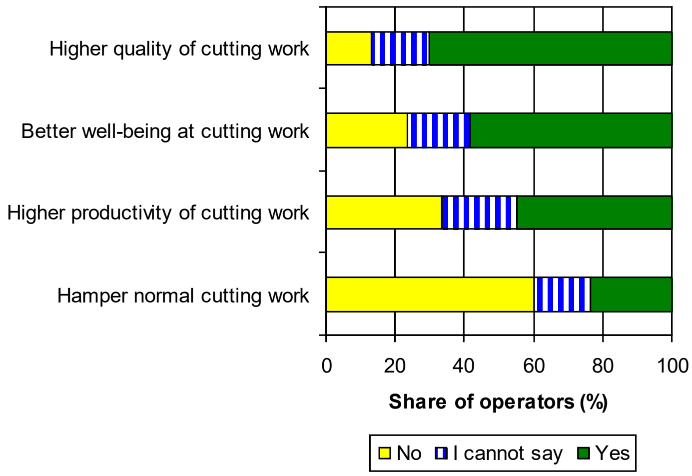

Figure 6. Operators' opinions on what possible effects the tree selection assistant system would have on the cutting work of thinning stands

4. Discussion and Conclusions

When planning and designing a novel assistant system, the first task is to determine the needs and study the daily work and behavior of the target group, including their most commonly carried out decision-making situations (cf., Tervo, 2010; Palmroth, 2011). This survey revealed the current problems and challenges facing harvester operators during tree selection and when dealing with thinning intensity according to the current silvicultural recommendations in Finland (Äijälä et al., 2019). The needs of harvester operators for additional information and assistance during cutting work were also investigated. Furthermore, the survey provided a basis for the development of a tree selection automation concept for forest machine manufacturers.

The survey conducted produced a set of the most useful characteristics for AHOASs during thinning, and particularly for tree selection and controlling the thinning intensity. On the basis of the survey, it can be concluded that, at the forest stand level, information regarding the boundaries of the harvesting site and the most favorable location for the main strip road network would be useful. Secondly, at the work location level, the AHOAS should illustrate the thinning intensity, including the proportions of tree species in the stand, for the harvester operator. Finally, at the tree level, the pivotal issue would be to obtain more accurate and comprehensive information on the possible quality defects of individual trees than the human eye can produce. In other words, information on defects in the shadows for the harvester operator is required. Information on the proportion of living canopy from the total length of the tree would also be useful for the harvester operator according to this survey.

The results indicated that the ages and thinning experience of the harvester operators have no significant effect on their decision-making during tree selection or their views and expectations of AHOASs. There were only a few statistically significant differences between the harvester operator groups concerning their ages and thinning experience in the selection criteria of the removable trees and the possible effects of the tree selection assistant system on cutting work during thinning. However, attention should be drawn to the fact that the survey data consisted of only 60 operator interviews. It can be assumed that if the survey material collected had been larger (>100–200 interviews), more statistically significant differences would probably have been found between the groups studied in the survey.

The harvester operators' tree selection when thinning stands is the result of a great many different factors, including the operator's way of working. In conclusion, rather than the AHOAS guiding the operator to leave or remove individual trees, it would be more useful for the assistant to provide information on the quality of individual trees and thinning intensity in the stand. Based on this information on trees and the forest stand, the harvester operator could make the final tree selection decisions and maintain a suitable thinning intensity for the stand. Furthermore, Palmroth (2011) emphasized that instead of precise guidance, useful hints and suggestions could be presented to the operator to help improve their performance and skill levels. As a result of such a process, the next natural development step in the use of quality information would be a self-learning DSS that utilizes quality information and operator selections.

The harvester operators interviewed had a positive attitude towards new AHOASs in this survey. The results of the survey are in line with earlier studies on forest machine operators and their attitudes towards forest machine operator assistance systems (e.g., Ylimäki et al., 2012; Kauppinen et al., 2016). These attitudes towards AHOASs provide a solid background from which to create and launch new AHOASs for harvester operators. Technological development of forest machines is necessary to enable the introduction of semi-automated and fully automated machines equipped with the advanced sensors of an MLS, MV or a combination of these in the future (e.g., Lindroos et al., 2019; Vahtila et al., 2019; Visser & Obi, 2021).

Given current sensor technology, producing sufficiently accurate and cost-effective quality information on individual trees will be challenging in the near future (cf., Palander & Kärhä, 2021). Nonetheless, recent machine vision studies on monitoring harvesting results with stem damage have shown that analysis of forest tree stands from collected images is already at a sufficient accuracy level to support forest machine operators in their decision-making (e.g., Palander et al., 2019).

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The Permanent German Forest Rescue Point System - Concept, Geographical Analysis, and Optimization

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ABSTRACT

Working in the forest is always associated with dangers. Manual forestry work, which still accounts for between 20 and 33 % of all forest work in Germany, is hazardous. Nevertheless, many accidents also occur during recreational activities in the forest. In the case of an accident, fast help is therefore crucial. Rural areas are usually not characterized by many salient points, and it can be challenging to navigate the help to the right place.

In Germany, a network of permanent points has been created, known to all persons involved in rescue operations. These can serve as meeting points and points of orientation. These points are clearly numbered, often marked, and the positions and other information are known. In an emergency, rescuers and helpers find each other there.

Currently, it also exists about 65,000 permanent rescue points. The network was set up to the best of one's knowledge and belief of the persons involved. The question emerges whether the number of points is sufficient and whether they are well distributed and ideally placed for a rescue in the forest. Therefore, this study aims to provide a granular complex geographic analysis of the distribution and the accessibility of existing rescue points. These analyses form the basis for improving and optimization of the existing permanent rescue point system.

Further results are shown in the presentation and the paper.

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Ergonomic Assessment of Motor-Manual Tree Felling and Processing Operation: A Comparison in Damaged and Undamaged Forest Stands

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ABSTRACT

Motor-manual tree felling is a technical approach widely adopted for logging operations, especially in difficult terrain worksites where the deployment of modern harvesting machinery is limited. Motor manual felling is commonly considered as exhausting work, ergonomically adverse and which expose forest workers to potentially critical working conditions. However, the occurrence of dangerous situations can be due to several factors, which can be attributed to the difficult conditions of the worksite as well as to the skill and experience of the operators. Few studies investigate the relationship between the ergonomic conditions of forest operators and the complexity of the worksites. The following study, which is part of an ongoing research project, aimed to assess the workload and risk of work-related musculoskeletal disorders (WMSDS) of operators carrying out motor-manual tree felling and processing in different working conditions. Several workers with different work experience and physic performance were heart rate monitored in tandem with a time study to analyze the workload experienced per work element. Average terrain slope and roughness was also collected for each site. In addition, short videoclips were realized with action camera to capture the workers motions during felling and processing operations. Workload analysis was following developed by applying the relative heart rate at work (%HRR), ratio of working heart rate to resting heart rate (HRw/HRr) and 50% level of heart rate reserve (50% Level) indices respectively. The risk of musculoskeletal disorders was whilst evaluated through the procedure proposed by the Owako Working Posture Analysis System (OWAS). Furthermore, heart rate data were deeply explored to investigate the relationship among forest operators workload and working conditions according to a gradient of severity of the workplace. The expected results should highlight that both workload and highly risk postures assumption may be attributable both to different working conditions and to intrinsic factors of the operator linked to his professional training and experience.

Fully Mechanized Pruning with the PATAS Module - A Joint Study in Northern Germany on Productivity and Ergonomics

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ABSTRACT

The increasing share of Douglas Fir and Larch in German forests requires new efforts in tree pruning to ensure supply of high quality forest products to the middle-European timber market in the future. Forest technology uses different manual or semi-mechanized work methods with pole saws, pneumatic modules or electric shear to prune these trees. The PATAS is a hydraulically operated module for pruning. The system allows for enhancing pruning efficiency. The objective of this pilot study was to analyze the work method using PATAS with respect to work time share and productivity, ergonomic workload, debranching quality and occupational health risk.

Therefore, a descriptive time study using international IUFRO nomenclature for work time studies was performed. Additionally, by recording distances between the tractor based supporting unit and the locations of pruned trees, the system´s working radius was assessed. By using a heart rate monitor, the individual strain of operating personnel was assessed. Pruning quality and occupational health were assessed via random samples after the operation.

Results show for the total time a share of work time and non-work time of 75 and 25%, respectively. The share of main work time was 42% and of complementary work time 29%. Work elements with highest time consumption were "tree search with aggregate" (27%), "pruning process" (15%) and "positioning of tractor" (12%). The average of working radius of the system was 10.5 m. The analysis of the heart rates during the operation indicated a high workload, in which the heart rate was often just under the individual performance limit. The evaluation of the pruning quality showed that 23% of the pruned trees had smaller pruning damage, 91% of damages were found at a tree height of 9 m and more. Analysis of occupational health risks revealed that 83% of branches fell down in a radius up to 3 m around the pruned tree.

Overall, the PATAS module showed a pruning productivity of 28.5 trees per hour (work time). Depending on calculation scenarios, pruning costs per tree range between € 3.70 and € 5.80. Compared to conventional methods, a cost reduction of up to 75% seems to be realistic. Limiting factors for time consumption are e.g. accessibility of the stand, presence of shelter and ground cover, and the number and spatial distribution of the pruned trees. As the demand for high-quality softwood will continue, the PATAS system could be an innovative addition to existing commercial pruning techniques.

A Search for Beneficial Work Practices of Forest Machine Operators - Interviews with Forest Machine Instructors and Scientific Literature Search

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ABSTRACT

Productivity and quality of mechanized harvesting is crucially dependent on the applied work methods and their implementation by forest machine operators. The implementation depends on the individual skill level of the machine operator which can vary vastly. In the current study we define “work practice” in accordance with the German REFA institute as “individual way of carrying out the work process, based on the work method used”. Thus, both operator skill level and work practices are inherently related and determine performance of the human-machine system. Skilled and efficient performance renders visible virtually within all work tasks of a forest machine operator. Therefore, we aimed to identify work practices (manners and ways of execution) in different work tasks that benefit the human-machine system performance.

We used a two-fold approach to identify beneficial work practices. First, we conducted semi-structured interviews with forest machine instructors in Sweden, Norway, and Germany. Secondly, scientific literature on work practices of harvesters and forwarders was reviewed. Sixteen experienced instructors were interviewed and queried about work practices within different work elements such as the machine positioning, crane movements, felling, and delimbing of the trees. Within each work element instructors described common execution errors and provided recommendations on how to instruct and support operators for increased future performance. We systematically searched databases for scientific literature on beneficial work practices. We focused on studies that compare work practices and their effect on performance measures; for example, productivity, mental workload or soil impact. Studies that provide insights to the work practices were reviewed and classified.

A major finding was that forest machine instructors described a wealth of work practices that may increase the performance of the human-machine system, whereas the literature unveiled a lack of common terminology and operator focused research on work practices. Overall the amount of scientific literature concerned with work practices is sparse. To gain a clearer picture on efficient work practices, we compiled recommendations that are generally beneficial to the operators’ performance. However, we have to bear in mind that generalizability always trades with specificity. Thus, work practices that may be beneficial in some contexts are not in others i.e. in difficult terrain or in adverse weather conditions.

Exoskeletons in Forest Work

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ABSTRACT

The profession of forest worker is still characterized by high physical stress. Despite technical developments, a considerable amount of work still has to be done that requires increased physical exertion. Forced postures cannot always be prevented. Tasks involving increased exertion and/or forced posture include various planting, thinning and pruning operations and motor-manual timber harvesting. Despite advancing mechanization, these activities will continue to be of great importance in the future and their share in the daily working time of forest worker will even increase significantly in some cases.

Experience in other industries shows that exoskeletons can help reduce the physical strain on workers, making the workplace healthier and more attractive. Exoskeletons developed for industry and used in the automotive or logistics sectors, for example, could also be considered for use in forestry. Whether exoskeletons will become established there depends in particular on their potential contribution to optimizing the workplace and their suitability for use in the demanding and diverse working conditions in the forest.

In order to provide the required information, comparative measurement series on the influence of exoskeletons on workload in different frequently occurring and physically stressful activities in forestry (planting, thinning, pruning, motor-manual timber harvesting) are to be carried out in the next few years.

In the first project, a PAEXO Shoulder exoskeleton from Ottobock will be used for pruning of Douglas fir trees at reach height with battery scissors. The PAEXO Shoulder is intended in particular for support during overhead work and belongs to the group of passive exoskeletons. No external energy source is used. Support is provided exclusively by mechanical aids to transfer the weight of the raised arms to the hips.

Physical exertion will be analyzed using ergospirometry, a method of performance measurement based on the analysis of respiratory gases. The amount and composition of the exhaled air of different test persons during exercise with and without exoskeleton will be analyzed. The data will then be used to calculate the internal energy metabolism for the respective test variant and for its comparison. In parallel, electromyography (EMG), a technique for evaluating the electrophysiological activity generated by muscles, will be used. Different EMG sensors will be placed in the shoulder and back area to detect possible differences in activity of the most stressed muscles.

At COFE-FORMEC 2021, the presentation of the currently ongoing pilot study and initial findings on the use of exoskeletons in pruning operations is planned.

Hazard Recognition and Risk Assessment by Cable Logging Rigging Crews

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ABSTRACT

Logging fatality rates as a function of the person years worked continually rank as one of the highest rates reported for US industry. A lack of training, supervision, and planning are commonly indicated as contributing factors in logging fatalities. Logging occupational safety and health regulations (OSH) in the Pacific Northwest rely on hazard recognition and avoidance to manage risk. This is necessary due to the workplace being a complicated natural environment with transient location. Combining the lack of training, with OSH regulations relying on hazard recognition and avoidance, emphasizes the need for innovation in training. This is particularly true for cable logging positions such as choker setting, where ensuring the worker is in a clear position before tensioning cables is the primary method of protecting the worker. To gain an appreciation of the risk posed by a hazard the worker has to experience incidents. The challenge is to gain this experience without endangering the worker. This paper explores using incidents modeled in a simulated environment for assessing choker setter hazard recognition and risk assessment.

This paper reviewed published summaries of safety incidents for cable logging rigging crews. The most frequent incident classes include; 53% of the incidents involved workers being struck by logs or debris, 18% involved falls and slips/trips, and14% involved a worker being hit by a cable. Three experienced cable loggers were interviewed to identify important safety incident scenarios that the loggers thought were useful for training and for understanding a worker's hazard recognition and risk assessment. Six incidents were selected for modeling in the simulated environment from the published incidents and interviews.

It was necessary to develop a measure of risk that had meaning to the worker and that was measurable in an interview. The level of involvement required by a worker to implement a safety system was identified as a surrogate for risk (i.e. probability of being injured). Level 1: the safety system is in place without requiring direct action from the worker, Level 2: a safety system is available but it has to be initiated by the worker, Level 3: no safety system is available and work has to be stopped and an alternate plan developed.

By using a simulated environment to stage the safety incidents we were able to evaluate 6 very different scenarios. Subjects share the researchers screen during a ZOOM meeting. A subject reports the hazards they see in the simulated incident and assigns a risk level. The reported hazards and risk levels are compared to the designed incident scenarios, with the goal of investigating the ability of subjects to recognize hazards and assess risk in the simulated environment and variation in the performance between subjects.

Shift Work, Fatigue and Cardiovascular Risk Factors Among Maine's Logging Workforce

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EXTENDED ABSTRACT

1. Background and Objective(s)
Logging is one of the most hazardous industries in the United States (US), despite many workplace safety improvements made in the last decades. Currently, little is known about regional trends in health conditions of logging workers, especially in the Northeast. To address this, we have undertaken a large health and safety study targeting Maine logging workers.

2. Methods
We enrolled participants between March 2018 and May 2019 using a variety of methods including telephone, postal mail, and in-person recruitment. Loggers took part in a longitudinal cohort study involving a series of seven quarterly surveys and an in-person health assessment. This abstract reports on a results from these surveys and physical measures data captured through the health assessment.

3. Results
Out of 1,738 loggers contacted, 393 enrolled in the study. Three hundred twenty-five (325) are included in the initial survey analyses, 246 mechanized loggers, and 79 conventional. On average mechanized loggers worked longer days (11.8 hours vs. 9.7 hours) and had longer commutes from home to the woodlot (72.6 minutes. vs. 40.7 minutes) than conventional loggers. Mechanized loggers were more likely than conventional loggers to begin their workday before 6:00 AM. Preliminary analysis of health screening data (sub-cohort of 81 loggers) identified several factors that require addition exploration: average body mass index (BMI) of 30.6, Mallampati scores of class 3 or 4 in 24%, along with average blood pressure of 138/83.

4. Conclusions
These factors contribute to a need to work with the logging community on cardiovascular risk and factors contributing to sleep quality. The ultimate goal is to make the industry a safer and healthier profession for the current workforce, as well as the workforce of the future.

Comparison of Battery Driven and Gasoline Driven Brush Cutters in Terms of Efficiency and Ergonomic Effects

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ABSTRACT

Battery technology has taken rapid development in recent years. Accordingly, battery-operated brush cutters are used more and more frequently for silvicultural measures.

The presented project aims are to investigate the performance of different battery driven brush cutters as well as their ergonomic benefits. The latter include vibration and noise measurements, which were assessed under laboratory, but also under real field conditions. Another focus was laid on ecological impacts like fuel or energy consumption during different working tasks. To better compare the outcomes of the study, gasoline driven brush cutters of different performance classes were included.

Keywords: Battery technology; brush cutters; grass mowers, energy consumption; hand arm vibration; noise impact

Promoting Occupational Safety and Health in Motor-Manual Tree Felling: A Postural Analyses

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ABSTRACT

Chainsaw is among the most used motor-manual tree felling machine. Despite the advantages of its high productivity in a demanding work environment, many studies have proved that this affordable portable machine is also known to cause occupational safety and health (OSH) disturbances on the operators' physical, physiological, and psychological domains. There is a common practice in felling large diameter of valuable trees to maximize the selling value of the timber, where the notch cut and felling cut are made as close as possible to the forest floor. This cutting point makes tree feller to do bending or squatting, both are awkward postures. This situation raises questions on potential OSH problems that threaten chainsaw operators. This study aimed to measure the musculoskeletal disorders (MSDs) risk experienced by chainsaw operators when cutting trees in a very low notch cut and felling cut heights (± 15 cm above ground). We identified the common working postures through field observations in a teak plantation forest in Indonesia. A static postural analysis (using a well-known instrument called Rapid Entire Body Assessment (REBA) and biomechanics analysis using 3 Dimension Static Strength Prediction Program Version 7.1.0 software) were carried out to the selected (awkward) postures. The biomechanics analysis focused on the low back segment (lumbar 5 sacrum 1, L5/S1), especially on the compression and shear forces. REBA preliminary analysis indicated that the works had burdened the chainsaw operators with a high MSDs-risk level (scored 11-15 out of 15-scale, high ergonomics risk, so that corrective action required). The biomechanics analysis confirmed this result, indicated by a very high L5/S1 compression force (> 6400 N) and shear force (>500 N). This study verified that despite the minimum stump volume, making a very low notch cut and felling cut will cause potential health problems to the chainsaw operator. Decreasing the L5/S1 compression force could be done by avoiding extreme bending during cutting and substituting the chainsaw, where the lighter chainsaw is strongly recommended.

Logging Practice in Indonesian Natural Forests: Adoption of Personal Protective Equipment Associated with Worker Safety

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ABSTRACT

The majority of fatal accidents in forestry globally occur during the timber harvesting activity. As the ninth largest forest area worldwide and the third largest tropical forests, Indonesia, cutting the tree by fellers also contributed at least 9% to the total national fatal accidents. Despite maintaining a safe work environment and eliminating of potential hazards, use of Personal Protective Equipment (PPE) is one important prevention to avoid catastrophic accident during work in the forest. Therefore, my study is focusing on what are the motivations and impediments factors for fellers to use PPE? I specifically focus on eight types of PPE recommended by the International Labour Organization for forestry operation: safety boots, safety trousers, close-fitting clothing, gloves, safety helmet, goggles, visor, and earmuff. My preliminary observation in two forest concessions in East Kalimantan and West Papua by a list of question through questionnaire, an in-depth semi structured interview, and a direct observation during harvesting activity revealed the use of protective equipment by the fellers. Both forests have been implementing international and national forest certification which are required strictly requirements in worker safety, however, their implementation still remain questions. At least a quarter from the list of required PPE was used during work, another quarter was not considered at all, and the rest were inconsistently used among fellers. Company supports (e.g., incentives or disincentives, safety briefing, monitoring by supervisor) to the workers may help to improve the likelihood of PPE use. Consideration to use these protection tools by the fellers, however, still remain challenges to be achieved related to the design, availability, protection effectiveness, material, or other uncomfortable issues. This preliminary study helps to understand potential strategies to improve the use of PPE among fellers, nevertheless, additional sample of forest concessions can be more better understand safety culture strategy specifically in the forestry sector.

Important Considerations for Using Mobile and Wearable Device Sensors to Model Worker Productivity and Develop Digital Health and Safety Applications for Motor-Manual Operations

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ABSTRACT

We discuss experience and lessons learned from developing two published forest engineering studies using the micro-electric sensors in smart phones and smart watches, respectively, to model human activities during motor-manual forest operations. Both studies were developed in the context of informing digital health and safety applications and were funded through grants from the National Institute of Occupational Safety and Health (NIOSH) and Pacific Northwest Ag Safety and Health (PNASH) Center. In the first example, smart phone sensors were used to collect time-study data during conventional timber falling activities on cable operations on three state and industrial logging operations in North Idaho. In the second example, smart watch accelerometers were used to develop machine learning models predicting rigging crew work cycle elements associated with setting and unhooking log chokers on 5 industrial and state logging operations, also in north Idaho. Sliding window sizes used during model development ranged from 1-10s and 1-15s. Accuracy of phone-derived models for felling ranged from 65.9%-99.6%. Smart watch models were evaluated using multiclass Area Under Curve (AUC). The best choker setter and chaser models were created using 1-3s windows with 90% overlap and had sensitivity values ranging from 71.95% to 83.59% overall for the two positions. Whereas conventional time-and-motion studies in operational forestry have largely informed simulation analysis at a coarse level, the successful application of smart watch and phone-derived analysis to monitor human work activities in real time introduces both opportunities and challenges for the forest engineering community. A primary benefit and advantage of using consumer-grade mobile and wearable devices is having the ability to quantify and record jobsite data at very high resolution throughout the workday in perpetuity once models are developed and implemented. This fosters a variety of new jobsite analytics and informs much higher resolution analysis of the factors affecting productivity and costs, worker health, and safety across sites as data accumulate over time scales from months to years. However, the emerging use of smart phone and smart watch derived human activity recognition also poses new kinds of analytical challenges and ethical considerations for both the research community and forest managers to approach carefully. Appropriate methods for informed consent and proper handling of confidential data are important and complex considerations that need to be addressed up front in order for these new methods of quantifying work productivity, health and safety to most benefit operational forestry.

Theme 2: Education, Training and Workforce Development

Exploring the need for feedback on performance - interviews with harvester operators

Karin Ågren, Maria Nordström, Martin Englund, Florian Hartsch, Felix Dreger, Even Hoffart, Eva Skagestad, Ole Bertil Reistad

Implementing VR and gamification in forestry education

Nopparat Kaakkurivaara

Developed collaboration in contractor forestry - an intervention in relational development

Lotta Woxblom, Christer Sandahl

European Chainsaw Certificate and European Machine operator Certificate: Experiences from skills assessments for forest operations

Edgar Kastenholz, Jessica Schmidt, Andrea Teutenberg

Stand-specific working methods for harvester operators: A simulation study

Simon Schmiedel, Daniel Beaudoin, Mikael Rönnqvist

Forestry sector employment, wage and safety data from public sources in the USA

Mathew Smidt, Dana Mitchell, Mingtao He, Yaoqi Zhang

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Exploring the Need for Feedback on Performance - Interviews with Harvester Operators

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ABSTRACT

Efficient use of the forest resource includes assuring a high value recovery of each stem. Forest machine operators rely on regular and tangible feedback on their operations to achieve continuous improvements in their work. Today, a lack of feedback often leaves the operators unaware of the quality of their work, as measured by the customer.

Within the AVATAR project, aiming at demonstrating a "digital coach" concept for forest machine operators, we performed a series of 16 exploratory interviews with professional harvester operators, in order to understand their views on overall performance, and more specifically on how they measure the quality of their work. Additionally, we discussed what factors that are strongly influencing their work, as well as the type and frequency of feedback that the operators would like to receive. The harvester operators were based in Germany, Sweden and Norway, and represented a range of ages and experience levels. They operated machines from all major harvester manufacturers.

When analyzing the interviews, we found that operators from the different countries seem to have a rather common view on performance, quality, and what kind of feedback they would appreciate on their work. Many of the interviewees mentioned personal relations and well-being as factors that are influencing their performance and the quality of work. Feedback that helps reducing the workload and increasing the wood value recovery was most requested. Further, we discussed how this input may be implemented in an onboard system for continuous feedback on value recovery. Continuous improvements based on the feedback aim at minimizing the knowledge and performance gap between operators.

Implementing VR and Gamification in Forestry Education

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ABSTRACT

Virtual Reality (VR) and games help to enhance the student's motivation and engagement. Virtual Reality is one of the best methods to encourage students and grab their attention. VR lately has been implemented in several disciplines, especially, in education. Forestry sector has also developed VR for various uses and education purposes. For example, "Limberjack", is a VR game developed by Husqvarna company. The aim of this game is to explore new possibilities to help improve skills and safety, as well as generate interest in logging. Limberjack has been released on Valve's platform Steam, and is free to download. The aims of study were to examine the influence factors that might affect the learning process and to ensure/prove that VR and gamification are beneficial in education.

This study divided the students into four different groups depending on the experience on using chainsaw and VR (A1: Has experience with VR, A2: No experience with VR, B1: Has experience with chainsaw, and B2: No experience with chainsaw). Thus, the combination of experiences can be grouped into A1B1, A1B2, A2B1, and A2B2. There were 40 students participating in this study. Each student has to play Limberjack at least 3 times or till the lead time of playing games becomes steady.

The results show that the lead time for playing games of A2B2 takes longer than other groups, while lead time of group A1B1 takes the shortest time. The learning curve is in the form of logarithm, which means that initially, people get better very fast when they learn a new skill, and then improvement gradually slows down. However, there is no significant difference within and between groups.

Developed Collaboration in Contractor Forestry - an Intervention in Relational Development

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ABSTRACT

This paper describes how a training effort in relational development is implemented at two forest companies in Sweden. The training focuses on professional feedback on prerequisites for work as well as quality of work performed. Openness and trust is expected to allow forestry contractors and their customer to operate more efficiently within the system, thus gaining benefits both economically and on working conditions.

Qualitative approaches were used to describe the training process and investigate how the efforts affect effectiveness and collaboration between the parties.

One of the forest companies included both officials and contractors in the training effort. Participants of this intervention all agree that openness and understanding of the processes in the supply chain have increased. However, systematic feedback has not yet been achieved; there is uncertainty about what to give feedback on and who is responsible for ensuring that feedback actually takes place.

The other company chose to implement the training effort with only forestry officials present. In this case, the contractors acted as a reference group to evaluate if and how relations between officials and contractors developed during the period studied. Most of the officials believe that their commitment and the effect on communication would have been better if the contractors had been involved. Halfway through the project, focus changed and was directed more towards the officials themselves. During the meetings the colleagues got to know each other better and got an opportunity to reflect on and discuss issues that they usually not have time for and this was perceived as positive.

European Chainsaw Certificate and European Machine Operator Certificate: Experiences from Skills Assessments for Forest Operations

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Abstract: Workers´ proficiency is key to success in profitable, environmentally friendly, and safe forest operations. The forest operation workforce is rather divers, particularly with regard to regional origin of the workers. Often seasonal/discontinuous employment is in place, due to demographic changes, and due to the lack of workers for specific tasks and competition of forestry with other sectors. It is a legal obligation for employers, and a requirement in forest certification systems that only workers shall be assigned to a task who are qualified, e.g., to work with a chainsaw or to operate a forest machine. When a worker does not have a verifiable certification of a formal forestry training it is generally hard to prove if workers have the necessary skills. This is not only relevant for foreign workers. Also, among employees of domestic contractors a considerable number has only been trained on the job.

Therefore in 2009, an EU-funded project was launched to develop common European standards and assessment procedures for chainsaw operators. Based on the standards and procedures, a common system of skills assessment was developed: the European Chainsaw Certificate ECC. Under the umbrella of a membership organisation, the European Forest and Environmental Skills Council (EFESC), ECC has successfully been implemented in nine countries.

EFESC offers structures and processes to govern a transparent and reliable process to verifying chainsaw operators' skills. Based on this experience, EFESC has embarked on developing a complementary skills assessment scheme for machine operators (EMOC). Funded as an EU Erasmus+ project, a first set of common European skills standards have been developed. Recent activities to set the project's scope led to the decision that EMOC will focus on basic level skills in machine work. Following the review of the machine operator standards by stakeholders, the next step is to describe the assessment criteria and procedures.

The experience with ECC and EMOC show that the endorsement of voluntary skills assessment schemes is a long process. It needs to be accepted by central actors in forestry practice, e.g., by forest owners to use it as a tool to verify (future) employees' competences. The endorsement process also needs to overcome barriers, such as employers´ reluctance to accept a system that is considered to raise costs and bureaucracy. But the key to success of ECC is that EFESC provides a transparent and credible process which is trusted to ensure that workers who hold an ECC certificate have undergone a reliable assessment based on common European standards.

Keywords: workers´ competencies, skills standards and assessment

1. Introduction

In this paper we present two case studies of skills verifications projects in forestry from practitioners' perspective: ECC and EMOC. The European Chainsaw Certificate (ECC) and the European Machine Operator Certificate (EMOC) are at different stages in their implementation. While the ECC has transitioned from project into an international organizational structure EMOC is still in its project stage, able to profit from lessons learned during the establishment of ECC. Our main focus will be on drivers and barriers of implementing skills verifications in European forestry.

First, we will demonstrate why standardised skills verifications in forestry are essential, particularly in a European context. We will then provide a timeline of development with a focus on ECC. In order to exemplify some of the drivers of successful skills verification implementation in forestry we will sketch out some landmark developments in Belgium and Germany. Finally, we will offer some reflections on challenges on the road ahead.

2. Why Do We Need Standardised Skills Verifications in (European) Forestry?

A standardised and, importantly, transnational skills assessment in forestry is necessitated by three interconnected factors: firstly, skills verifications are needed due to the fact that forestry by its very nature requires competent, highly skilled workers, secondly, because the forestry labour force in Europe is characterised by high mobility, and thirdly, because of legal obligations of employers to employ qualified personnel.

2.1 Complex Nature of Forestry Work

Despite its reputation to the contrary, forestry work is surprisingly complex. While it belongs to the economic area of primary production which is often characterised by a high percentage of unskilled or low-skilled workers, the harvesting of trees cannot be standardised in the same way processes in industrial production can be standardised (and even automated). As a product of nature, each tree is different, each surrounding and terrain is different, and environmental factors such as weather conditions also change.

This means, forest workers need to not only be trained in the technical skills of operating chainsaws but also need to be competent decision-makers able to evaluate each individual situation. In addition to its complexity, forestry work is also dangerous work. Potentially deadly risk is posed not only by machinery in use, such as chainsaws, but also – and foremost – by tree trunks and branches being put in motion.[1] It therefore demands of workers firm knowledge of and compliance with high standards in health and safety.

2.2 Workforce Mobility

Forestry in Europe is characterised by a rather diverse and mobile workforce, both in terms of qualifications as well as country of origin. In Germany, according to official numbers, approximately 20% of regularly employed workers in agriculture and forestry are foreign nationals, 80% of which come from EU accession states (since 2004) (see Federal Employment Office 2019, 2020).[2] Often seasonal or discontinuous employment is in place, due to

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[1] In 2019 39 fatal accidents were registered in forestry in Germany („Mehr Unfalltote bei der Waldarbeit", press release, 10 July, 2020, Sozialversicherung für Landwirtschaft und Forsten, available at: https://www.svlfg.de/pm-unfallzahlen-waldarbeit).

[2] These are Estonia, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Czech Republic, Hungary, Cyprus, Bulgaria and Romania.

demographic changes, and due to the lack of workers for specific tasks and competition of forestry with other sectors.

Not unusual for jobs in the primary sector, qualifications for forestry work are often not strictly regulated. This mainly concerns chainsaw and machine operations. Together with major waves of privatisation in the former Eastern bloc countries since the 1990s, this has led to a myriad of different certificates both in domestic as well as consequently in international contexts. As qualification in forestry work often is not officially regulated to the same extent as it is in other sectors, there are rarely official structures in place that have a mandate to verify equivalence of foreign qualifications. For forest owners and contractors who depend on employees from abroad it is therefore close to impossible to gain any certainty about the level of skills and competences prospective candidates bring with them. By the same token, it can be difficult for foreign workers to gain entry into the labour market.

2.3 Legal and Other Obligations

Employers in forestry are either legally obliged by European (and often subsequently domestic) regulations to employ only qualified staff or are obliged to do so through forest certification systems demanding the deployment of qualified personnel. On EU level, it is regulated that employers need to make sure that workers have or receive "sufficient training appropriate to the particular characteristics of the job" (Article 4, 91/383/EEC). This regulation holds for both regular as well as seasonal workers. This mandate then translates into national laws and regulations concerning safety at work (see Art I.2-7 of the Belgian regulation on health and safety at work; Sec. 5(3) and Sec. 12 of the German Health and Safety at Work Act).

The two major international forest certifiers, the Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification Schemes (PEFC) constitute another demand scheme for qualified, well trained and skilled workers. Principle 2 of the FSC International Standards emphasises the employers' responsibility to ensure that workers have "job-specific training and supervision" and "implement health and safety practices to protect workers" (FSC International Standard 2015: 11). PEFC underlines the importance of planning and organisation in forest operations to allow for the identification of risks and the protection of workers from these work-related risks (PEFC Benchmark Standards 2018, 6.4.3: 1).

3. Birth and Trajectory of ECC and EMOC

The development and implementation of a transnational acknowledged skills certificate is a long and winding process. This was particularly true for the ECC which has a history of more than one decade. It all started around 2008 with the idea of training providers in some Western European countries to update their chainsaw training curricula and align them to skills standards which should be applicable across Europe. Further, the idea arose to develop a skills certificate based on these standards. While the concept of skills certificates as a verification of competencies was at those times already applied in the United Kingdom, this was rarely the case on the European continent. On a number of occasions representatives of training providers and the forestry sector met to find a consensus about the demand and opportunities for a European chainsaw skills certificate. As a result of the co-operation in 2009 EU funds could be gained from the EU-programme Leonardo da Vinci. This facilitated to develop a modular set of standards for chainsaw operators and the complementary set of assessment criteria.

Today, the European Chainsaw Standards are available for 5 skills levels[3]:

ECS 1: chainsaw maintenance and crosscutting
ECS 1 (Tension): cross-cutting timber on tensioned timber sections by a simulator
ECS 2: basic tree felling
ECS 3: advanced tree felling
ECS 4: windblown and damaged trees

[3] The detailed and regularly updated standards are available at: https:/efesc.org

ECS (Height): chainsaw use at height

As the project was successfully completed in 2011, its outcomes were transferred into an organisational structure. It was felt necessary to establish an infrastructure which offered an open and transparent structure in terms of a membership organisation, and that strived to ensure reliability and most importantly credibility. In 2013 the European Forestry and Environmental Skills Council (EFESC) was founded as the umbrella organisation for skills verifications in forestry. It has since matured and grown in membership with actually nine National Agencies, and in acknowledgement in European forestry.

In 2018 the time was considered right to aim at another challenge. From its origin it was consensus that EFESC should not limit its activities to the implementation of the ECC, but should focus on a variety of skills in the sector. EFESC decided to add a skills certificate for forest machine operators to its portfolio. Hence, the European Machine Operator Skills Certificate (EMOC) was born in 2018 and, following the model of the ECC, started as another EU-funded project (Erasmus+) in 2019 under the auspices of EFESC. Today, EMOC‘s project partners are in the process of completing the definition of respective standards and assessment criteria which will be designed in a format which will be designed complementary to the ECC.

Following the experience with the ECC it can be expected that it will take a number of rounds of debates in the EFESC membership and the stakeholder community to get the EMOC standards and assessment procedures readily available for implementation in practice. The expectation is that the EMOC will fall on fertile grounds. Like the ECC meets the need for a reliable proof of competencies of chainsaw operators, EMOC aims at verifying that machine operators have the skills to operate a machine safely and effectively

4. Putting Things to Work: Two examples of implementing international skills verifications in forestry

One of the most intriguing and sometimes also challenging facts about ECC is that it nowhere enters onto a blank slate. Each participating country faces its own domestic constellations into which ECC is introduced and to which it must be adapted to the extent possible. There may be pre-existing qualifications and certifications in forestry work that need to be incorporated or there may be certain political realities that need to be addressed.

In order to exemplify the variety of entry ways into the implementation of ECC we will briefly compare the “coming of age” of ECC in two countries, Belgium and Germany. In both countries, ECC today is mandatory in certain regions or forests.

4.1 ECC in Belgium[4]

Natuurinvest is the seat of the Belgian National Agency of EFESC. As an organisation Natuurinvest’s mission is to create marketable services and products from nature in Flanders (one of the two major regions in Belgium). These funds are then invested in knowledge programmes, nature conservations projects and environmental protection.

Natuurinvest used to be a Nongovernmental Organisation (NGO) and today is an independent state company. As such it is loosely attached to the Flemish Administration for Forestry and Nature Conservation, a body of the Flemish government. This means that the Managing Director of Natuurinvest is also on the Board of Directors of the Flemish Forestry Administration. In other words, there is a mediated connection between Natuurinvest and the Flemish government that can be activated.

ECC started as a voluntary certificate initiated by Natuurinvest at the beginning of the 2010s. The organisation decided in a second step to make ECC mandatory for its own staff. Hence, all Natuurinvest staff that operates

[4] Based on an interview with the current Managing Director of Natuurinvest, Tom Embo, conducted via phone and video chat on 27 July 2021.

chainsaws has been certified with ECC. Through its connection with the Flemish Forest Administration, it also sought to raise awareness on governmental level.

Next to the connection between Natuurinvest and the Flemish Forest Administration, Belgium has a strong litigation and legal implementation system in place. Similar to laws in Germany that regulate health and safety at work, in Belgium employers are responsible for ensuring that their employees are qualified for the tasks they are mandated with. Decisively, it is also regulated by law that employers need to prove their competence to actually evaluate their workers' skills.

Tragically catalytic to process of raising awareness about ECC on the level of official decision-makers was a fatal accident in 2017 and an ensuing court case. The legal investigation was initiated because of breaches of fiduciary duties that were suspected to stand in causal connection with the deadly accident of the chainsaw operator. In this court case (as well as in other prosecutors' investigations) both prosecution and the court itself asked not only for proof of training that workers had received but, moreover, demanded proof that this training was, in fact, effective. As a consequence of this legal case, the Flemish Forest Authority realised that in order to fulfil their fiduciary duties as forest owner they had a demand for a skills certification that was effective and reliable. With ECC, Natuurinvest had precisely that – an assessment-based skills certificate that could deliver the legal proof for effectiveness of training. Consequently, ECC was introduced as mandatory requirement in wood selling contracts between public forest owners and forest contractors.

4.2 ECC in Germany[5]

In Germany, the National Agency of EFESC is based at the Kuratorium für Waldarbeit und Forsttechnik (KWF) e.V.. KWF is a nongovernmental organisation that is partially funded by public money. It conducts research on health and safety in forestry as well as on forestry technology and also advises decision-makers on these issues. As an organisation KWF seeks to function as a hub for all stakeholders in the industry.

In the case of Germany, the way into establishing ECC as a reliable skills certification scheme so far has been somewhat less straightforward than in Belgium. As it was not directly KWF's leadership that was mainly involved in the founding of EFESC and the introduction of ECC, ECC itself did not take the immediate governmental route.

Rather, the implementation happened indirectly through another certification scheme: the Forest Stewardship Council (FSC). After initial consultations between representatives of KWF and FSC, FSC very quickly realised that ECC fit its own mandate of strengthening health and safety in forestry. ECC provided a ready-made package deal for implementing quality assurance in this area. Moreover, via the adoption ECC as quality assurance of workers' qualification into the German FSC standard, the idea of FSC was to also address the otherwise tricky issue of adequate pay. While FSC had little influence over workers' pay, the hope was that better qualified workers could demand a higher salary but also that employers saw better qualified staff as a benefit worth paying for. By making an ECC mandatory for those without formal forestry qualification there was indirect leverage with regard to adequate pay that FSC stands for.

In much the same way as ECC found its way into FSC, FSC as a forest certifications scheme with high sustainability standards found its way into regional governmental bodies. It particularly resonated with political decision-makers from the Green Party. In respective ministries where the Green Party was part of the governing coalition, FSC provided a handy implementation tool and quality assurance mechanism for realising sustainability goals in forestry. Consequently, in those states with Green Party involvement in government, FSC was made mandatory for state-owned forests.[6]

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[5] Based on an interview conducted with Elmar Seizinger, Director of Forest Management at FSC, via phone on 02 August 2021.

[6] ECC is part of the FSC criteria and as such must be complied with by all forest owners in Germany who wish to receive an FSC certification. The point of this paper is that an FSC certification was made compulsory for regional state forests by regional governments.

5. Challenges Ahead

Now, almost one decade after its inception what also becomes clearer are the challenges that still lie on the road ahead for ECC. These challenges can also fruitfully inform the approach to implementation for EMOC. The current success story of ECC in European partner countries is, to a large extent, to be credited to enthusiastic individuals with a clear vision. The strength of the organisation behind ECC, EFESC, is its embeddedness in principles of transparency, non-profit and partnership. Moreover, the idea of setting *minimum* standards allows for adequate flexibility when it comes to national implementation and problem-solving. Setting minimum rather than highest possible standards, for instance, allows partner countries to set higher standards for their ECC assessments (to be documented). It also provides the opportunity of comparing, adapting or extending existing trainings and qualifications so as to add an ECC logo "on top" rather than setting it up as a parallel qualification.

These mechanisms also allow ECC to be quite cost-effective while still maintaining transnational standards and quality assurance. Cost effectiveness is key for stakeholder acceptance, in particular, for those that are often most sceptical: forest contractors who employ – often seasonal – forestry workers and, sometimes, forest workers themselves.

In order to further advance acceptance among forest contractors and individual workers sound quality assurance mechanism and healthy organisational structures are crucial. A key factor in the road ahead, therefore, is organisational development. As ECC transitions from project to transnational organisation some desiderata emerge in terms of its organisational structure. First, starting off with only a few members it is often not immediately clear what kind of structures and processes will be needed as the organisation grows. By the same token, as the organisation grows in members, a point will come at which a transition from unanimous decision-making based on shared enthusiasm and vision needs to be replaced by clear-cut, fixed rules and procedures for (majority-based) decision-making and sanction mechanisms. These clear-cut decision-making rules are also required because there is a natural bias towards founding members.[7] Establishing a regular process of revision as part of the organisational structures and processes can address these issues.

Another crucial task for the future is to further advance financial sustainability. In the transition process from project to organisation staff is still often voluntary and unsalaried for their specific tasks within the organisation. This can mean shorter attention spans and the exigent prioritisation of other commitments and projects. A procedure needs to be established to revise where and when full-time staff is required to uphold the organisational procedures and processes as EFESC grows – or to even allow it to grow further. First steps have been taken in this direction.

6. Conclusion

As we have demonstrated in this paper, there are several reasons why reliable and ideally transnational skills certifications are important in European forestry. Tree-felling and forest operations in general are complex, risky and non-standardisable activities that need qualified workers. There are legal obligations for employers to ensure their workers are qualified for the tasks they are mandated with and there is a high degree of mobility and fluctuation among forest workers with a large proportion being employed on a seasonal basis.

As ECC has already undergone implementation processes in several European countries there are some lessons that can be distilled for EMOC from these experiences.

[7] Due to lack of staff, each founding members almost necessarily must hold a key position within the organisation.

1. For effective implementation key actors that are in a position to make skills certification mandatory need to be activated. There are generally two routes for this: either the direct governmental line as, for instance, in Belgium or the somewhat more mediated route via forest certifiers or insurers as, for instance, in Germany.
2. In order to maintain momentum and be able to also incorporate new products such as EMOC, organisational development of EFESC is key. One central aspect here is to embed a regular revision process into its organisational structure.

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Stand-Specific Working Methods for Harvester Operators: A Simulation Study

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ABSTRACT

It is widely known that harvester operators greatly influence productivity together with the working method they use. Several studies have compared multiple working methods to assess their merits, but operators typically always use the same method for clear cutting or final cutting regardless of the stand's attributes. The aim of this study is to investigate the impact of stand characteristics on the performance of a harvester operator's working methods. There is a need for operators to understand how a specific method performs in various stand conditions and since it takes time to become proficient with a specific method, it is impractical for them to experiment in the diverse settings they encounter. This study assesses the effects of stand density and average tree height on the performance of multiple working methods to identify stand-specific criteria for method selection.

To model the problem, a discrete event simulator was designed representing a Tigercat H845E harvester equipped with a Log Max 6000 head, which operated in 50 virtual harvesting corridors of varying average tree heights and stand densities, each measuring 100 meters in length by 17.39 meters in width. In total, 36 working methods were defined and simulated in every harvesting trail. The indicators used to assess the performance of the working methods are the productivity in logs per productive machine hours and the time spent for every element of the harvester's working cycle.

Differences in productivity of up to 18.6 % were observed between working methods for the same harvesting trail and all the methods performed better in specific stand conditions and worse in others. It was found that stand density is the main factor affecting the performance of individual working methods and could be used as a criterion to select stand specific methods. A key finding is that operators can perform within 0.75% of the best productivity in every stand by using only two working methods: One for stand densities greater or equal to 800 stems/ha and one for stand densities lower than 800 stems/ha. Our results suggest that using multiple working methods will improve the global productivity of the harvester. These findings can be used to enhance operator training and in the long term may be useful to the automation of harvesting operations. Further research should consider multi-products settings, partial cutting, and the impact on forwarder productivity.

Forestry Sector Employment, Wage and Safety Data from Public Sources in the USA

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Abstract: The forestry sector excluding mills spans a small number of North American Industrial Classification System (NAICS) codes including Timber Tract Operations (1131), Forest Nurseries and Gathering of Forest Products (1132), Logging (1133) and Forestry Services (1153). Forestry occupations are classified by Standard Occupation Codes (SOC) and include Foresters (19-1032), Forest and Conservation Technicians (19-4071), Forest and Conservation Workers (45-4011) and Logging Workers (45-4020). The US government uses surveys and census methods to accumulate data on employment, wages, and occupational injuries and diseases. Much of that data is publicly available at the national level and on occasion at state and county level and can be accessed through the Bureau of Labor Statistics (BLS). Establishment, employment, and wage data are available in Current Employment Statistics (CES), Quarterly Census of Employment and Wages (QCEW) and Occupational Employment Statistics (OES) programs. The Survey of Occupational Injury and Illness (SOII) and Census of Fatal Occupational Injuries (CFOI) are also accessed through BLS. Census Bureau data provides information about the working populations through the Community Population Survey (CPS) and businesses through Non-Employer Statistics and County Business Patterns (CBP). This paper summarizes the data sources, data collection methods and discusses how those data might interact with the structure of forestry businesses and regional variation in Forestry in the USA.

Keywords: forestry, logging, employment, labor, wages, safety and health

1. Introduction

Data for forestry establishments and employees are collected by the federal government using an array of techniques including data aggregation across reporting systems, surveys, and censuses. While these industries and occupations are locally and regionally important, on a national scale they represent a very small proportion of US businesses and employment. Additionally firms in the forestry sector have few employees per firm and on occasion no employees. Firm size and population size are important in direct data collection by the federal and state governments through tax information and survey techniques. Data collection techniques may interact with attributes of forestry employment to result in complexity in interpreting statistics and trends. Reporting or sampling protocols within these data sets may specifically exclude small firms or decrease the likelihood that they will be surveyed. The objectives of this paper are to describe the data source and the available data, display some of the most recent representative data and discuss the interpretation of available data. The descriptions in the text use the terms from the database rather than attempting to standardize the terms. So terms like firm, establishment and business could refer to the same type of entity.

2. Establishments and Employment

Federal economic data, mainly employment and wages, for the forest industry are included in a small number of North American Industrial Classification System (NAICS) codes. Following the North American Free Trade Agreement (NAFTA), the US adopted NAICS which moved logging from the manufacturing sector in the Standard Industrial Classification (SIC) (2411) to the agricultural sector (NAICS 1133). The change resulted in the omission of logging from the business census with no additional data collection effort from USDA, which is responsible for the collection of economic data in the NAICS agricultural sector (11). Forestry and Logging are included in NAICS code 113 and data may be available for Timber Tract Operations (1131), Forest Nurseries and Gathering of Forest Products (1132), and Logging (1133) depending on the significance of forestry in the geographic area of interest. In addition, significant forestry activities are categorized as Forestry Services (1153). NAICS codes 1131, 1132, and 1153 were classified in the agricultural sector prior to the NAICS transition as SIC 0811, 0831, and 0851 respectively. Within the four forest industries activities may overlap to produce misclassifications by employers, individuals or Bureau of Labor Statistics (BLS) or Census processes. For example, some of the same tasks in 1153, when completed by the property owner, would be appropriate as 1131. If the forest owner's or manager's business, classified as NAICS 1131, decided to log and haul timber rather than sell stumpage, they might be engaged in logging (NAICS 1133). Some forestry services (NAICS 1153) which result in the production of forest products could be logging (1133). The data sources updated quarterly or monthly are Current Employment Statistics (CES), Quarterly Census of Employment and Wages (QCEW), and Quarterly Workforce Indicators (QWI). County Business Patterns (CBPB), Occupational Employment Statistics (OES), and Non-employer Statistics (NES) are annual data.

2.1 Current Employment Statistics (CES)

The Current Employment Statistics (CES) data are from monthly surveys conducted by the Bureau of Labor Statistics. The survey results provide employed population, hours, and earnings estimates based on payroll records of business establishments. The CES dataset includes monthly and annual data for type of worker (e.g. supervisory, production, and gender), average weekly hours, and average hourly and weekly earnings (constant dollar and nominal dollar).

The CES sample is a stratified, simple random sample of worksites, clustered by Unemployment Insurance (UI) account number. The sample strata, or subpopulations, are defined by the state, industry, and employment size, yielding a state-based design. The CES survey of all businesses is based on approximately 145000 businesses and government agencies representing approximately 697000 worksites throughout the United States, selected primarily from the QCEW administrative records of UI-covered employers. For 2019 the 90% confidence interval (CI) for a 1-month change for logging employment was 1400 employees. For most states CES data were available for mining and logging combined, logging data alone were only available for a few states.

The annual fluctuation in employment of about 10% reflected mid-summer peaks and late winter lows (Figure 1). The 2008 financial crisis disrupted the pattern and reset employment 15% lower than 2008 winter low. Consistently about 16% of employees had supervisory roles. CES includes wage data and the monthly variation in logging wages (in 1982 dollars) is displayed in Figure 2. The wage data show the effect of the financial crisis and the beginning of the pandemic. Wages for non-supervisory and production workers were typically greater or equal to all workers and wages appear to be stable or declining from 2010 to 2020.

2.2 Quarterly Census of Employment and Wages (QCEW)

The Quarterly Census of Employment and Wages (QCEW) publishes a quarterly count of employment and wages reported by employers covering more than 95 percent of U.S. jobs available at the county, state, and national levels by detailed three digit (e.g. 113) and often four digit (e.g. 1133) industry. For each state, the QCEW microdata is a byproduct of the unemployment insurance (UI) accounting system in that state. The states receive a Quarterly Contributions Report from all private-sector employers, as well as from state and local governments covered under the UI program. The QCEW conducts two surveys in addition to administrative data. Approximately one-third of all private-sector U.S. businesses with more than three employees are contacted annually to verify their primary business activity and physical location address via the Annual Refiling Survey. Eligible multiple-establishment employers are required to report quarterly employment and wage data via the Multiple Worksite Report.

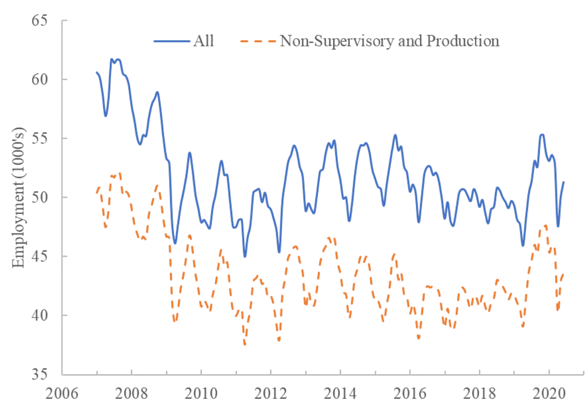

Figure 1. US monthly employment (not seasonally adjusted) from the CES for non-supervisory/production employees and all employees.

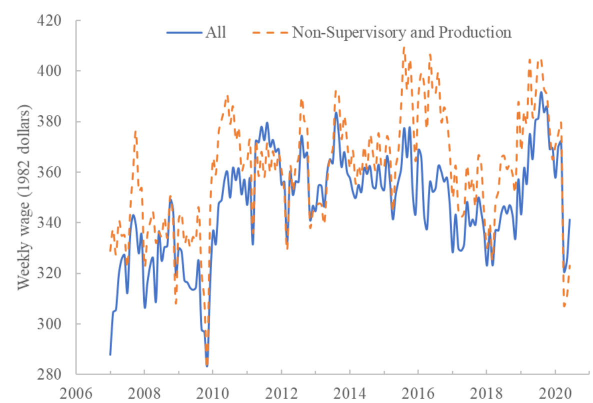

Figure 2. US weekly wage estimate (1982 dollars, not seasonally adjusted) from the CES for non-supervisory/production employees and all employees.

At the national level and state level, the QCEW program makes quarterly and annual data available for the number of establishments, employment, total wages, average weekly wage, and annual wages per employee for NAICS 113, 1131, 1132, 1133, and 1153. Of course, state level data is limited to forested states. For counties data for forestry (NAICS 113) data may be available in forested areas. Data for four digit NAICS codes are available on an inconsistent basis at the county level due to data suppression to avoid disclosure. The QCEW data are censuses of establishments and therefore are not subject to sampling error. However, some other types of errors can occur, such as industry misclassification, invalid codes, data entry mistakes, and over- or underreporting of employment and wages.

2.3 Quarterly Workforce Indicators (QWI)

The QWI is a set of 32 economic indicators, including employment, job creation/destruction, wages, hires, and other measures of employment flows. The QWI is reported based on detailed firm characteristics (ownership, geography, industry, age, size) and worker demographics (sex, age, education, race, ethnicity). QWI data set includes quarterly national and state employment and wage data for NAICS 113, 1131, 1132, 1133, and 1153. A variety of record sources contribute to the construction of the QWI, including the administrative records on employment collected by the states, social security data, federal tax records, and other census and survey data. The main data inputs are Unemployment Insurance Earnings Data (UI), QCEW, Business Dynamics Statistics (BDS), and Demographic Data Sources. The demographic information about the worker, such as age, sex, race, ethnicity, education, and place of residence, comes from a variety of sources, including the 2000 and 2010 Census, American Community Survey, Social Security administrative records, and individual tax returns. These are linked to the UI earnings data using the Protected Identification Key (PIK), which is an encoded Social Security Number.

QWI data from NAICS 1133 for four states (Alabama, Oregon, Pennsylvania, and Wisconsin) were used to represent industry differences related to forest type. QWI data enable the crosstabs of population and wage for worker age, firm age, and employment change at individual and firm level. Oregon and Alabama had about the same employment proportion in new firms over the time period (Figure 3). The proportion was more variable and elevated in Pennsylvania compared to the other three states. Wisconsin showed a decline in employment within new firms in 2009 and a substantial rebound in employment in new firms from 2016 to 2018.

Since the data were accumulated by employee age class we compared age class data rather than age statistics. From 2007 to 2018 the mode employee age class (age class with the highest population) in this group was 45-54 years old for Alabama and 35-44 for Pennsylvania and Wisconsin. Beginning in 2015, the Oregon mode age class increased from 45-54 to 55-64. QWI is one of two potential sources of age class data. We used an example year of 2018 to compare age classes from QWI data for the logging industry to American Community Survey (ACS) data (Figure 4). The ACS is an annual survey of the US population and the publicly available microdata can be accessed by interface to acquire population statistics by many demographic variables including age, class of work, industry, and occupation. ACS data in Figure 4 refer to the logging occupation as private employees and private self-employed workers. The QWI and ACS data are not equivalent since the logging occupation accounts for only about 60% of the logging industry population. It appears the employees in the logging occupation from ACS skew somewhat younger the QWI logging industry employees. However the age distribution of self-employed (ACS) appears similar to the QWI distribution.

The QWI provides data on workforce dynamics like employment turnover which is a ratio of hiring and separations to total employment at the individual level. The average quarterly employment turnover over the period was similar in all 4 states at about 8-9%. The quarterly variations in turnover were lowest in Alabama with a total range from 8-10% while turnover for the other three states ranged from 6-13%. Turnover among workers less than 25 years old averaged 15% or roughly twice the rate for all employees, but Oregon had higher turnover in these age classes of 16% to 24% since 2012.

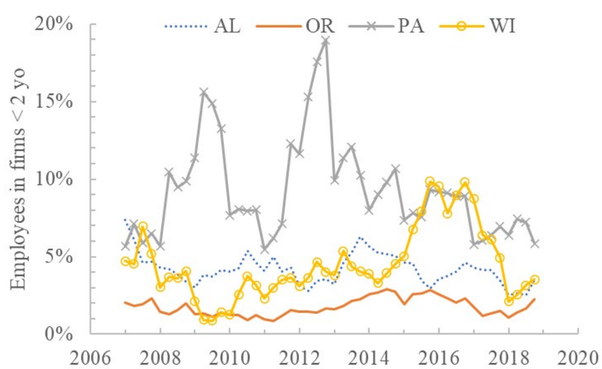

Figure 3. The ratio of employment in establishments < 2 years old to all employment for Alabama (AL), Oregon (OR), Pennsylvania (PA), and Wisconsin (WI). Data was extracted from Quarterly Workforce Indicators (QWI) for NAICS 1133.

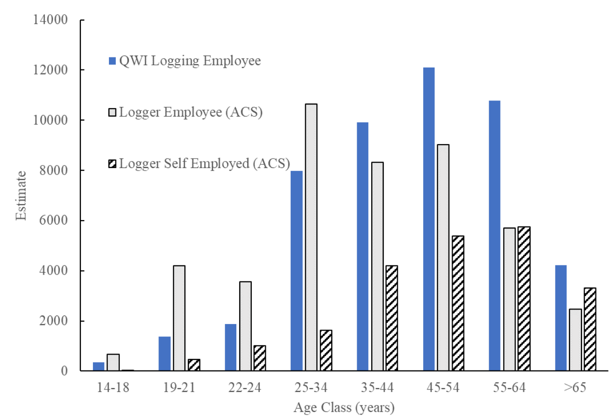

Figure 4. US employment in each age class defined Quarterly Workforce Indicators (QWI) for NAICS 1133 for 2017. American Community Survey (ACS) 2017 estimates for the US population of employed and self-employed loggers (SOC 45-4020).

2.4 Occupational Employment Statistics (OES)

The Occupational Employment Statistics (OES) dataset results from semiannual surveys designed to produce estimates of employment, hourly wages and annual wage for about 800 occupations. The November 2017 and May 2018 panels of the OES survey allocated and selected samples of approximately 186,000 establishments each.

However, only 0.12% of all establishments were forestry establishments (NAICS 113 and 1153) for an expected total of about 230 establishments in the survey. For interpretation the national estimates probably represent average conditions in the Pacific Northwest and the Southeast due to the expected frequency of establishments. State data are available where significant forestry activity and employment might be expected. Small sample sizes sometimes result in large sampling error which are indicated by the Relative Standard Error (RSE) displayed in the public interfaces and downloaded tables.

The occupations are classified by Standard Occupational Code (SOC). Logging (SOC 45-4020) is a broad occupational division and is divided into 4 detailed occupations: Fallers (45-4021), Logging Equipment Operators (45-4022), Graders and Scalers (45-4023), and All Other Logging Workers (45-4029). Detailed occupations included in the sector include Foresters (19-1032), Forest and Conservation Technicians (19-4071), and Forest and Conservation Workers (45-4011). Occupation by NAICS industry provides information of the range in occupations that contribute to Forestry (NAICS 113) and Logging (1133).

Annual surveys revealed that the relative makeup of the logging workforce by occupation was similar from 2007 to 2019. Production workers (including logging workers) were 61-67% of employment, administrative and support workers were 14-17%, and transportation workers were 18-22%. Since production workers are about two thirds of the total, they strongly influence the average wage of all occupations (Figure 5). Hourly wages (in nominal dollars) for administration, support, and transportation occupations showed little increase from 2007 to 2012. From 2012 to 2019 wages for all groups increased. Annual wage rate growth from 2007 to 2019 was 2.9% for transportation workers, 1.2% per year for admin/support, and 2.4% for production workers. Wage rate increases from 2012 to 2019 were led by transportation workers at 4.2% per year, 2.3% per year for admin/support, and 2.9% for production workers.

For larger occupational groups in forestry (>2000 employees) the RSE was typically 6% or less. For logging equipment operators in 2019 the population estimate was 21110 with an RSE of 3.3% indicating a 95% confidence interval of 19800 to 22500. The wage RSE was typically smaller, and for logging equipment operators the value of RSE at 1.4% indicated a 95% confidence interval of $20.15 to $21.29 per hour.

2.5 County Business Patterns (CBP)

The County Business Pattern (CBP) data are a census of businesses compiled from several sources. For categories with low numbers the CBP inserts noise or error to avoid disclosure and the level of noise introduced is referenced with the data. Currently, data are removed when cell values might contain results from less than three establishments. Since CBP is a census and not a sample the most likely error is misclassification and methods are employed to accommodate missing and extreme values which occur in a very small number of cases. Data availability four digit NAICS codes becomes reduced at the county level if there are few establishments. Even in the most forested states not all forested counties have data for logging.

The CBP provides data on establishment size class and organization, employment and payroll. Over the time period considered the firm size distribution across the US has been static. About 70% of employees were employed by establishments with less than 20 employees and 40-46% employed by establishments with fewer than 10 employees. However, most establishments were small and 80% had fewer than 10 employees and 60% had fewer than 5 employees. From 2008 to 2018 the ratio of S-Corp establishments increased from 38% to 47%. The changes came from a decline in C-Corp (22% to 15%) and sole proprietor (30% to 26%). Ratio of partnerships were steady from 10% to 12% over the period. By 2018 over 50% of employees were in establishments organized as an S-Corp. S-Corp and C-Corp refer to the subchapter of the tax code under which the businesses are organized and differences relate mainly to ownership and taxation.

2.6 Non-employer Statistics (NES)

Non-employer Statistics (NES) are an annual series that provide economic data for businesses that have no paid employees and are subject to federal income tax. Data for NAICS 113 and 1153 are available for states and counties where there are more than three businesses. National trends for Forestry Services (NAICS 1153) are stable over the period from 2007 to 2018 at just over 12000 businesses (Figure 6). In Forestry and Logging (NAICS 113) there was a decline of about 20% over the same period. Both industries showed the same dip in gross receipts per non-employer in 2009. By 2018 the receipts per non-employer had recovered to 2007 levels for Forestry Services but not for Forestry. Figure 7 displays the relationship between the number of forestry (NAICS 113) establishments per state from QCEW to the number of non-employers (NAICS 113). We coded the data for Forestry (NAICS 113) by region using the FRA regions with Tennessee in the Appalachian region, and Virginia and North Carolina in the Southeast. The importance of non-employers as a contributor to forestry labor varies consistently by region. In regions dominated by industrial softwood production (W, SE and SC) the ratios of non-employers to establishments were about 3:1. In the Appalachian region the ratios were 13:1 and the regional ratios for Lake States and the Northeast

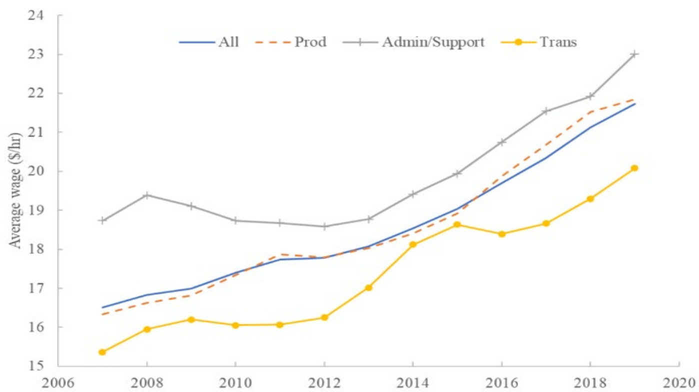

Figure 5. Average hourly wage from the Occupational Employment Statistics for NAICS 1133 for all workers and occupational groups including production workers and loggers (Prod), Administration and Support (Admin/Support), and Transportation (Trans) occupations.

were similar at about 7:1.

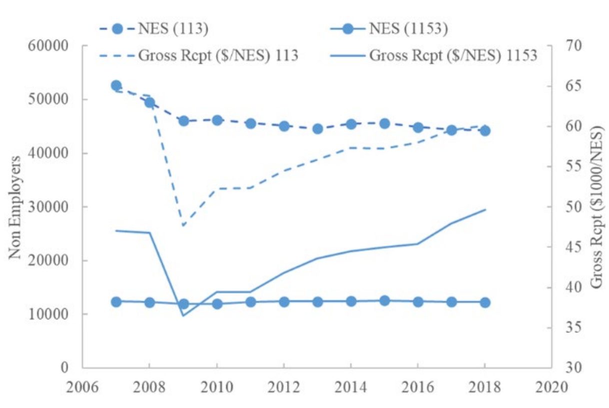

Figure 6. National non-employer statistics from 2007 to 2018 including the count of establishments (NES) in NAICS 113 and 1153 and the gross receipts per establishment ($/NES).

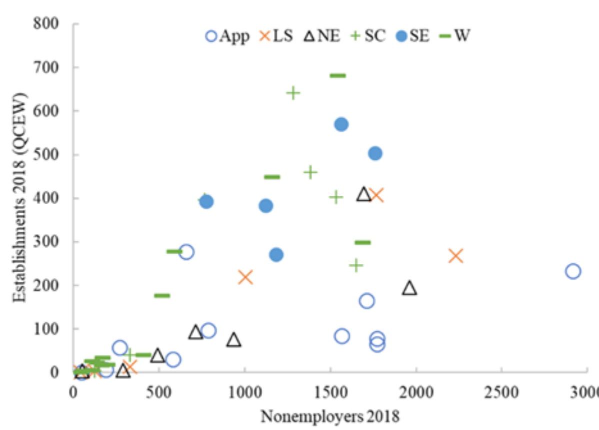

Figure 7. NES and establishments with employees (QCEW) by state NAICS 113. States are grouped FRA region: Appalachian (App), Lakes States (LS) Northeast, Southcentral (SC), Southeast (SE) and West (W).

2.7 Employment Summary

We developed the employment for the major industries and occupations for 2017 to compare the datasets (Table 1). For counties no data or a count or sum of zero for that attribute means that the value was below the reporting threshold for the methods employed and not that there were no establishments or employees. For the two datasets available at the county scale, the differences perhaps relate to the timing of the data collection. QCEW (QWI uses QCEW data) is an annual average and CBP is the value in the first quarter. At the state and national level for NAICS 113 and 1133 the values from the surveys (CES and OES) were similar to the censuses (QCEW and CBP). For comparison American Community Survey (ACS) estimate was at least 25% larger than the others. The difference and the consistent bias are interesting, but conclusions are difficult to make since the classification procedures are different. In the QCEW and CBP, the employer may select from a list of codes and may be familiar with the classification scheme. ACS relies on the analysis of text responses of individuals who have varying levels of appreciation for the specific business of their employer. It is reasonable to conclude from the evidence supplied by NES and ACS that the population of people involved in these industries are significantly larger than the employment data like QCEW would imply. ACS (all) for industries and occupations are influenced by the large number of state and federal employees in the western US.

Table 1. 2017 population estimates from CES, QCEW, CPB, OES and ACS. NAICS codes include private business and SOC data include all employers. ACS (all) includes all self-employed and government workers and NES statistics reference non-employer businesses.

	Employees					Other	
Industry or occupation (location)	CES	QCEW	OES	CPB	ACS	ACS (all)	NES
NAICS 113 (US)	-	54044	49250	54097	68324	103150	44362
NAICS 1131 (US)	-	3063	-	3883	14515	64101	-
NAICS 1132 (US)	-	2209	-	1133	-	-	-
NAICS 1133 (US)	50200	48771	49250	49081	76604	116738	-
NAICS 1133 (OR)	5300	5126	-	5563	7534	9634	-
NAICS 1133 (OR-Coos Co.)	-	448	-	559	-	-	-
SOC 53-3000 (US) in NAICS 1133	-	-	8790	-	10587	13360	-
NAICS 1153 (US)	-	16752	-	12445	-	-	12312
SOC 45-4011 (US)	-	-	7080	-	11589	23557	-
SOC 45-4020 (US)	-	-	37730	-	56569	97717	-

Table 2 is the summary of current links and descriptions for the data reviewed in this paper. The data tools are usually referenced on these sites and there may be more than one tool to extract, visualize or download the data. In general the data tools for CES and QCEW make it easy to generate data for a few data series at a time and they can be exported to excel. The most recent CBP data provides for easy access to forestry data at the state and national level. The county level data was limited to two digit NAICS codes on the interface but there were data to 4 digit NAICS code in the data downloads. Downloading the BLS (CES, QCEW, and OES) data is possible, but datasets may have more rows than spreadsheet software can handle. Additionally much of the information is included in long text strings which must be parsed before the non-target information can be discarded. The QWI interface or extraction tool provides the most logical data selection and downloading tools for national, state and county data for employment, wage, and establishments. However if the data for multiple indicators in multiple regions for a few years are needed the use of an API (Application Programing Interface) with statistical analysis software is required. The QWI and CBP data together provide a fairly complete picture for establishment, employment, and wage dynamics. While it is based on very few samples with significant error the ACS is the best source for national and regional workforce demographic trends especially regarding the logging occupation.

3. Safety and Health

The understanding of occupational safety and health risks is supported by surveillance of the hazards or the outcomes (injuries and illnesses). Analysis of data from private workers compensation insurance (WCI) providers (Lagerstrom et al., 2017; Roberts et al., 2005; Shaffer and Milburn, 1999) and state workers compensation funds (Bell and Helmkamp, 2003; Bonauto et al., 2019; Longwell and Lynch, 1990; Pine et al., 1994) have provided valuable surveillance data for logging. However, the analysis of WCI data might be an incomplete or biased perspective of hazard exposures related to the variation in state rules and the emphasis on acute exposures for WCI (Utterback et al., 2014). Safety and health experts have sought to supplement surveillance information with reporting through voluntary surveys (Lynch et al., 2014; Rodriguez et al., 2019) and reports from health services (Holman et al 1987; Scott et al. 2019). Two databases, Survey of Occupational Injuries and Illnesses (SOII) and Census of Fatal Occupational Injuries (CFOI), provide national and state level surveillance data on occupational illnesses and injuries. Since the forest industries and forest work across the country are diverse, interpretation of national data has limitations. The need for improvements to injury and illness surveillance data for logging and forestry has been recognized (Alamgir et al., 2014; National Research Council, 2008).

Table 2. Major sources of forestry employment data. Region refers data availability for National (N), State (S), and County (C) levels. Data may include estimates for Employment (Emp), Wage, Hours, Demographics (Dem) and Establishments (Est) Size, Age, or Organization Type (Org). Links were last accessed June 2021.

Data	Region	Link	NAICS	SOC	Data
ACS	NS	https://data.census.gov/mdat/#/	113 (without 1133), 1133	45-4011, 45-4020	NA
CES	NS	https://www.bls.gov/ces/, https://www.bls.gov/sae/	113, 1133		Emp, Wage, Dem, Hours
QCEW	NSC	https://www.bls.gov/cew/ https://data.bls.gov/PDQWeb/en,	113, 1131, 1132, 1133, 1153		Emp, Wage, Est
QWI	NSC	https://ledextract.ces.census.gov/	113, 1131, 1132, 1133, 1153		Emp, Wage, Dem, Est (Size and Age)
OES	NS	https://www.bls.gov/oes/	113, 1133, 1153	19-1032, 19-4071, 45-4011, 45-4020	Emp, Wage
CBP	NSC	https://www.census.gov/	113, 1131, 1132, 1133, 1153		Emp, Wage, Est (Size and Org)
NES	NSC	https://www.census.gov/	113, 1153		Number, Gross Rcpts

3.1 Survey of Occupational Injuries and Illnesses (SOII)

SOII data are generated from surveys of establishments which are primarily selected from those that pay unemployment insurance (one or more employees) and contribute data to the Quarterly Census of Employment and Wages (QCEW). The sample number is determined at the state level based on the characteristics of the population and the state's interest in the data for industries and types of cases. The survey participants provide data from their employer injury and illness logs and detailed information on a sample of cases that resulted in lost time or job restriction for at least one day. The cases are weighted to determine the number of similar cases among the population of workers.

For SOII data the industry code and description is entered by the firm and the occupation of the injured person is entered as text by the firm with the record of the injury. The text for job title or occupation is classified into a Standard Occupational Code (SOC). Classification of injuries or illnesses in the current data set were completed with the Occupational Injury and Illness Classification System (OIICS 2.01). NAICS, SOC, and OIICS classification schemes have been consistent since 2011. Developing trends over longer time periods are subject to classification changes as well as OSHA reporting requirements, definitions, and forms with the last revision in 2004 (BLS 2017).

Nationally, forestry establishments were just 0.12% of private establishments in 2017. It is likely the 5 forestry NAICS codes (1131, 1132, 1133, and 1153) account for only a few hundred of the 230,000 annual surveys. The small sample number across forestry results in large confidence intervals. For example, the rate of total recordable cases for logging (NAICS 1133) in 2017 was 2.8 with a relative standard error of 21.2%, resulting in a 95% confidence interval from 1.6 to 4.0. Most forestry establishments have less than 11 employees and research indicates that small firms like these are likely to under-report cases (Morse et al., 2004). Since SOII sampling intensity is weighted due to state interests, there is little expectation that the sampled firms proportionally represent the firms by system type (e.g. mechanized and non-mechanized, aerial and ground based, etc). Logging hazards and injuries rates are likely to vary by harvesting system and geography (Myers and Fosbroke 1994). The SOII sample might be more representative of mechanized firms since they would be a larger proportion of the employed population. Mechanized case rates (total case incident rates - TCIR) from WCI data for the southern US (Roberts and Shaffer 2003), Oregon and Washington (Pilkerton and Wimer 2008) and SOII lost time rates were similar in magnitude and trend. WCI claims would typically include a wider range of incidents than SOII lost time cases and within the sample periods the TCIR is slightly higher than the reportable injury rate. Few state level SOII estimates for NAICS 113 (forestry and logging) or 1133 (logging) means that there is little information to identify regional trends that might reflect logging system differences.

An explanation of the SOII data coding and survey methods is presented in the handbook of methods (BLS, 2017). The data structure is complicated and there are missing values for some combinations of variables that might be of interest. Data for forest industries and occupations are included in case codes 3 and O, respectively. The industry data is available only for private industries (ownership code 1), and occupational data may be available for both private industry and government (ownership codes state - 7, local - 8, and combined - 9). Rate (3), case number (6), and median lost time (7) data may be available for industries or major occupations (Category 00X). For more specific categories within industry or occupation (e.g. event, person, source, body part, and injury), only case number and median lost time data are available. The rates are based on the estimated number of cases (6) and the estimated population of workers represented. Even for industries and occupations where the data are generally available, estimates may not be produced every year due to low case or sample number.

The SOII lost time injury rates and median lost time per case are displayed in Table 3. Industries and occupations which have greater injury frequency or larger populations typically have estimates for each year and reduced volatility from year to year. The effect of small numbers of cases can be seen in the volatility of median lost days per case for fallers (45-4021) where the range extends from 2 to 100. NAICS 1131 and 1132 have similar employment for 2017 at 3063 and 2209, respectively, with only 1 data point in 1132 from 2011 to 2019.

Recordable injuries and illness are defined by OSHA as specific illnesses or generally treatment beyond first aid. The SOII recordable injury and illness data is presented in Table 4 and is available for industries only. National illness rates are available for most years for 113, 1133, and 1153, but data is reported sparingly for states. Only three states have any data for illnesses (CA, OR, and WA) for any of the industries. Nine states have some data for recordable injuries for forestry (113) but only four states have data for most years from 2014 to 2019 (CA, ME, OR, and WA). With a few exceptions the confidence intervals are 50% to 100% of the rates reported. Availability of state data is related to injury or illness frequency, large target populations, and state emphasis in sampling.

3.2 Census of Fatal Occupational Injuries (CFOI)

The Census of Fatal Occupational Injuries (CFOI) is not a survey but a compilation or census of occupational fatalities from several sources and includes the records of fatal injuries of employees, employers, and self-employed people. SOII includes only employees. Since data are from a variety of sources the amount of information available for classification varies, there is some chance of misclassification of the occupation or industry in CFOI. Workers and events in site preparation (23891), landscaping services (56173), timber tracts (11311), forestry services (11531) and logging (11331) might be difficult to differentiate and firms may be involved in activities that are not easily classified. Fatal injuries of logging truck drivers maybe classified in transportation (484) depending on their employer and the location of the fatality. Occupations may present similar challenges, as individuals on small firms typically have multiple roles, and the task related to the accident may be used to determine the occupation. Since inclusion in CFOI requires that the person be at work, unpaid family members or by-standers may not be included. Most of the forestry occupations and industries are too small in population to determine a fatality rate from CFOI (Table 5). Rates are only estimated for those industries and occupations with a minimum of 15 fatalities and 40 million hours worked. Fatality rates have significant error since the denominator is from the Current Population Survey (CPS), an annual survey of 60,000 households. For small populations like logging the low confidence in the population estimate produces large standard errors in the rate estimate. For 2016, the 95% confidence interval was 58 to 158 for the logging industry (1133) and 50 to 222 for the logging occupation (45-4020).

Table 3. Lost time injury rates and median lost time per case. Industries and logging workers (45-4020) include only private employers, other occupations include public and private employers. Missing data are indicated by "-".

Data type	Occupation or Industry	Year								
		2011	2012	2013	2014	2015	2016	2017	2018	2019
Rate (#/10000 workers)	19-1032	172	92	35	26	48	29	61	68	55
	19-4093	284	78	240	80	88	205	206	76	71
	45-4000	-	367	277	205	191	235	184	256	278
	45-4011	394	773	389	160	486	193	-	228	381
	45-4020	299	278	238	220	133	230	100	233	-
Median lost time per case (days)	19-1032	1	5	2	23	2	2	13	10	8
	19-4093	4	3	11	3	12	8	3	4	3
	45-4000	11	21	5	9	6	10	20	7	3
	45-4011	11	8	8	9	6	4	24	31	5
	45-4020	10	51	5	9	10	16	9	5	3
	45-4021	56	100	14	23	41	8	8	27	2
	45-4022	10	51	3	7	5	81	9	7	8
	45-4023	21	-	-	3	7	-	-	-	-
	45-4029	5	21	14	9	13	16	24	1	16
Rate (#/10000 workers)	1132	-	-	-	-	-	189	-	-	-
	1133	306	234	221	212	137	252	106	280	209
	113	276	212	206	195	144	233	133	260	220
	1153	278	540	355	108	223	108	61	92	148
Median lost time per case (days)	1132	-	-	-	-	-	44	-	-	-
	1133	17	21	21	13	5	18	24	5	3
	113	14	21	21	14	5	18	12	5	3
	1153	7	12	16	20	5	4	3	5	8

As expected, the state data for fatalities is nearly absent for occupations and industries except for logging. Due to reporting limitations some fatalities are not reported in state data and in 2019 about 40% of US fatalities in logging occupations were not recorded by state. For the logging industry, fourteen states averaged more than two fatalities per year from 2011 to 2019 and they accounted for nearly two thirds of the logging fatalities identified by state. Those states are from the primary forested regions: the west (CA, OR and WA), southeast (AL and GA), mid Atlantic (NC and VA), Lake States (MI), and central and northern hardwood regions (KY, MO, NY, PA, TN, and WV). Those states have a combination of greater hazard exposure and the larger forest industries. Since rates are not developed by state or region, the state variation provides little additional information in hazard assessment. The ability to generate fatality rates by region (Myers and Fosbroke 1994) would help direct attention and interventions to regions with lower employment and production but significant hazard exposure.

3.3 Analyzing and Using Surveillance Data

The rate for reportable cases in logging (1133) in 2019 was 2.6 per 100 workers or 200,000 work hours (Table 4). Based on the historic rate, the 9-worker logging firm might expect 0.26 reportable cases per year or 1 reportable case every 4 years assuming approximately 20,000 work hours per year. It would be likely the case would be lost time since about 4 of every 5 reportable cases (2.1/2.6) were lost time cases. For the available states, the reportable rates for 1133 ranged from 1.8 to 12.8 which indicates how the probability of injury could be affected by terrain, logging system, or other local attributes. Given that variance the reportable incident occurrence for a firm could range from 50% (1 every 8 years) to 500% (more than 1 per year) of the average.

Table 4. Recordable injury (cases per 100 workers) and illness (cases per 10000 workers) data by industry. The 95% confidence interval is in parenthesis (+/-). Missing data are indicated as "-".

Data	Industry	Location	2014	2015	2016	2017	2018	2019
Illness	113	US	19.9(16.0)	5.6(4.5)	33.0(37.1)	25.9(20.9)	15.9(12.3)	-
	1133	US	12.9(12.7)	5.7(4.9)	36.4(41.0)	26.8(22.9)	10.7(10.1)	-
	1153	US	37.9(35.5)	58.9(54.5)	44.4(44.3)	15.6(18.0)	-	69.6(75.3)
Injury	113	US	-	2.2(0.6)	3.3(1.1)	2.9(1.1)	3.4(1.5)	2.8(1.7)
	1132	US	-	-	5.4 (3.2)	-	2.8 (1.3)	-
	1133	US	-	2.1 (0.7)	3.5 (1.2)	2.6 (1.1)	3.4(1.6)	2.6(1.7)
	1133	CA	6.1(3.1)	2.4(0.3)	5.5(3.5)	-	6.6(6.9)	-
	1133	ME	4.2(2.8)	4.6(2.4)	5.2(5.0)	4.2(3.0)	1.8(1.7)	-
	1133	OR	9.8(4.5)	4.8(2.3)	12.8(3.8)	8.2(3.6)	4.4(1.4)	4.8(2.1)
	1133	WA	11.3(7.8)	3(2.2)	7.2(2.7)	5.6(4.2)	8.2(2.4)	5.6(4.4)
	1153	US	2.7(2.0)	6.5(3.1)	2.3(1.1)	1.9(1.2)	4.4(2.2)	3.0(1.7)
	1153	OR	4.3(3.9)	12.5(8.3)	3.5(1.2)	8.0(2.5)	5.9(3.5)	6.0(3.9)

Table 5. Fatal injury number and rate (number per 100,000 workers) for forest industries (Ind) and occupations (Occ). The population for 2016 (Pop.) from QCEW (industries) and OES (occupations) is shown for reference.

Data	Ind/Occ	2011	2012	2013	2014	2015	2016	2017	2018	2019	Pop.
Number	1131	1	0	3	3	0	0	0	1	0	3268
	1132	0	0	0	0	0	0	0	8	0	2114
	1133	76	61	77	92	80	105	74	75	57	51352
	1153	7	4	3	3	3	0	4	0	0	15153
	19-1030	3	0	0	1	0	0	0	3	0	28890
	19-4093	0	1	0	1	1	0	0	1	0	30090
	45-4011	3	0	3	0	2	0	0	0	3	7170
	45-4020	65	63	59	78	67	91	55	56	46	38650
	45-4021	55	52	52	66	50	70	40	42	38	5370
	45-4022	5	0	4	3	12	12	6	7	4	27250

Rate	45-4020	104	130	91	111	133	136	84	98	69	
	1133	77	72	86	100	99	100	71	64	48	

Surveillance data may help to identify risk or the relative risk of activities. Risk is the product of the hazard probability and potential severity of the outcome. The probability information is presented by the rates and by the distribution of cases across categories. For categories like events (e.g. struck by object, falls, etc.), nature (bruises, fracture, etc.), source (equipment, material, etc.), and others the relative risk can be assessed by examining the distribution of cases within those categories. For categories like gender, race, length of service, and age, the information from the distribution of cases would be more valuable if the distribution of the population were known. Median lost time is an indicator of injury severity and is available for all data with recorded cases. Additionally, the comparison of case distribution between the lost time injuries and fatal injuries is an indication of relative potential severity.

For an example of risk assessment, some of the data for events or exposure (events) are presented for both SOII and CFOI data as an aggregate for 4 years (2016-2019) in Table 6. Event classifications are defined for both CFOI and SOII by the OIISC 2.01 manual although more detail is presented for the CFOI data. Some categories, especially those below the major division, are not reported by SOII by design or because the minimum case number estimated is less than 15 which for logging (NAICS 1133) is 1 to 2% of total annual cases.

The distribution among the events for lost time cases is an indicator of relative probability. The events coded as violence (E1X), fires and explosions (E3X), and exposure to harmful substances or environments (E5X) appear to be infrequent with numbers below at least below the reporting threshold for SOII and less than 1% of fatal injuries. Logically for every event category with a fatality there should be lost time cases. Those are either too few to report or the too infrequent small for detection by the sample. For other categories like overexertion and bodily reaction (E7X) there is no reason to expect fatal cases. Slips and trips without a fall (E41) is the only event reported in SOII with too few cases to report over this time period. The lack of reported cases is not the same as low probability of occurrence. However the incidents seldom result in lost time injuries. The pyramid model for incident occurrence with progressively fewer numbers but similar proportions for close calls, incidents, lost time injuries and fatal injuries has been described in documents like “Learning from Close Calls” (FRA 1996). The model probably fits for events like struck by object events (E6X). However each recorded incident for events like violence (E1X), transportation incidents (E2X), and explosions or fires (E3X) are likely to be represented by more severe outcomes rather than minor incidents or close calls.

3.4 Safety and Health Summary

Navigating the BLS data tool is difficult and relies on users understanding the source and limitation of the injury and illness data. The availability of a representative national dataset for the forestry industry and related occupations is limited by state and federal decisions related to SOII sampling and varying industry importance by state. State variation in forest industries and limited sample number makes it difficult to clearly identify trends or areas of concern for improving safety and health. In the absence of firm data for close calls, incidents, or injuries the SOII and CFOI data can provide an indication of both the potential likelihood and severity of injury across many attributes. The BLS data profile tool (https://data.bls.gov/gqt/InitialPage) can be used to compare all the SOII or CFOI data for the selected industry or occupation in area of interest.

Table 6. Case data for lost time (SOII) and fatal (CFOI) injuries for NAICS 1133 by event for 2016 to 2019. Relationships between codes are indicated by Parent vs Code. Events where SOII does not report data is indicated by “-“ and events with no cases are indicated by 0. All other is the ratio of cases included in the total but in none of the major codes (E1X, E2X, E3X, E4X, E5X, E6X, and E7X).

Event					
Parent	Code	Description	SOII ratio	CFOI ratio	Days lost range

All	00X	All	1.00	1.00	3-24
E1X	E1X	Violence and other inj. by person or animal	0	0.01	-
E2X	E24	Pedestrian veh. incid.	-	0.01	-
	E26	Rdwy. incid. involving mot. veh.	0.10	0.21	3-35
	E27	Nonrdwy. incid. involving mot. veh.	-	0.05	-
	E2X	Transportation incid.	0.11	0.31	3-35
E3X	E3X	Fires and explosions	0	<0.01	-
E4X	E41	Event - Slips, trips without fall	0	0	-
	E42	Event - Fall on same level	0.09	0	2-164
	E43	Falls to lower level	0.08	0.02	4-60
	E4X	Falls, slips, trips	0.19	0.02	2-33
E5X	E5X	Exposure to harmful substances or environ.	0.02	0.01	4
E6X	E62	Struck by obj. or equip.	0.42	0.59	3-24
	E63	Struck against obj. or equip.	0.09	0	1-8
	E64	Caught in or compressed by equip. or obj.	0.01	0.02	60
	E6X	Contact with obj., equip.	0.56	0.62	3-24
E7X	E7X	Overexertion and bodily reaction	0.08	0	21-180
		Not classified	0.02	0.02	-

4. Acknowledgements

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Theme 3: Inventory, Remote Sensing and Precision Technology

Quality Certification of Tree Measurement by Harvester - Reliability of Harvester Report Data to Provide Digital Information for an Efficient Wood Supply Chain

Hans-Ulrich Dietz, Gerrit Balindt, Thomas Purfürst

Opportunities for Acoustic Technologies in the Wood Supply Chain

Dana Mitchell, Mathew Smidt, Munkaila Musah, Brian Via

Post-thinning evaluation of harvester operator consistency and adaptability using UAV derived imagery

Hugo Zandberg, Munyaradzi Makoto, Simon Ackerman, Bruce Talbot

Verification Study of Measuring Tools in Processing Heads

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A comparison of pre-harvest TLS based inventory data with harvesting-head measured outcomes in mature pine stand

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Image based analysis of surface unevenness and its applicability in an operational setting

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General data protection conditions for motor-manual timber harvesting in forestry 4.0

Michael Ottl, Dirk Jaeger, Ulrich M. Gassner

Automatic detection of decay and resin in felled Scots pine stems using convolutional neural networks

Eero Holmström, Antti Raatevaara, Jonne Pohjankukka, Tuula Piri, Juha Honkaniemi, Jori Uusitalo, Mikko Peltoniemi, Aleksi Lehtonen

GreenLane IBM - Insect, Blue stain and Moisture content prediction for enhanced value tracking in supply chain simulation

Christian Kanzian, Thomas Holzfeind, Peter Baier, Thomas Kirisits, Lone Ross Gobakken, Dag Fjeld

Use of harvester data to estimate non-utilized merchantable volume of coniferous trees remaining after mechanized cut-to-length forest operations

Myriam Delmaire, Eric R. Labelle

Positioning accuracy of Cut-to-length (CTL)-harvester integrated Global Navigation Satellite Systems during a thinning operation

Kari Väätäinen, Antero Kukko, Harri Kaartinen, Mikko Vastaranta, Antti Raatevaara, Perttu Anttila, Eero Holmström, Robert Prinz, Ville Kankare, Tuomas Yrttimaa, Johanna Routa

Performance of dedicated UHF RFID tags in timber automatic identification

Gianni Picchi, Carla Nati

Influence of UAV flight parameters on the quality of terrain models

Dariusz Pszenny, Tadeusz Moskalik

Stack volume accuracy of broadleaved tree specie

Ferréol Berendt, Tobias Cremer

Analysis of the influence of log parameters on the conversion factors for wood stacks using a novel 3-D simulation model

Felipe de Miguel Diez, Tim Pettenkofer, Thomas Purfürst, Eduardo Tolosana Esteban, Tobias Cremer

Operational Evaluation of the Three-rows Automated Irrigator

Guilherme Oguri, Júlia Ifanger Faria, Saulo Philipe Sebastião Guerra

Quality Certification of Tree Measurement by Harvester - Reliability of Harvester Report Data to Provide Digital Information for an Efficient Wood Supply Chain

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ABSTRACT

Real-time or timely digital product information is decisive to effect efficient logistical processes within the wood supply chain. Actually, harvesters and forwarders provide about two-thirds of the annual softwood supply in Germany. Report of work progress and product data (assortments) are sent automatically by machines to promote the logistical value chain from forest to mill. The communication protocol is provided according to StanForD, the standard of forest machine data and communication.

Prerequisite to using these machine data within the logistical process is reliability and adequate precision of the measuring results. KWF, the German test center for forest machines and technology, has developed and implemented a quality certification procedure QS Harvester. Affiliated contractors send their harvester measurement control data (ktr-files) to the QS Harvester system for documentation and evaluation once a week. About 21.360 ktr-files have been sent to the system from 2008 until 2021. They have been checked and analyzed to evaluate the reliability and precision of produced harvester measuring data. The deviation between manual measuring with a digital caliper by harvester driver (M2) to machine measuring device data (M1) was in focus. Results of accumulated experience over the last ten years have been depicted by statistical computation.

In the present study the following questions were dealt with:

- Is the data reliable and the sample representing the population?
- What characteristics show the relation of M2 to M1?
- Is there a variation of the results within a year or over the analyzed period?
- Are there differences between various machine types and sensors?

The study points out that harvester control measurement data is reliable and rises transparency and confidence of harvester product data reports. Anyhow, future attention has to be turned to put into practice effective control routines to provide an elevated quality standard for an efficient wood supply chain.

Opportunities for Acoustic Technologies in the Wood Supply Chain

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ABSTRACT

This study seeks to examine opportunities for improving wood quality along the supply chain through the application of acoustic technology. This technology is a proven method for measuring wood stiffness and is an important property in the production of a variety of forest products. It may also be a way to identify voids in logs, such as those that may result from storm damage. This paper explores opportunities to operationalize acoustics at various points from the stump to the mill.

Post-Thinning Evaluation of Harvester Operator Consistency and Adaptability using UAV Derived Imagery

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ABSTRACT

For fast growing tree species, timely and accurate thinnings are important in directing and maximizing growth to targeted products. Plantation forests of fast-growing pines (Pinus spp.) targeting the production of saw- and veneer logs are subject to intensive management and rigorous silvicultural regimes. A 25-year sawtimber rotation would typically include two thinnings and up to four pruning interventions. Out of necessity, it is commonly assumed that mechanized thinning operations are carried out as prescribed, as the costs of manually assessing the outcome on a continuous basis is often excessive.

The aim of this study was therefore to evaluate how effective UAV data is in providing key information related to thinnings, including; stocking, relative spacing, thinning degree, thinning consistency across the site, as well as the adaptability of the operator in switching between thinning instructions.

Two high elevation (1700 m asl) neighboring stands of roughly 30 ha each were included in the study. Both were stocked with Mexican weeping pine (P. patula) at roughly 1100 stems per hectare before thinning. A Ponsse Beaver thinning harvester was used with the same operator throughout both stands. The stands were divided into blocks in which combined row and selective, and diagonal row and selective thinning was carried out. Each block consisted of multiple plots in which all trees were manually measured before and after thinning.

Thinning quality, measured in terms of meeting targeted stem numbers and dimensions of trees removed, was assessed on the basis of UAV captured imagery. The data generated was further used in retroactively assessing the need for thinning using a number of indicators. The stands were imaged immediately before and after thinning using a consumer grade DJI Mavic. Images were captured from an altitude of 100 m above ground level with an overlap of 80% in the forward, and 70% in the lateral directions. The pre- and post thinning image sets from each stand were

processed using structure-from-motion (SfM) in Agisoft Metashape® software. The resultant point clouds for each stand were aligned in CloudCompare®, where the ground points classified in the post-thinning models (visible) were used to define the ground for both.

This paper presents the comprehensive set of results obtained from the above comparisons.

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Verification Study of Measuring Tools in Processing Heads

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ABSTRACT

Today's timber market in the Southeast US demands a specific size log; thus, the harvested trees need to be processed at the landing. The utilization of a processing head in the logging industry is encouraged due to the presence of technological 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. This study evaluated the accuracy of processing heads in merchandizing logs by analyzing the bias and precision of measurement differences. The results showed that the processing heads resulted in biased measurements and very low precision in measuring length, butt diameter, and top diameter. The majority of produced logs (62% of the observed data) were on acceptable length as they were produced between trim allowance. It was also found that processing heads showed better performance in measuring top diameter than butt diameter (0.55 inches and 0.71 inches of overall measurement differences respectively). Butt diameter measurement differences that were equal to zero were found on 25% of total observation, while it was found that 42% of the total top diameter measurements were showing equal reading with the post-measurements. In addition, it was found that the measurement difference had a positive correlation with the length of merchandized logs with an R-squared of 3%. Longer logs were likely to contribute to a higher difference between processing head and manual measurement. Today's timber market in the Southeast US demands a specific size log; thus, the harvested trees need to be processed at the landing. The utilization of a processing head in the logging industry is encouraged due to the presence of technological 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. This study evaluated the accuracy of processing heads in merchandizing logs by analyzing the bias and precision of measurement differences. The results showed that the processing heads resulted in biased measurements and very low precision in measuring length, butt diameter, and top diameter. The majority of produced logs (62% of the observed data) were on acceptable length as they were produced between trim allowance. It was also found that processing heads showed better performance in measuring top diameter than butt diameter (0.55 inches and 0.71 inches of overall measurement differences respectively). Butt diameter measurement differences that were equal to zero were found on 25% of total observation, while it was found that

42% of the total top diameter measurements were showing equal reading with the post-measurements. In addition, it was found that the measurement difference had a positive correlation with the length of merchandized logs with an R-squared of 3%. Longer logs were likely to contribute to a higher difference between processing head and manual measurement.

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A Comparison of Pre-Harvest TLS Based Inventory Data with Harvesting-Head Measured Outcomes in Mature Pine Stand

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ABSTRACT

The capture and use of harvesting head data in productivity studies, inventory, and growth and yield modelling is gaining widespread acceptance around the globe. However, many issues relating to the accuracy of this data in correctly representing tree heights, diameters, and tapers are still being dealt with despite a number of studies demonstrating an acceptable accuracy under controlled conditions. In complementing this data source, pre-harvest inventories are carried out in some forms of forest management, typically to either calculate a suitable stumpage price when point-of-sale is pre-felling, or in facilitating stand-level bucking and assortment prediction for own use. The aim of this study was therefore to evaluate how closely a high-resolution pre-harvest inventory matches the volumes measured by a well calibrated harvesting head.

In order to assess the validity of both, this study compared measurements extracted from terrestrial laser scanner (TLS) point clouds, scanned immediately before clear felling, with harvesting-head measured stem data. Manual measurements were carried out as a control. The stand used for the trial consisted of mature Mexican weeping pine (P. patula) grown in a high altitude (1700 m asl.) plantation regime, which had been thinned twice and pruned to 7 m. Four plots of 200 trees each were used where each tree was measured for DBH by the three methods; manually with diameter tape, TLS, and machine caliper in the harvesting head. For height, a sample of 40 trees in each replication was measured by Vertex hypsometer and an estimate of each tree height was extracted from the point cloud. The machine file stored only a merchantable length measurement and a taper model had to be used in predicting total tree height on the basis of the diameter vector recorded.

Diameter comparisons showed a significant difference between manual and TLS measurements with an error of about 2%, despite compensating for stump height. Machine measurements had a negative bias of about 8% compared to the other measurements. This study shows both the extent and distribution of errors between 3 measurement methods on both DBH and tree height, despite repeated control of the harvester head measurement accuracy and calibration when necessary. The results are immediately applicable as a basis for calculating correction factors for harvested tree dimensions under similar conditions.

Image Based Analysis of Surface Unevenness and its Applicability in an Operational Setting

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ABSTRACT

Surface unevenness (or ground roughness) is one of the terrain factors that affect the productivity of ground-based timber extraction operations (skidding, forwarding, high leading) most, yet it remains difficult to quantify on a scale useful for forest operations (i.e. over multiple hectares). Although most terrain classification models address surface unevenness, the assessment requires a composite value that is made up to reflect both the height, height distributions, and relative spacing of the obstacles being described. The terrain classification model used in South Africa for example comprises 4 obstacle height classes (<30 cm, <50 cm, <70 cm and >70 cm), and four incident classes(isolated, infrequent, moderately frequent and frequent), (Erasmus, 1994). Making an accurate assessment requires experience, and demonstration plots are needed in developing and calibrating skills. In order to neutralize the effect of clustering or bunching, demonstration plots are recommended to cover areas of at least 100 m2.

One example of a standardized surface unevenness trial is the forwarder test track developed by the Swedish Forest Research Institute, Skogforsk (Gelin & Björheden, 2020). Their track consists of a mix of obstacle heights and obstacle incidence in each wheel track, and is used to assess how well various forest machines perform when traversing it at a given speed. In normal conditions, an operator only has the options of reducing speed or driving a circuitous route in avoiding obstacles. The Skogforsk track essentially blocks both of these options, meaning only vehicle performance is being assessed. However, in evaluating productivity in a field trial or in a normal production setting, a more objective and consistent method of evaluating surface unevenness could contribute to the accuracy of the results.

Proximal sensing methods are beginning to be applied in a forest operation setting (Melander & Ritala, 2020), and assessment or recording of surface unevenness could be considered as one of the more rudimentary applications. Actual unevenness experienced could potentially be measured using sensors monitoring pitch, yaw, roll and speed over ground, or proximally using sensors such as LiDAR or images.

This study reports on the use of UAV and ground based imagery in assessing surface unevenness on three sites representing mild, moderate and severe examples. In all three cases the results are compared with conventional manual assessments and the differences are discussed.

General Data Protection Conditions for Motor-Manual Timber Harvesting in Forestry 4.0

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ABSTRACT

Numerous well-known manufacturers of machines for forest processing are now equipping their systems with sensors that record operational data and transmit it to the users, owners and / or the clients as users. Based on the term Industry 4.0, numerous observers in the field of forestry are already talking about Forestry 4.0. The German manufacturer Stihl offers the Stihl connected product line for chainsaws. The Swedish manufacturer Husqvarna AB (Husqvarna Group) offers the so-called Husqvarna Fleet Services. The two systems collect information about operating times, utilization and load as well as indirectly about the productivity of the machines in forest work. Locating the machines in real time is also becoming more and more important. This makes it possible to generate extensive information about the location, condition and utilization as well as maintenance requirements of machines and the workload of the people operating them. The information obtained in this way can be valuable both for the management and for forest companies. The data are also of great importance for manufacturers. The acquisition of process data, however, always opens up the possibility and at the same time harbors the risk that this also results in monitoring of people, be it intentional or unintentional. The article deals with an analysis of the collection of personal data and an assessment of the methods of anonymization and pseudonymization of personal data. The processors assume that both the Stihl connected product line and Husqvarna Fleet Services collect not only machine-related data, but also personal data within the meaning of Art. 4 No. 1 GDPR indirectly via the identification of the respective machine. This opens up the scope of data protection law. Methods that make re-identification of the machine operator as individual persons impossible (anonymization) or at least make it more difficult (pseudonymization) lead, in the view of the processor, to the fact that the data can only be used to a very limited extent. In order to be able to use the recorded data in a legally secure manner for the most economically sensible use, the only way to do this is to give consent to the collection of personal data by the data subjects in accordance with Article 6 (1) (a) GDPR.

Automatic Detection of Decay and Resin in Felled Scots Pine Stems Using Convolutional Neural Networks

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ABSTRACT

Root rot caused by Heterobasidion spp. is the most severe fungal disease of conifer forests in the Northern Hemisphere. In Scots pine stands infected by H. annosum, the disease reduces sawlog quality through decay and resin-soaked patches. Automatically detecting the disease during harvesting operations could be used to optimize the bucking of stems and to efficiently collect data on root rot incidence on stand level as well as on larger geographical scales. In this work, we create deep learning models based on convolutional neural networks for detecting root rot disease and the presence of resinous wood in stem end images of Scots pine. First, using transfer learning on pre-trained feature extractor networks, we construct a classifier model for detecting severely rotten wood in a given stem

end image. Second, we develop a classifier for detecting the significant presence of resin outside of branch knots. In root rot detection, our model reaches a binary classification accuracy of (63 +- 6), higher than the result of (54 +- 7)% given by a baseline model of uniform prediction of the dominant class in the test data. In resin detection, we find a classification accuracy of (75 +- 7)%, considerably higher than the baseline result of (52 +- 8)%. Finally, we discuss the economic and ecological implications of implementing such computer vision algorithms in a future generation of forest harvesters.

GreenLane IBM - Insect, Blue stain and Moisture Content Prediction for Enhanced Value Tracking in Supply Chain Simulation

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ABSTRACT

Intensified forest disturbances across the globe challenge the forest sector. For example, in 2019, salvage cut volume (due to bark beetle infestation and abiotic disturbance such as windfall and windthrow) reached 62 % of the annual cut in Austria. Extended transport throughput times can lead to wood value losses resulting from staining and decay fungi, insects or changing mechanical/chemical properties. To guarantee that the wood harvested arrives at industry with the specified quality fulfilment , well-coordinated transport management is essential. Furthermore, it is necessary to understand how the wood value develops over time under varying weather conditions in order to take the right transport action.

Therefore, an integrated weather-driven framework for wood quality prediction or more precisely for the main drivers of wood quality development, Insects (I), Blue stain (B) and Moisture content (M) has been developed. The IBM model will enable value-tracking within a virtual supply chain laboratory environment and for digital log twins. The focus is on finding the appropriate models, implementing them conceptually and validating existing models for insects (particularly the Eurasian spruce bark beetle, Ips typographus), blue stain and moisture content.

In case of blue stain development during storage of logs, limited knowledge exists. Likewise, moisture content

prediction models like TorkCalc have not been tested outside Sweden. Representatively for the I-B-M model, the current prototype of the blue stain (B) model, validation experiments on TorkCalc and the underlying study and analysis concept will be presented.

This work is part of the project GreenLane, which receives funding by the ERA-NET Cofound Action “ForestValue – Innovating the forest-based bioeconomy”.

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Use of Harvester Data to Estimate Non-Utilized Merchantable Volume of Coniferous Trees Remaining after Mechanized Cut-to-length Forest Operations

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ABSTRACT

The Gaspé region of Quebec, Canada, is confronted with a shortage of pulpwood (softwood and hardwood) buyers. Despite having two processing facilities requiring hardwood and comminuted poplar, wood supply costs from more remote areas, which contribute to a significant proportion of the region, outweigh potential revenues. Sawmills in the region are therefore faced with costs that make the harvesting of certain strata less financially viable. The amount of non-utilized woody material (NUWM) is currently being monitored via expensive field inventories (approx. 50$ per hectare) performed after harvesting operations.

Within a rationale of lowering costs associated with the current NUWM field inventories, this study aims to reconstruct the non-utilized merchantable section of coniferous trees (balsam fir (Abies Balsamea Mill.) and white spruce (Picea glauca (Moench) Voss)) remaining on the harvest site using data from on-board computers (OBC) of single-grip harvesters. Reconstruction algorithms will be based on species dependent stem taper functions and assortment specifications.

This project focuses on balsam fir and white spruce, which represent about 70% of the standing coniferous volume in the Gaspé region and exhibit different stem architecture. In total, six sites of suitable size (15–30 ha) with rather homogeneous conditions will be selected within pre-scheduled forest operations. The experimental design will therefore consist of collecting data from six harvesters operating at six test sites of mixed wood coniferous stands. For every test site, the goal will be to harvest between 1000 and 1500 m3 of wood for each target species. OBC's installed in the harvesters will vary between Ponsse, John Deere and LogMax. For each site, one third of the area will be selected and a forest inventory before and after cut-to-length forest operations will be performed to assess the performance of the algorithms and spatialization tool. For each target tree, diameter at breast height, height, and tree form will be assessed. After harvesting, logs resulting from the processing of each target tree will be individually evaluated in terms of product type, small and large end diameters, and length. Harvester on-board computer production report (hpr and .stm) will be extracted from the machine after harvesting operations and ran in the decision support system to obtain the average volume of NUWM at the block level.

Since NUWM field inventories are mandatory across the province of Québec, obtaining the NUWM from harvester OBC could considerably reduce the costs associated with conventional field inventories, thereby increasing the forest industry competitivity.

Positioning Accuracy of Cut-to-length (CTL)-Harvester Integrated Global Navigation Satellite Systems During a Thinning Operation

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ABSTRACT

Due to the development of Global Navigation Satellite System (GNSS) technologies and the increased availability of constellations and orbiting satellites, the positioning accuracy of GNSS has improved steadily. Today, with the GNSS devices with differential data correction capabilities, positioning accuracy close to mm-accuracy level may be reached on open areas. However, during logging operations, particularly in selective cuttings and thinnings, dense tree canopy cover may limit GNSS satellite visibility and distract received signal. In such conditions, positioning error of CTL-machines' GNSS systems may be up to 5 to 10 meters. More accurate machine and boom-tip positioning would enhance and enable more precise spatial stand inventory with up to date tree mapping, detection of the boundary lines of logging sites and no-go areas, such as environmentally sensitive objects (e.g. tree groups, springs, creeks), and pinpointing of the processed log assortments next to strip roads. Furthermore, high precision machine positioning is seen as a precondition for the development towards autonomous forest machines.

The main objectives of the experiment were a) to compare positioning accuracy of different GNSS-devices and setups with various price and technology levels, and b) to investigate factors affecting the positioning accuracy during the thinning operation. Positioning experiments were conducted during 15th-17th of March 2021 in Eastern Finland with a Ponsse Ergo CTL-harvester in Norway spruce (Picea abies (L.) H. Karst.) dominated first-thinning stand. Tested GNSS devices were Trimble R12 VRS-GNSS, Risutec ASTA-X RTK-GNSS, Risutec ASTA-X, and NovAtel CPT7 GNSS-IMU with two NovAtel GGG-703 antennas, in addition to the GNSS system of the harvester. To validate the positioning accuracy, reference positions were provided using a total station automatically tracking a reflector prism. GNSS devices and the reflector prism were mounted on an aluminum platform to ensure rigid mutual relative geometry during the tests, and the platform was installed on rear-top of the harvester cabin. To permit the analysis of the environmental factors affecting the visibility of the satellites in the forest, thinning site was scanned by GeoSLAM Horizon handheld laser scanner before and after the cutting.

Performance of Dedicated UHF RFID Tags in Timber Automatic Identification

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ABSTRACT

The development of precision forestry techniques for data generation requires reliable tools to identify single items (trees or logs) and relate them to the database of the digital forest inventory. Radio Frequency Identification (RFID) is regarded as one of the most promising systems, and is already widely applied in a plethora of applications, ranging from manufacturing to livestock management. One of the most relevant benefits of RFID technology is the possibility to perform bulk reading at relatively long distances (> 2m). In timber supply chains this would allow to automatically identify at mill's gate (or any other relevant position) all the logs carried by trucks, disclosing several opportunities for product track and tracing services. Yet, for commercial application it is essential that all of the marked items can be correctly identified. This is still a challenge in timber logistics due to the specific conditions of this operation. The study tested a new model of RFID tags (Sundog), specifically designed for timber marking, comparing its performance with a common tag model designed for logistic of goods. 56 logs were marked with a total of 224 tags, with one tag per model fixed on each butt end section. An RFID gate with 4 fixed antennas was set up, comparing different configurations (reading angles) in detecting the timber loaded on a truck and trailer unit. Additionally, an improved manual reading system, based on a telescopic antenna, was tested. The Sundog tags strongly increased the performance of automatic bulk reading compared to the reference tags thanks to the more suitable transponder configuration. Yet, in fully automatic reading about 13 % of tags of the new type could not be identified. This could be partially due to the phenomenon of reading collision, caused by the large number of tags deployed, and partially to the unfavorable layout of the truck used in the test. Improved manual reading proved capable of identify 100% of Sundog tags and 90% of common RFID tags, but the operation requires about 90 seconds and must be performed on a stationary condition. Further studies are ongoing to define the reliability of the solution throughout the whole supply chain.

Influence of UAV Flight Parameters on the Quality of Terrain Models

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ABSTRACT

The use of machinery for forestry work has allowed work productivity and safety to increase. Despite the use of a wide range of technological solutions, the passage of forest machinery strongly affects the soil environment causing the compaction and deformation of the ground. With the development of photogrammetric techniques and laser scanning, there are new opportunities to determine the deformation of soil resulting from the passage of forest machinery.

The use of aerial photography taken with the help of UAVs makes it possible to obtain reliable terrain models at a relatively low cost. This paper presents the results of an attempt to determine the best flight parameters to create terrain models showing the deformation of the soil as a result of the passage of forest machinery.

The research was conducted in the spring of 2021 in the Celestynów Forest District. The study included 48 flights over the study area. Each raid differed in its parameters. Based on the photographic material from the BSP, terrain models were created, and their accuracy was compared to manual measurements in the field.

Stack Volume Accuracy of Broadleaved Tree Species

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ABSTRACT

In terms of economic impact, one of the most important factors in the wood supply chain is the measurement of the round wood. Timber measurement systems currently used are i) the manual measurement method, ii) opto-electronic systems and iii) photo-optical methods. Besides the one-by-one measurement of logs (the most accurate technique which is widely used at the infeed of sawmills through opto-electronic measurement devices), logs are often measured when stacked at the forest road. The gross stacked volume includes the volume of the wood, bark and airspace and is widely used for industrial wood assortments. The increasing international attention given to photo-optical measurement systems for portable devices is due to their simplicity of use and efficiency. Especially when compared to manual measurement, photo-optical measurement systems are faster, less complicated and allow a transparent documentation of the measurements. However, only two photo-optical measurement system are currently calibrated and thereby fulfil the legal requirements to be used for official billing purposes in Germany. The other systems, which are mostly smartphone based, are used by many forest companies to determine stack volumes as control measurements, for documentation purposes but also for comparability reasons.

The aim of this study was to compare the volumes of broadleaved tree species stacks measured using one widespread photo-optical app with the manual measurement method based on the German framework agreement for timber trade (RVR). The study focused on broadleaved tree species of industrial wood quality as first studies showed satisfying results regarding the accuracy of photo-optical measurements for softwood, especially for stem wood.
The average deviation between the photo-optical volume measurement in comparison to the manual measurement method was -2.09 % and -3.66 %, depending on the direction of measuring along the stack. Thus, in total, the smartphone application underestimated the stack volume. The comparisons showed that when starting manual measurements from the right side of the stack, the volume was in average 2.54 % greater in comparison to starting the measurement at the left side of the stack. The results show that the total stack volume has a highly significant effect on the deviation and better results are reached for larger stacks. Moreover, volume estimations of higher quality stacks were differing less compared to estimations of poor-quality stacks.

Analysis of the Influence of Log Parameters on the Conversion Factors for Wood Stacks Using a Novel 3-D Simulation Model

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ABSTRACT

One of the essential processes for commercializing industrial wood is the estimation of the solid wood content in a stack. This parameter is usually estimated by applying a conversion factor on the stack volume measured before. This conversion factor can be determined "*in situ*" by different methods or is predefined based on statistical data. However, the conversion factor can vary considerably for different assortments due to several log parameters, e.g. (1) midpoint diameter or (2) length. Although many of these parameters have been investigated and are considered in the measurement guidelines of many countries, their influence has not been analyzed individually so far. One reason is the high costs required to collect sufficient data in order to create a broad statistical database that grounds their analysis. Accordingly, a 3D-simulation model was developed to provide such large databases. The simulation results are the stacked cubic volume, solid wood cubic volume, and the respective conversion factor. The model, fed with both real data and user-defined data, allows a detailed analysis of each parameter's effect on the results, as the user can vary their values discretionary. The model was validated preliminary based on the measurement of real stacks. According to the calculated Mean Bias Error, the predicted gross volumes were underestimated on average by 0.06 %. Based on simulation outcomes, it could also be proven that parameters can affect the conversion factors differently depending on the tree species. For instance, the conversion factors for a length range from 1 m to 3 m differ by 7 % for Scots pine and by 5 % for Norway spruce. Regarding the parameter midpoint diameter, the conversion factors increase on average when this parameter increases. However, according to the simulation results, its effect is modest for Norway spruce, 1 %, and moderate for Scots pine, up to 10 %, for a variation from small (under 20 cm) to large (over 20 cm) average midpoint diameters. In contrast, the simulation results demonstrated that the parameter ovality barely alters the conversion factors. Furthermore, the model provides reliable information

that can serve as basis, e.g. to analyze more influencing parameters on the conversion factor and deduce the latter for each assortment. In addition, the model presents a practical tool that is easy to apply for the forest and wood industry to optimize the wood supply chain's logistics.

Operational Evaluation of the Three-Rows Automated Irrigator

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Keywords: forestry, eucalyptus, automation

EXTENDED ABSTRACT

1. Introduction

Dombroski et al. (2014) state that the water deficit decreases wood production at the end of the cycle, decreasing the rate of plant's photosynthesis, transpiration and stomatal movement. In the absence of adequate water availability, stomata closure is inevitable, reducing transpiration. Therefore, irrigation becomes an essential technique for the forest sector with the potential to increase productivity (Fernandes et al., 2012). This work aimed to evaluate the irrigation assertiveness and determine the operational performance of the automated prototype irrigation set of three post-planting rows in the eucalyptus crop. The evaluated mechanical irrigation set is classified as Level 7 - Automated (Automatic Operation), according to the Forestry Mechanization Level Survey (Guerra et al., 2020).

2. Materials and methods

2.1 Experimental Area

The assisted operation was carried out in the state of Bahia, Brazil, in the region of Teixeira de Freitas, which has a tropical climate, with coordinates 17° 32' 45" S and 39° 43' 26" W. There is significant rainfall in most months of the year. There is only a short dry season, and it is not very effective. The climate is classified as Aw according to Köppen. The average annual temperature in Teixeira de Freitas is 24 °C, and it has an average annual rainfall of 937 mm (Climate-data). The spacing used varies from 3.00 meters between lines and 1.50 meters between plants to 3.30 m between lines and 2.00 m between plants, with 98.06 hectares.

2.2 Equipment

The FM Copling irrigation package is mounted at the rear of a 15.000 litres water tank truck – 6 x 4 Mercedes-Benz Axor 2831 – 305 kW, adapted for forest operations. The FM Copling irrigation machine has two hydraulic arms with nozzles (sides) and a central fixed nozzle. Hydraulic arms and the irrigation valves actuation is carried out after processing the images generated by three RGB High-Resolution Cameras, 60 fps (optical sensors) on a computer embedded inside the cabin.

2.3 Performance evaluation

During irrigation evaluation, 30 seedlings were visually analyzed in sequence, recording them as effective or failed irrigation. Functionality and operational performance items of the set were raised (mechanical availability, operational efficiency, operational utilization rate and productivity), in addition to the study of time and movement.

The operational performances collected were:

Mechanical availability (MA): percentage (%) of the time the machine is available for operation.

$$MA\ (\%) = \frac{schedule\ time\ (h) - maintenance\ time\ (h)}{schedule\ time\ (h)} \qquad (1)$$

Operational efficiency (OE): operation efficiency.

$$OE\ (\%) = \frac{production\ time\ (h)}{production\ time\ (h) - maintenance\ time\ (h)} \qquad (2)$$

Operational utilization rate (OUR): efficiency of the operation considering the programmed time.

$$OUR\ (\%) = MA\ \times OE \qquad (3)$$

Effective field capacity (EFC): productive capacity effectively demonstrated by the group.

$$EFC\ (ha\ h^{-1}) = \frac{worked\ area\ (ha)}{scheduled\ time\ (h)} \qquad (4)$$

Operational field capacity (OFC): productive capacity observed under real operating conditions.

$$OFC\ (\ ha\ h^{-1}) = \frac{worked\ area\ (ha)}{scheduled\ time\ (h) + maintenance\ time\ (h)} \qquad (5)$$

3. Results

Operational performances were calculated from data collected at the Bahia unit over four weeks and are presented in Table 1.

Table1. Operational performances

MA	OE	OUR	EFC	OFC
(%)	(%)	(%)	(ha h^{-1})	(ha h^{-1})
79	44	35	3,1	1,6

The time and motion study totalled 2.8 hours of data collection. For the work cycle, the time spent from the beginning of irrigation with a complete water tank to the end of its replenishment was considered. On average, a full water tank was able to irrigate 4.6 hectares. The assers is shown in Figure 1.

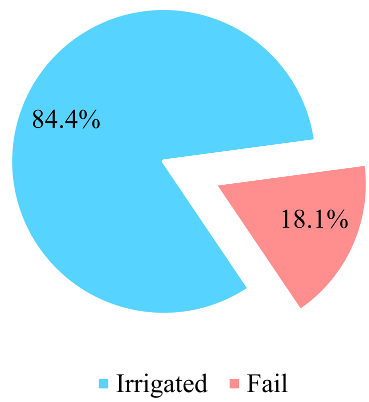

Figure 1. Assertiveness

4. Conclusion

During the entire period of assisted operation, it was possible to highlight some points:
1- The construction of the prototype meets the functionality issue. As for the component's durability, no severe or unsolved problems were observed during the period that comprised the evaluations.
2- The productivity of 1.6 hectares hour^{-1}, evidenced through the study of times and movements, indicates that the prototype reaches the expected value. We can also infer that works aimed at increasing productivity will positively affect daily productivity operation.
3- The minimum expected percentage of correct answers - 85%, could be comfortably achieved over the assisted operation.

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Theme 4: Supply Chain and Logging Industry

A Review of Data and Information Acquisition Opportunities to Improve Predictability of Forest Supply

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ABSTRACT

In Canada's extensively managed forests, compagnies have noted a lack of reliable data as well as imprecise or erroneous information in the supply chain of wood transformation plants. Even if there are existing means to collect information on wood volume accumulating along the supply chain, their effectiveness, cost, and applicability is not fully documented. As new technologies are being developed, studies have highlighted the importance of data visibility to increase predictability of the deliveries. In Canada, industry representatives have blamed the lack of supply predictability causing higher production costs.

This project covers the whole supply chain, from standing timber to logs being fed to a sawmill. The main objective is to document all locations that allow for data acquisition and exploitation in the forest supply chain. The first specific objective is to identify the most useful information in the management of the supply chain by the forest industry. The second objective is to identify the data available at each location of the chain. The third objective concerns the temporal notion of information, more precisely, the specific moment the information is visible to supply chain managers. The fourth objective is to identify the means used to acquire and exploit this data as well as the effort needed to do so.

The literature review and collaboration with industrial and technological partners made it possible to identify locations that allow data acquisition in the supply chain. The mapping of these locations highlights several information gathering opportunities. Then, for each location, specific acquisition technologies were studied and compared based on their cost and the benefits they provide. A matrix presenting all the locations and the most promising data acquisition solutions will be presented.

In 2021, technological solutions are continually emerging, however, not all of them are mature and their costs can still turn out to be high. Their reach may also be limited because of the issue of forest connectivity in Canada, as the large distances between forests and plants can create communication challenges. Results from this project will make it possible to identify opportunities and means allowing forest industrials to improve their supply chain and obtain positive spinoffs at the plant, particularly in terms of predictability of supply, reduction of inventory costs, and securitization of customers' orders.

What can we Learn with Forest Entrepreneurs? A Literature Review

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ABSTRACT

In the last decades, several regional surveys on forest entrepreneurs were conducted. Some follow strict protocols while others are more informal. Ensuring that the sample of people surveyed is representative of the larger population to be studied requires important efforts. Failing to follow a rigorous methodology will limit the usefulness of the survey and could lead to misguided recommendations. One way to remedy such shortcomings is to shift away from research focusing purely on entrepreneur demographics to more comprehensive research looking on entrepreneur perspective. However, previous research has not been examined to identify trends in research design. One important question becomes: what can we learn «with» forest entrepreneurs, that can really help them in the development and management of their business? While most surveys described economic, demographic and business factors, few have paid much attention to motivations, values and strategies of the entrepreneur. Few studies provide a longitudinal perspective on the forest entrepreneur population and, more specifically, have investigated the contribution of indigenous entrepreneur in regions where forestry operations are conducted. Some questions remain: Can we find differences between entrepreneurs living in different political, economic or social context? Can we find distinct traits among entrepreneurs, some found worldwide and some exclusive to forest entrepreneurs?

In order to address these gaps, we carried a literature review of published research. Our main research objective was to evaluate how forest entrepreneurs have been described and studied in various countries. More specifically, our study identified their entrepreneurial motivations, the main obstacle face for the development of their businesses, and their role in the supply chain. In achieving our objectives, we were sensitive to the evolution of the entrepreneur's profile over time, as well as possible comparison, where relevant, with indigenous and non-indigenous workforce. In the end, we identified the motivations, challenges and needs of forest entrepreneurs. More fundamentally, we developed an analytical framework that can be used to better understand the conditions under which the work of forest entrepreneurs is related to performance, well-being and innovation. So as to go beyond the limitations of survey, one of the next steps of this study is to use focus group in order to work more directly and collaboratively with forest entrepreneurs.

Business Success Factors of Latvian and Swedish Forestry Contractors

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ABSTRACT

Purpose
Forestry contractor's business strongly depends on the main buyers of their services and there are plenty of factors that influence successful business. The competitiveness of forest management companies' supply chain is related to the competitiveness of all companies involved in it. Thus, it is important to assess the factors that might lead forestry contractors to succeed in business and factors that might hinder it.

Methodology
To search for the factors that might lead forestry contractors to success in business, a survey of 110 forestry contractors from Latvia (LVA) and Sweden (SWE) was conducted. Qualitative and quantitative research methods are used to assess financial performance and the factors that are driving the company's success. A questionnaire with a five-point Likert scale, text coding, principal component analysis, Spearman's rho correlation and Mann–Whitney U test were used to answer the research questions.

Findings
In business success, the company's internal factors prevail over external factors. While external factors prevail over internal factors in hindering the success in the business of forestry contractors. The most substantial common driver of success in business for forestry contractors in LVA and SWE altogether is the skillfulness of employees. At the same time, the lack of skilled employees is considered to be the most hindering factor. Teamwork, treatment of employees, service flexibility and labour force stability are more important for the LVA forestry contractors. While the reputation of the company and quality of work is more important for their counterparts in SWE. Also, entrepreneurial orientation and financial indicators such as net turnover, net profit, ROA, ROS and number of employees are significantly higher for LVA forestry contractors. However, net profit and net turnover per employee is significantly higher for SWE forestry contractors. In both countries, the activeness of forestry contractors in improving of services provided to a buyer is related to the responsiveness of the buyer.

Value
This study extends the knowledge in business success factors for forestry contractors in the Baltic sea region.

Managing the Performance of Forest Entrepreneurs for Increased Wood Supply Predictability: A Fleet Approach

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Keywords: Forest entrepreneurs, wood supply, performance; monitoring tools, dashboard

EXTENDED ABSTRACT

1. Introduction

Measuring the performance of forest entrepreneurs in cut-to-length (CTL) mechanized operations requires an effective and efficient monitoring of harvesting activities. However, despite technological improvements, key information, such as reliable production data, may not be readily accessible. In forest operations of eastern Canada, production data is generally disclosed once a week by entrepreneurs, and can be based on simple metrics such as the number of forwarder loads. This approach allows to broadly measure productivity and is sufficient to provide a partial payment to the entrepreneur. Obviously, such productivity information provides limited insight on the causes of variations. Several authors have documented sources of variations in the performance of harvesting activities. These include the operator (Purfürst & Erler, 2011), volume per stem (Liski & al., 2020; Purfürst & Erler, 2011), stem diameter (Olivera & al., 2016), operation shift (day/night) (Rossit et al., 2019), and terrain slope (Fernandes & Burla, 2013). Monitoring productivity and those explanatory variables allows for a better predictability (Kemmerer & Labelle, 2021; Melander & al., 2020). Furthermore, Rabhi & al., (2019) suggest that a Big Data approach allows to perform descriptive, predictive and prescriptive analyses. However, to facilitate monitoring purposes, collected and processed data requires visualization tools. To this end, many companies use dashboards to communicate the performance, and the factors affecting it (Kokina & al., 2017). A dashboard should include indicators to monitor performance, and suggest improvement actions (Daniels, 1990). Previous efforts were conducted to monitor the performance of forest entrepreneurs, and dashboards were suggested as an effective means to benchmark performance. Both Bonhomme, (2004) and Lepage (2007) concluded that a constant participation of the entrepreneurs is required. Drolet and LeBel (2010) developed a prototype that was designed to be closely aligned with strategic objectives expressed by the entrepreneurs. Results indicated that entrepreneurs developed a better comprehension of performance management but would, nevertheless, lack time and means to update the dashboard on a regular basis (Drolet & LeBel, 2010). Recent progress related to GPS, on-board computers and data transfer technologies provides opportunities to simplify data collection and processing.

Therefore, the main objective of this research is to develop methods to monitor the performance of a fleet of forest entrepreneurs. New data collecting and processing methods that are user-friendly and quick to process are sought to facilitate the development of performance indicators and lead to a passive monitoring required to manage a wood supply fleet. By the end of this project, managers will be able to guide their decisions based on a multidimensional approach supported by key performance indicators. It can be hypothesized that this would contribute to increased wood supply predictability.

2. Methods

Many sources of data are now available to generate indicators related to harvester and forwarder productivity. Location and machine production data are critical. This data, available from the industrial partner and its entrepreneurs, can then be merged with ecoforestry data, mostly available through government forest agencies. Once the data is processed, cleaned and verified for completeness, it has to be stocked on a database. As more machines working on a large array of forest sites become part of the experiment, multivariate analyses will be performed in an attempt to go beyond basic production reports.

2.1 Data transfer protocol

The main industrial partner in this project is a large forest products company with harvesting operations in the Saguenay-Lac-Saint-Jean region of Quebec, Canada. They contract with approximately 40 entrepreneurs for their wood supply. Each entrepreneur is provided with tablets that serve to collect location data. Detailed harvesting head data will be available from the tablet as soon as an Android phone software is made available early in the fall of 2021. Currently, production is estimated through the number of forwarder loads declared daily on an Excel file. The tablets also serve as the on-board GPS with Windows-based applications for navigation. Once a week, a forest supervisor wirelessly collects the location data with an Android phone after which it is uploaded directly on the company server for post processing by a geomatics professional. Data are then stocked on a PostgreSQL database accessible with the server on a shapefile (SHP) format. This database also includes other important information such as the operation maps that identify the type of harvest and the operation sector. Log trucks entering the mill yard will also contribute data to the Postgre SQL database as each load is weighted for final payment to the entrepreneur. A factor is applied to convert the net weight in cubic meter. Meteorological data, obtained from the nearest meteorological station, such as the temperature, humidity, snow depth, wind speed, and precipitations are downloaded automatically from a government website. Ecoforestry, dendrometric, and digital elevation models (DEM) data are all downloaded from the Quebec Ministry of Forests, Wildlife, and Parks website.

2.2 Data processing

Five steps are presently required to process the data. Depending on how many GPS points are collected, processing time may require up to three hours for a three-week period of localization data from 60 forest harvesters. The first step is the determination of a production status for every GPS point collected. A time and motion software was developed specifically for this task. The software takes the SHP from the machine data as input. According to the time, the distance, and the speed between consecutive points, the software can determine four kinds of status: production, pause, displacement that is when the machine is moving without harvesting , and stop. The second step involves the merging of all GPS and cartographic data. QGIS is the geographical information system (GIS) used. A graphical modeler that can perform multiple GIS process by automating a complex workflow was developed to process all data automatically. Inputs required are SHP from the first step, the company data such as the operation area and type of harvest, and the ecoforestry, dendrometric, meteorological and DEM data. At the end of this process, a SpatiaLite file is generated. This file contains every GPS point with all the production status, the ecoforestry, dendrometric, meteorological, DEM data, and company data. The third and fourth steps of data processing are to import all the data in a Microsoft Access database. Software was developed to generate the machine details such as the name of the machine, working team, make and model, construction year, type of harvesting head, and on-board computer type. The principal input of this software is the CSV file in which all the production status time of the machine is compiled. Some other inputs that are not currently used are the harvesting head production data ASCII files and HPR files. Once a tool is available to transfer those types of data wirelessly, this developed software will be used. When the Access database is created, the GPS data SpatiaLite file as well as two operation maps with ecoforestry and dendrometric data are imported to the database. The final step links the Access database to the dashboard for regular update. A Microsoft Access database is easy to share with the supply managers but is limited in terms of data storage. As the project progresses, a more efficient database will be considered such as a PostgreSQL database. The resulting dashboard will be presented using the Microsoft Power BI Desktop free software. This software offers the possibilities to link the Access database and many performance indicators can be created. It has major similarities with Microsoft Excel and offers a large variety of data visualization tools. Various databases can be linked with Power BI including CSV files, text files, Excel spreadsheets, Access database, SQL server database, PostgreSQL database, and many others. Power BI is a user-friendly software, and the filter possibilities give it a major advantage. In our context, filters can be applied to a specific entrepreneur, machine, sector, date, and any other condition types. It is possible to create many tabs like in Excel, so each tab has its own characteristics. Figure 1 summarizes the five processing steps.

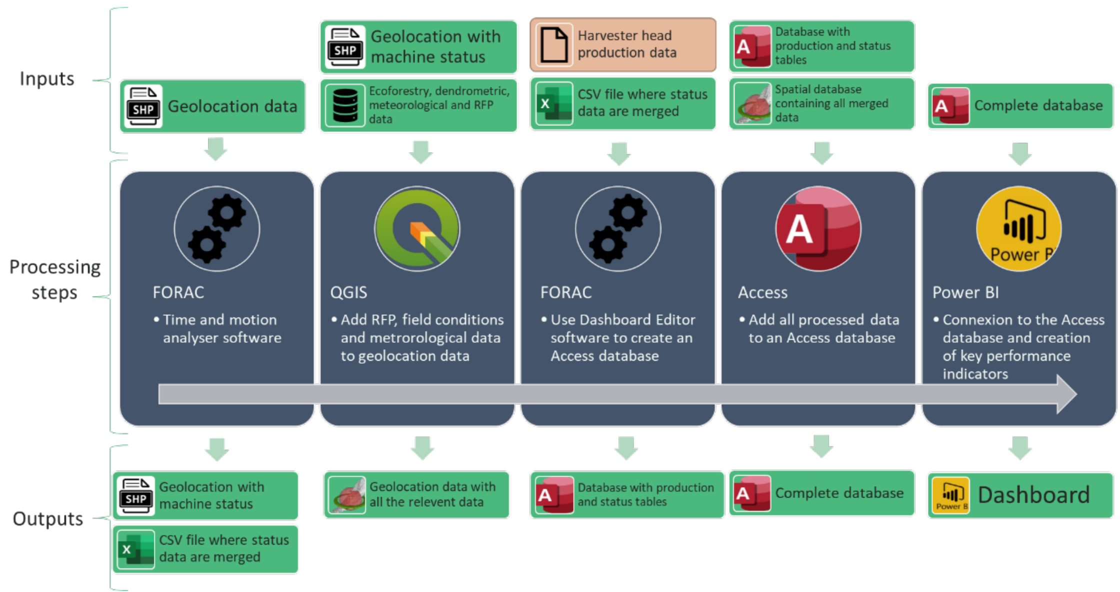

Figure 3. Processing steps with the required inputs and the outputs leading to the fleet management dashboard in development.

3. Results

The resulting dashboard has already been used by the supply managers. At this moment, twelve tabs on the Power BI dashboard are proposed. Three of them describe the utilization rate depending on machine status and scheduled hours. Five other tabs relate the meteorological condition and the field condition with the operation time or cutting sector. Three others are used for the disclosed harvested volume by entrepreneurs, for each operating sector, and the log trucks weighted load data. The last tab is a map that shows the GPS localization data with the machine status. To date, geolocation data from 65 machines is available from 41 forest entrepreneurs that represent 1.1 million GPS points and more than 40 000 recording hours. Each of the processing steps is relatively simple and the data transfer is well implemented. Once a week, all data are processed, and it is followed by an update of the dashboard prototype. Then, PDF reports are extracted from the dashboard and sent to the factory managers to test the monitoring tools such as certain key performance indicators. Preliminary feedback from managers showed that the dashboard provides useful information to improve forecasting. A forest entrepreneur who has seen the prototype showed enthusiasm, and intends to use it as soon as they are available to benchmark his performance with other entrepreneurs.

4. Conclusion

This project is aimed at improving the monitoring systems for large wood supply operations. Managers of a major forest products company operating in Eastern Canada confirmed the need for fleet-level performance dashboards. New simplistic methods were developed to collect and process the available data from a fleet of forest entrepreneurs. Performance indicators are shown on a dashboard prototype. This dashboard offers many possibilities such as benchmarking the entrepreneur's performance with factors influencing their productivity. Next steps of this project are to focus on reducing the data processing time. Since harvesting head data will soon be added, a more efficient database is considered to improve the dashboard updating performance and avoid any storage problems. Ultimately, increased wood supply predictability should be possible once the factors that influence individual machine production and fleet level output are monitored on a permanent basis.

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Workflow Variations in Harvesting Services - a Case Study on the Need to Manage Flexibility

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ABSTRACT

In many parts of the world, contractors have an immense impact on the wood supply since they account for the main share of the harvesting work. It is common that contractors rely on a business relationship with a single customer, who needs workflow flexibility due to seasonal variations and uncertainties in weather conditions and wood demand. However, variation in workflow has the potential to affect contractor profitability, and thus their ability to provide competitive harvesting services. To handle the need for flexibility, different methods can be used to maintain an even workflow in the harvesting services. However, both the knowledge about variations in workflow and the efficiency of the methods to manage flexibility are limited. Therefore, this study investigates the needs and management of flexibility in harvesting services by comparing monthly variations between contractors' workloads in terms of the amount of time spent on the operations and the resulting harvesting volumes. The data originates from 77 harvesters and forwarders belonging to contractors working for a large Swedish forest company, and their harvesting of 6.6 million m3 of roundwood in Sweden during a two-year period. For medium-sized harvesters the workflow in terms of time operated was more even between months than it was for volume produced. For large harvesters and forwarders, on the other hand, volume and time workflow varied similarly, with a significant correlation between the two. The time workflow variation decreased with the total amount of operation during the studied two years, both in terms of volume and time. Single machines had in most cases a more uneven workflow, compared to when aggregating the total workflow of all machines that a contractor owned. Typically, the more machines a contractor owned; the less total workflow variation was observed. The results indicate differences between contractors in both need for and management of flexibility, which can be attributable to the number of machines, machine sizes and the amount of harvesting services that they provide. These findings are relevant for guidance of practitioners and for further research to develop the management of the flexibility need in harvesting services.

The Impact of COVID-19 on the Northeast and Appalachian Logging Industry

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ABSTRACT

Background and Objective(s)
Early in the pandemic, a New York Times article highlighted the risk of contracting COVID-19 by occupation. It was no surprise that loggers showed up on the low end of the risk scale, both because of outdoor work and being naturally socially distanced. So why would we undertake a large-scale survey of COVID-19 impacts on logging workers across the Northeast? Because we know this public health crisis has ensnared nearly all aspects of our lives, and essential workers (a category that includes loggers) have been hit especially hard. In late 2020, the Northeast Center for Occupational Health and Safety in Agriculture, Forestry, and Fishing surveyed loggers across the region on impacts of COVID-19 on their health, family and businesses.

Methods
Mailing lists were gathered from logger trade organizations in each state. Paper surveys were mailed to loggers in six Northeast states: Maine, New Hampshire, Vermont, New York, Pennsylvania, and West Virginia. Surveys were returned via postal mail and data entered into REDCap. Record level data was exported from REDCap into SAS 9.4 for statistical analysis.

Results
Four hundred eighty-four (484) loggers responded to the survey. Nearly 59% of those surveyed, said they knew more than two people who had tested positive and 4% of those asked had tested positive themselves. Many (44%) of the survey respondents indicated that COVID-19 pandemic affected their daily work activities in profound ways including loss of jobs, loss of laborers, loss of market for wood, increased quotas at mills, and significant changes in home life and work responsibilities. Beyond COVID-19, Eighty-three percent (83%) of loggers surveyed in Maine said the digester explosion at the Androscoggin Mill in Jay, ME had affected their business. An additional 18% of loggers surveyed who did not reside in Maine said the closing of that mill also affected their business. Sixty-six percent (66%) of survey respondents who answered the question indicated that they work with more than one person. Of those, that were not owner/operators, over half said their employers did not provide any PPE relating to

the COVID-19 pandemic. If their employer did provide PPE, it was either a face covering (cloth face covering, neck gaiter or bandana) and/or hand sanitizer. However, over half of those indicated that they personally do not use a face covering at work when within 6 feet of coworkers. The same group answered that only about 9% of their co-workers always wore a mask when they were within 6 feet of others at work. Forty two percent of loggers reported that their co-workers never wore a mask when within 6-feet of each other while at work. Additional results will be discussed in the full presentation.

Conclusions

The COVID-19 pandemic has negatively affected Northeast loggers. These impacts need to be considered by industry stakeholders and policy-makers to best support the industry moving beyond the pandemic and continuing to be a robust sector in the future.

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Survey of Harvesting Capacities and Forest Maintenance Capacities of Austrian Forest Enterprises and Forest Entrepreneurs as well as Development of a Database as an Information System for Forest Management

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ABSTRACT

The Austrian chamber of economics counts more than 3.500 forest entrepreneurs. According to federal statistics, 9 to 10 million solid cubic meters, meaning around 50 % of the whole harvested wood, is harvested by forest entrepreneurs every year. But there is no knowledge about the equipment and harvesting capacities of these companies.

In order to obtain a comprehensive overview of the regionally available harvesting capacities, a survey was carried out among all forestry companies and forest entrepreneurs, in which they were asked about their equipment, their employees and their skills.

As one result, a database has been established in order to gather the availability of different machines and harvesting systems according to various geographical and forestry criteria.

Another goal of this project is to get an overview of entrepreneurs and their available harvesting capacities. This publicly available database enables the user to search entrepreneurs according to geographical and factual criteria and to obtain the availability of certain harvesting machines within different time periods.

Keywords: wood harvesting capacity, data base, forest entrepreneurs

Theme 5: Harvesting and Processing

Benchmarking operational conditions, productivities and costs of harvesting from industrial plantations in different global regions

Fulvio Di Fulvio, Mauricio Acuna, Pierre Ackerman, Simon Ackerman, Raffaele Spinelli, Dalia Abbas, Sandra Sánchez, Nopparat Kaakkurivaara, Saulo Guerra

Development of a Modality-Invariant Multi-Layer Perceptron to Predict Operational Events in Motor-Manual Willow Felling Operations

Stelian Alexandru Borz

Testing the Capability of Low-Cost Tools and Artificial Intelligence Techniques to Automatically Detect Operations Done by a Small-Sized Manually Driven Bandsaw

Marina Viorela Marcu, Marius Cheta, Eugen Iordache, Stelian Alexandru Borz

Evaluation of the mechanized CTL harvesting system in different geometric thinning operations in terms of productivity and residual stand damage

Munyaradzi Makoto, Bruce Talbot, Simon Ackerman

Battery vs. petrol chainsaws: a cutting time comparison on different tree species

Andrea Laschi, Francesco Neri, Cristiano Foderi,Fabio Fabiano, Niccolò Frassinelli, Elena Marra, Enrico Marchi

Comparative analysis of commercial thinning operations in BC and other jurisdictions

Juliana Magalhães, Omar Mologni, Camilla Moioli, Steffen Lahrsen, Eric Nance, Jodi Axelson, Ken Byrne, Lauri Sikanen, Hannu Salminen, Leena Leskinen, Dominik Roeser

Simulating the difference between forwarding short and normal length timber

Simon Berg

Key Factors influencing Productivity of Whole Tree Ground-Based Felling Equipment

Steffen Lahrsen, Juliana Magalhães, Omar Mologni, Dominik Röser

Assessment of timber felling techniques for a reduced harvesting impact in the secondary Atlantic Forest, southern Brazil

Pedro Britto, Dirk Jaeger, Stephan Hoffmann, Renato C. Robert, Alexander C. Vibrans, Alfredo C. Fantini

Productivity and Cost of Mechanized Harvesting in Large-Dimension Hardwoods - Effects of Machine Type and Harvesting Season

Herbert Borchert, Eric R. Labelle, Peter Aurenhammer, Lorenz Breinig, Raffaele Spinelli, Natascia Magagnotti

Influence of Loading Distance, Loading Angle and Log Positioning on Time Consumption of Forwarders Loading Cycles: A Pilot Study in Germany

Florian Hartsch, Marian Schönauer, Lorenz Breinig, Dirk Jaeger

Integrated in-stand debarking with harvester in cut-to-length operation

Franz Holzleitner, Thomas Holzfeind, Stefan Messner, Christian Kanzian

Effective small scale harvesting and forwarding in industrial plantation first thinning operations

Simon Ackerman, Heather McDermid, Pierre Ackerman, Marius Terblanche

Historical transition of logging methodology in Turkey, the example of Zingal to Ayancik

Ugur Yildiz, Arif Oguz Altunel

Automated Driving on a Skid Road with a Forwarder in a CTL Logging Process

Chris Geiger, Sebastian Beiser, Marcus Geimer

Artisan Forestry: Draft animals and low impact mechanization in upland Family Forests

Ian Snider

The potential of mini forestry crawlers to support mechanized harvesting operations at extended machine operating trail spacing

Ferréol Berendt, Stephan Hoffmann, Dirk Jaeger, Janine Schweier

Predicting productivity of skidders in Eucalypt plantations

Mohammad Reza Ghaffariyan

Benchmarking Operational Conditions, Productivities and Costs of Harvesting from Industrial Plantations in Different Global Regions

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ABSTRACT

In the last few decades, there has been a global increase in industrial demand for woody biomass. The need to achieve high production per unit of land while preserving natural forest resources has led to the expansion of

intensive forest cultivations in the form of industrial plantations. The expansion of the global bioeconomy is expected to increase further the supply of biomass for material and energy uses from industrial forest plantations.

To plan efficient supply from these industrial resources, there is a need to have up-to-date information on current systems and their efficiencies.

Therefore, this study aimed to provide an overview of current harvesting systems and their performances in industrial plantations located in seven relevant global regions.

This study gathered knowledge from eight regional experts and combined it with literature to create a unique database applied for benchmarking harvesting systems, their productivities, and supply costs.

Currently, highly mechanized systems reach harvesting productivities exceeding 100 m3 per productive machine hour (PMH) and harvesting costs at the roadside between 5-20 $/m3.

Local socioeconomic factors and historical sectorial evolution in each region significantly impact the selection of harvesting systems, mechanization levels, type of machinery, and the resulting harvesting costs. There is an ongoing adaptation of harvesting systems to the plantations' characteristics and the industrial requirements in the different regions. The expansion of plantations to more marginal lands requires further research on agricultural/construction machinery adaptation to steep terrain in industrial plantations. It also appeared that the international literature tended to provide a good representation of large-scale highly mechanized systems. In contrast, there is still a limited number of studies able to characterize small-scale and motor-manual based systems, particularly in developing global regions.

Development of a Modality-Invariant Multi-Layer Perceptron to Predict Operational Events in Motor-Manual Willow Felling Operations

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ABSTRACT

Motor-manual operations are commonly implemented in the traditional and short rotation forestry. Deep knowledge on their performance supports the practice and science and is needed for various strategic, tactical and operational decisions which are relying on large amounts of data. However, collecting, handling and interpreting such data is often impractical by the use of traditional methods due to the large amount of resources needed, requiring new methodological approaches to the problem. Artificial Intelligence (AI) has been proven to be a reliable, highly performant option for classification and regression tasks, being able to deal with various types of signals and problems to be solved. In this study, a Multi-Layer Perceptron (MLP) with backpropagation was developed and used to learn and classify operational events from bimodally-collected acceleration data specific to motor-manual willow felling operations. Data collection modalities were treated by fusion in the training dataset, then four single-modality testing datasets were used to check the performance of the model on a binary classification problem. Fine tuning of the regularization parameters (α term) has led to acceptable testing and generalization errors of the model measured as the binary cross-entropy (log loss). Irrespective of the hyperparameters' tunning strategy, the classification accuracy was found to be very high, in many cases approaching 100%. Hence, modal data fusion in the training set was found to be a good strategy to build a robust model, able to deal with data collected by single modalities. As such, the developed MLP model not only removes the problem of sensor placement on the observed tools, but also automatically classifies the events in the time domain, making it possible to integrate data collection, handling and analysis in a simple less resource-demanding workflow.

Testing the Capability of Low-Cost Tools and Artificial Intelligence Techniques to Automatically Detect Operations Done by a Small-Sized Manually Driven Bandsaw

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ABSTRACT

A low-cost experimental system was developed to enable the production monitoring of small-scale wood processing facilities by the means of sensor-collected data and the implementation of artificial intelligence (AI) techniques, which provided accurate results for the most important work operations. The manufacturing of wood-based products by small-scale family-held business is commonly affected by a lack of monitoring data that, on the one hand, may prevent the decision-making process and, on the other hand, may lead to less technical efficiency that could result in business failure. Long-term performance of such manufacturing facilities is limited because data collection and analysis require significant resources, thus preventing the approaches that could be pursued for competitivity improvement. An external sensor system composed of two dataloggers—a triaxial accelerometer and a sound pressure level meter—was used in combination with a video camera to provide the input signals and meta-documentation for the training and testing of an artificial neural network (ANN) to check the accuracy of automatic classification of the time spent in operations. The study was based on a sample of ca. 90k observations collected at a frequency of 1 Hz. The approach provided promising results in both the training (ca. 20k) and testing (ca. 60k) datasets, with global classification accuracies of ca. 85%. However, the events characterizing the effective sawing, which requires electrical power, were even better recognized, reaching a classification accuracy of 98%. The system requires low-cost devices and freely available software that could enable data feeding on local computers by their direct connection to the devices. As such, it could collect, analyze and plot production data that could be used for maintaining the competitiveness of traditional technologies.

Evaluation of the Mechanized CTL Harvesting System in Different Geometric Thinning Operations in Terms of Productivity and Residual Stand Damage

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ABSTRACT

The South African commercial forestry industry produces high-quality saw logs from intensively managed plantations (DAFF 2017). This is achieved through the careful and timely application of different forest management prescriptions at defined rotation periods (Dickens and Moorhead 2015). These forest management prescriptions are aimed at stimulating tree growth and enhancing stand quality. Once a stand is established, competition for resources ensues with time and partial cuts through thinning become the main method of influencing stand development towards achieving management objectives (Kerr et al. 2011).

This study aimed at comparing the conventional row thinning with diagonal thinning in terms of productivity and residual tree damages. The study was based on two adjacent Pinus patula compartments in the Mpumalanga Highveld. A time study was conducted to test for time consumption and productivity of both harvesting and forwarding between the two treatments. Residual tree damages were assessed by inspecting all individual trees within research plots for any wounding.

Harvesting results showed a significant difference between the two treatments at $0.0001331 < p < 0.05$. Conventional 7th row thinning had the highest mean productivity at 16.49 m3/PMH. Diagonal thinning had the lowest mean productivity at 14.36 m3/PMH. Forwarding results also showed a significant difference between the two treatments at $0.0003295 < p < 0.05$. Diagonal thinning had a mean productivity of 4.61 m3/PMH compared to 5.36 m3/PMH for the conventional row thinning. Residual tree damages showed a significant difference between the two treatments at $0.0154 < p < 0.05$. Diagonal thinning had an average residual damage of 8.9% compared to 4.39%.

The study showed that conventional 7th row thinning is a better method in terms of productivity and residual tree damages. Further research could potentially look at different planting geometries, spacing uniformity, thinning quality, and the costs associated with the two treatments.

Battery vs. Petrol Chainsaws: A Cutting Time Comparison on Different Tree Species

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ABSTRACT

The use of chainsaws in forest operations is still common in many areas of the world. Despite the high risks and fatigue related to their use, chainsaws guarantee to operate efficiently with low investment costs. In forestry, petrol chainsaws are traditionally used, while electric and battery ones have been considered only for professional gardening, green maintenance and hobby sector. In the last years, the most important brands producing chainsaws have improved the performances of their top models of battery chainsaws. Declared values of power are comparable with light petrol alternatives. Moreover, performances of modern Li-ion batteries have been improved in terms of autonomy, and producers declare more than 40 minutes of actual time cutting. For these reasons, considering also the rapid improvement of battery chainsaws in terms of performances, it is probable that these machines can be introduced in forestry in the next future. Before their use in forest operation, it is important to understand if performances of similar (in terms of declared power) battery and petrol models are really comparable. In this context, the aim of this study was to compare the performances in terms of cutting speed of three Stihl chainsaws, a MS 220C-B (battery powered), a Stihl MS 201 C-M and a MS 261 C-M (petrol powered). The latter have a higher power than the others, but it represents a very popular model between forest workers, and it has been considered as

reference point. Chainsaws were tested cutting wood beams of six different tree species, characterized by different wood densities, i) Silver fir, ii) Douglas fir, iii) Black pine, iv) Chestnut, v) Beech, vi) Turkey oak. Three squared fresh beams (section 15x15 cm) per specie were cross-cut obtaining at least 50 wood “slices” of 1-2 cm per each model, and related cutting time. Cutting operations were videorecorded and cutting times were later obtained with a resolution of one hundredth of a second, using a video editor software. The obtained results showed that MS 220 C-B are close to MS 201 C-M, but clearly inferior in comparison with MS 261 C-M. Moreover, wood density influences the cutting speed of analyzed chainsaws. Finally, battery chainsaws need some additional improvement to be introduced in forestry, but their high potential is evident. Beyond performances, technology will have to solve the problem related with battery autonomy and recharge in forest.

Comparative Analysis of Commercial Thinning Operations in BC and Other Jurisdictions

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ABSTRACT

The timber supply in the Interior of the British Columbia (BC) has shifted markedly in the last two decades. BC ‘s legacy of surplus mature forest shifted to a substantial composition of managed, harvest constrained forests, usually distributed across many management units with declining harvest volumes and significant forest health issues. In large parts, this shift is due to nearly two decades of extensive salvage harvesting of mountain pine beetle (MPB) damaged timber, unprecedented wildfire losses, ongoing mortality losses from other conifer bark beetles and disease, as well as ongoing reductions in the Timber Harvesting Land Base (THLB) for a multitude of competing values.

It is believed that commercial thinning can partially offset short- and mid-term timber supply shortfalls in BC through proactive age class management to ensure more predictable forest-level wood flows. This includes a more prominent focus on the health, condition, and overall resilience of our forests - including immature stands – to better manage risks to future timber supply (e.g. fire, insects, etc.).

Despite the large opportunities that commercial thinning operations present, the adoption of commercial thinning in BC is facing significant challenges due to operational, economic and policy barriers. The challenge is that practitioners and policy makers are facing with do not seem to be in line with commercial thinning opportunities found in other jurisdictions where thinning is commonplace (e.g. US, European Nordic countries and eastern Canada). Hence, it is important to better understand the underlying differences between BC and these other jurisdictions.

A comparative analysis has been carried out to explore whether these large differences are due to environmental or operational factors, differences in the approach to evaluate feasibility or other external considerations. The objectives of the comparative analysis between commercial thinning in BC and other jurisdictions have focused on the following key issues:

- Investigate and review methodologies used to examine the economic feasibility
- Operational approaches to commercial thinning
- Role and impact of intensive forest management (e.g. pre-commercial thinning)
- Impact of other external factors such as e.g. land ownership and public perception

Results of this study highlighted key differences in the operational environment and practices that contribute to commercial thinning operations being more challenging in British Columbia. Outcomes from the comparative analysis will also help to provide valuable input into the commercial thinning guidelines for British Columbia.

Simulating the Difference Between Forwarding Short and Normal Length Timber

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ABSTRACT

There are from time to time a demand for short saw logs (about 2.5 m) in Norway. These shorter assortments affect the productivity of both harvesters and forwarders. However, very little is known about how it affects the productivity for the forwarders. There is more or less consensus about that the productivity will decrease with short timber forwarding, but there are quite contradicting views on how large this effect is. It is therefore a matter that is important to investigate so that contractors that are binding on the work at different cutting sites can assess their expected productivity better.

The productivity of forwarding was investigated trough simulation of the forwarding work. The same site was simulated when both a mix of short timber and normal long assortments were bucked, and when only normal long assortments were bucked. This was done for different site conditions, as forwarding distance, log concentration and terrain conditions. As well as forwarding size and the ability for forwarder to load one or 2 stacks of sort timer in tandem.

It was found that in most cases were the productivity of the forwarder decreased when short timber assortments were bucked at a site. Even thou there were some situations where it did not have any effect or even a positive effect on the productivity.

Key Factors Influencing Productivity of Whole Tree Ground-Based Felling Equipment

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ABSTRACT

Around the globe, various types of machinery are employed to conduct fully mechanized ground-based timber harvesting. Each operational environment comes with unique factors that allow certain machines to be more suitable and productive. Machine productivity has been the focus of many studies, and these investigations have highlighted key factors that influence productivity. Some of these factors include environmental site conditions, choice of equipment, harvesting method, and operator experience. Nevertheless, few studies have focused on the diverse operational environment in British Columbia (BC) characterized by its challenging varying terrain. The most common felling machine for mechanized, ground-based harvesting in BC are tracked swing-to-tree feller-bunchers equipped with circular saw felling heads (TSFBCS). Furthermore, in the last decade, steep slope harvesting with feller-directors has increasingly been employed in BC as a specialized system for the unfavorable conditions in mountainous regions. These two machine types typically operate in the whole tree method. Increasing costs and fiber shortages are a significant challenge in the BC forest sector and a key step towards maintaining global competitiveness is a greater understanding of machine performance in varying conditions and silvicultural practices. Research is required to make educated decisions on how to predict accurate machine productivity in order to improve operational planning and layout.

This literature review compiles and analyses the existing evidence on productivity studies of TSFBCS and feller-director heads in a systematic manner. It investigates the impact of the most critical factors influencing TSFBCSs' and feller-directors' productivity, such as piece size, slope, and regeneration methods. The results of this literature review are kept in a bibliography library that enables to compare individual studies conducted under similar conditions to a given scenario in British Columbia. This review recommends that further research that includes the measurement of identified and yet unstudied variables is vital.

Assessment of Timber Felling Techniques for a Reduced Harvesting Impact in the Secondary Atlantic Forest, Southern Brazil

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ABSTRACT

The lack of knowledge on low impact harvesting techniques is an important constrain limiting the success of a sustainable forest management in the Atlantic forest region. In the past, the Atlantic Forest was subject to overexploitation, conducted with inappropriate harvesting techniques. Consequently, at present stage, only 12 % of the Atlantic Forest remains. The remnant forest is highly protected, and commercial logging is very restricted. This situation generates largely conflicting goals between conservation and management as the landowners are not compensated and law enforcement is insufficient. A previous research showed that the felling process caused most of the observed damages on residual forest stand. Therefore, to identify the best felling technique for a reduced harvesting impact, we assessed the felling methods of a traditional conventional method (CM, by an operator trained on the job) compared to an alternative and professional method (AM, by a professionally trained operator). In total the felling process of 135 trees was monitored. We assessed the predominant direction of terrain slope together with the felling direction of each tree for determining the potential impact of terrain slope on tree felling directions. We also recorded the operator's intended felling direction for comparison to the actual felling direction. Additionally, a check list was applied to identify compliance with safety rules, including the use of personal protective equipment (PPE). The high tree diversity, density and heterogeneity found in the studied forest, stipulated extra effort for both

operators and complicated the felling process. The high rates of tree hang-ups (up to 59 % of the felled trees) also required to take special care for both operators. As expected, most of the trees were felled following the predominant slope direction. Moreover, while for CM most of the trees were felled in a range up to 45° of the predominant slope directions, for AM, due the improved felling technique, most of the trees could be felled in a range up to 60° of the predominant slope directions. CM fulfilled all the requirements of the safety checklist in only 5% of the felled trees. Among the main deviations are the inappropriate use of PPE and lacking preparation of the escape routes. AM fulfilled the requirements in 87 % of felled trees. Although CM felling followed the minimum requirements to be used in secondary Atlantic Forest, AM demonstrated the benefits of appropriated training for higher compliance of safety rules and lower harvesting impact.

Productivity and Cost of Mechanized Harvesting in Large-Dimension Hardwoods - Effects of Machine Type and Harvesting Season

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ABSTRACT

In Germany, deciduous trees are still mainly felled and processed with chainsaws, but efforts are being made to increase the share of cut-to-length harvesters. Main reasons triggering this change are that motor-manual harvesting of hardwoods bears great risks of accidents, the workforce is decreasing, the costs of timber harvesting are to be reduced, and there are financial incentives from the sawmills to provide hardwoods earlier in the year. To reach the latter, deciduous trees must be harvested early in the fall when they still have their foliage. However, motor-manual felling of deciduous trees with green foliage is particularly hazardous because of the associated difficulties in assessing crown structure. Additional challenges for fully-mechanized harvesting of hardwoods include the heavy weight of the trees in combination with the wide spacing between machine operating trails. As a result, some of the trees must still be felled with chainsaws (semi-mechanized harvesting). The use of remote-controlled felling wedges can reduce the risk of accidents during motor-manual timber harvesting. In an applied research project, combined harvesting by cut-to-length harvesters and forest workers in stands with large-dimension deciduous trees was investigated at two sites in Bavaria, Germany. Type of machine and season of operation were the treatments. Specifically, a wheeled harvester (Rottne H20) was used at one site and a tracked harvester (Atlas Kern T-50) at the other. Each site was further subdivided to address seasonality (fall and winter) and a minimum of 100 target trees were harvested per treatment. Forest workers were also able to use remote felling wedges when needed. The influences of machine type, season, and in the case of felling by chainsaw, the influence of wedge type on harvesting productivity and costs were analyzed. Also, a seasonal effect on the proportion of trees needed to be felled by loggers was considered. The study is intended to identify ways to improve the operational procedures. Preliminary results indicate that using the tracked harvester in the fall operation, coupled with the increased proportion of trees felled by chainsaw, contributed to increased costs.

Keywords: deciduous trees, cut-to-length harvesting, tracked harvester, wheeled harvester, work safety

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Influence of Loading Distance, Loading Angle and Log Positioning on Time Consumption of Forwarders Loading Cycles: A Pilot Study in Germany

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ABSTRACT

Mechanized cut-to-length (CTL) harvesting systems consisting of harvesters and forwarders are used in forest operations around the globe due to the high levels of productivity and work safety they provide. The efficiency of such work is determined by different factors. Besides stand and terrain conditions, productivity of operating forwarders is influenced by a number of additional factors, which are generally not as extensively explored, as compared to those related to harvesting operations.

The positioning of logs during harvesting is an important factor influencing the performance of the consecutively driving forwarder. Mostly the logs are placed at the edge of the skid trail, usually in a slightly varying angle perpendicular to the machine operating trail. Depending on the position of the loading forwarder, variable loading distances and loading angles arise. As a contribution to productivity improvements in modern CTL harvesting systems, it was the objective of this pilot study to assess the influence of varying loading distances, loading angles and also positioning angles of logs on time consumption of forwarder loading cycles.

Therefore, a loading scenario was prepared and conducted with an experienced forest machine operator on a physical forwarder simulator. Different loading angles, loading distances and log positions in relation to the machine axis resulted in a total of 45 variants to be evaluated.

Results showed that all three considered variables had a significant influence on time consumption per loading cycle. However, the comparison of variants showed varying degrees of influence on loading performance. The least time consumption for loading was reached when logs were loaded in 45° angle and positioned in 90° angle,

respectively. Time consumption per loading cycle increased significantly by up to 75% while loading in 135° angle, compared to operational settings with least time consumption per loading cycle of 13.3 seconds. Results of all three loading angles revealed that a loading distance of 4 to 6 m leads to lower time consumption per loading cycle, compared to other tested ranges (3 and 7 m). The results of this pilot case study could contribute to a better understanding of efficiency-determining factors in highly mechanized harvesting systems.

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Integrated In-stand Debarking with Harvester in Cut-to-length Operation

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ABSTRACT

Norway spruce is one of the most important economic coniferous species in Europe and has a long tradition of cultivation as source for raw material. Climate change and natural hazards fostered one of the most destructive spruce pests, the Eurasian spruce bark beetle. One measure to control bark beetle outbreaks could be debarking by the harvester using adapted processing heads.

The aim of this study was to analyze harvesting and forwarding performance using conventional machine settings compared to integrated in-stand debarking with modified machine settings.

The studied operation covered two spruce stands on 2.1 ha. Each stand was divided into sample plots, whereby half of them were threatened as debarking and the other as conventional processing. All trees were measured and numbered before to calculate stem-wise volume and harvesting intensity. Harvesting was carried out with an 8-wheeled 1270G harvester equipped with a common H415 head, both manufactured by John Deere Forestry Oy. The head was modified with special designed feed rollers, adjusted hydraulic settings for controlling delimbing knives and feed rollers. The measuring wheel and delimbing knives where not changed. Continuous video recordings of the harvesting and forwarding operation allowed a post hoc time and motion study. Furthermore, fuel consumption data with refueling in short time intervals for the harvester or after each forwarding cycle were collected. For each treatment, logs were sampled randomly to determine debarking efficiency. 50-60 images per log were taken from each side. Statistical analysis encompassed regression modeling taking stem volume, stand density and treatment as influencing variables into account to predict productivities and analyse differences between treatments. To measure debarking efficiency, 3D models of the logs were computed with the photogrammetric structure from motion

technique. After unrolling the shell surface, the bark and non-bark areas were measured with a GIS.

Altogether, 443 trees were harvested having an average diameter at breast height of 24.8 cm resulting in a mean stem volume without bark of 0.45 m^3. Harvesting productivity reached 27.1 m^3 PSH_{15}^{-1} without integrated debarking and 20.3 m^3 PSH_{15}-1 respectively. This results in 25% lower productivity and 2.47 € additional harvesting costs per cubic meter if the additional debarking-process is applied. Forwarding productivity did not differ significantly between the treatments.

In average 75% bark was peeled off during applying integrated debarking. Conventional use of the adapted harvester head removed 34% of the bark.

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Effective Small-Scale Harvesting and Forwarding in Industrial Plantation First Thinning Operations

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ABSTRACT

An assessment of the feasibility of using a combination harvester/forwarder in selection type first thinning operation in the Highveld region of South Africa was done. Each of the machine components, harvesting and forwarding, were assessed separately with resulting mean machine productivities of 10.84 $m^3 \cdot PMH^{-1}$ and 5.03 $m^3 \cdot PMH^{-1}$ respectively. These results, however, cannot be dealt with individually as the machine should assessed as a system with one systems productivity. Hence total systems productivity (total machine hours and total volume to roadside) is 3.47 $m^3 \cdot PMH^{-1}$ with a system cost to operate the machine being USD 66.13$\cdot PMH^{-1}$ and USD 19.06$\cdot m^{-3}$. However, when further analyzing the system (both harvesting and forwarding), there is a discrepancy between standing volume, volume harvested and volume reaching roadside. These differences are related to felling and processing trees with no merchantable volume (i.e., felling to waste), inevitable other fiber losses during log assortment production and log assortments not forwarded to roadside. To determine system productivity and cost, calculations must be based on volume reaching roadside otherwise harvester actual productivity is inordinately inflated. Re-calculating harvester productivity with volume to roadside productivity is reduced to 6.81 $m^3 \cdot PMH^{-1}$. This drop in machine productivity is mainly due to the low quality of the trees harvested and not the quality of the machine harvesting the timber.

In general this study highlights the importance assessing machines working in combination as a system, as discrete parts of a system hour. Similarly, accounting for fiber loss in harvester productivity calculations a to avoid over-estimations and incorrect assumption in the supply chain. Furthermore, modelling productivity with data representing the adjusted volume demonstrates what is effectively being produced by the whole operation, taking into account the effect of tree size and quality variability present on these sites.

Historical transition of logging methodology in Turkey, the example of Zingal to Ayancik

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Abstract: The utilization of forest resources in Turkey has evolved since the beginning of industrialization. Ayancik district of the Sinop province can be called the cradle of this development. The establishment of a sawmill in 1929 to process the long overdue standing stock by a Belgium funded joint venture company, Zingal-Turkish Joint Stock Incorporated, pave the way for the district to become one of a few major industrialization centers of the young republic. The region equipped with all the amenities of the period correct advancements became the center stage for Turkish foresters' upbringing. Although the 40-year contract was cancelled by the government on the grounds of excessive exploitation in 1945, Turkish forestry has continued to develop over the principles rooted in Ayancik. The status of logging which had been sufficiently mechanized during the company's reign, has gradually turned to motor-manual supported by excessive amount of forest roads, today. This study looked into the transition of logging preferences from Zingal Inc. period to the current practice. Zingal era, 1959, 1993 and the current records were evaluated in a geoscience environment, and the fragmentation level within the Turkish forests was displayed. The figures showed if the road build trend continues in this level, the repercussions will be too much to bear environmentally.

Keywords: Forest mechanization, logging, hauling, GIS

1. Introduction

Forests are precious if a global consensus is reached to remedy the adverse effects of the climate change. Turkey with its rich biodiversity and reasonable forest wealth, has a long history in the management and safeguarding this crucial resource. Ayancik district of the Sinop regional directorate of forestry has long been the synonym of forestry and forest operations in Turkey. The extents of the growing and standing stocks, diverse forest tree compositions and high quality timber production capabilities affirm a well-deserved recognition among other timber production assigned regions within the country. Heavily beech, fir, Scots and Corsican pine and oak laden forests also include other occasional deciduous species. These untouched, old-growth forests, which were seen as a cash generating opportunity by the government in the early years of the young Turkish republic, were leased to a Belgium backed joint venture company, named as Zingal Inc., for a period of 50 years in 1928. After the establishment of a lumber mill, which was the third largest in the world in 1929, timber production, which was in line with the most up to date technological advancements of the early 20th century was continued by the company until 1945 within 57000 ha designated forest area. Excessive exploitation of the land was behind the early cancelation decision however the principles taught and the infrastructure put in place during the 17-year operational period, propelled the timber production not only in Ayancik, but also in the rest of the country for years to come. As opposed to the current practice of selective logging, timber production back then, relied heavily on clear-cutting and the transportation systems were devised, responding to the unusually large amounts of volumes, being generated.

Trees were felled down and bucked using cross-cut saws and axes, and the primary transport, logging, was performed through 19.1 km skidding chute, 6.5 km dry, 17.5 km wet flumes, 33.9 km trestles and 140.4 km skidding roads. Man and animal power assisted by the favorable gravity, and occasional machinery were behind this initial part of timber transport (Figure 1).

Figure 1. Log skidding by mules and transporting through waterways

Secondary transport, hauling, on the other hand, was performed through period correct, rather sophisticated machinery imported and established within the region by the company. Main 28 km skyline yarding allowed up to 400 m^3/ha log transport when operated flawlessly between 1929-32. Additionally, a 4.5 km extension was attached to the main line in 1936. Their combined efficiency was documented to be 120000 m^3, annually. Using the yarding method alone, 590000 m^3 log was transported between 1935-39 (Bayoglu, 1960) (Figure 2).

Figure 2. Steam donkey and yarding operation

The second big investment working alongside the skyline was the railways. The tracks laid through the valley bottoms helped facilitate the transportation of logs produced elsewhere to the skyline. In total, 95.4 km railway was in operation after 1932. Four small locomotives and 50 or so flatcars managed to carry 10-12 log truck worth volume in one go (Figure 3).

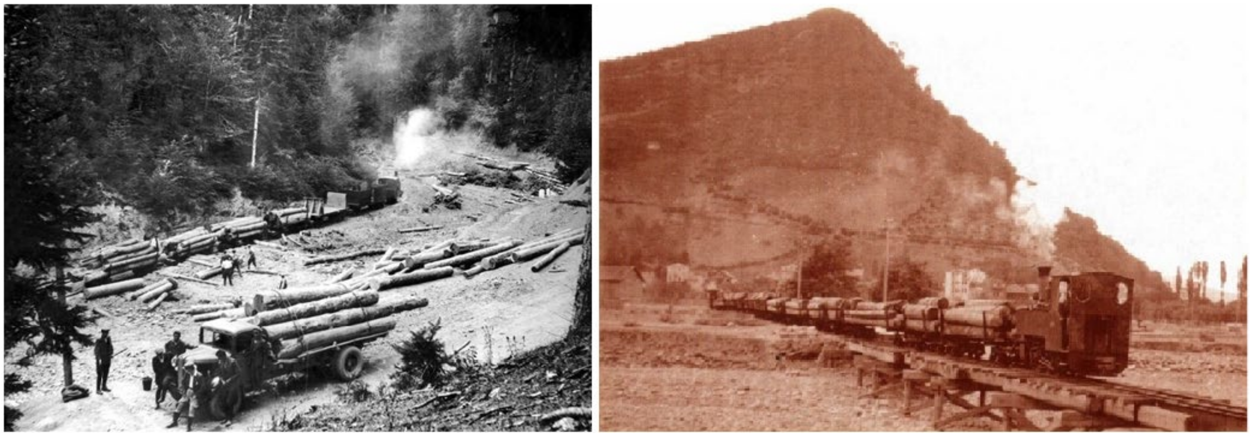

Figure 3. Truck forwarding and rail hauling

Completely import dependent maintenance protocols and the resulting long out-of-service periods eventually brought an end to the skyline yarding in 1968, and the system was gradually dismantled starting from 1953. Similarly, railway system was hampered by a number of severe flooding occurrences until 1963. A complete railway system overhaul was not preferred, and the intact parts continued to be used for timber transport for couple more years.

Following the cancelation of the Zingal Inc.'s contract, Ayancik forest enterprise (FE) was simultaneously established in 1945, including the eastern part of the land, Cangal side, left by the company along with 10 other newly established forest administrative units, called as forest directorates. The western part of the land, Zindan side, was included within the neighboring Turkeli FE.

Although the new techniques have steadily been integrated into the primary transport, the secondary transport has started depending gradually more on the forest roads since then (Figure 4). Although managed sustainably, more than 50% of all Turkish forests are managed for their economic returns. Thus, forest roads, which are considered as the main arm of forest management necessities in Turkey, are planned to effectively reach every corner of a particular watershed or an established forest directorate. Same universal construction principles, such as the transport direction consideration, serviceability of fire susceptible areas, limited forest removal, slope and erosion risk sensitivities, etc. are applied in drafting. However, due to low level of mechanization initiatives, almost total dependence of tractor skidding or winching, and their operational restrictions, a rather tightly knitted forest road network, which has started looking as excessive overkill in the least expected sites (Altunel et al. 2021), is not an uncommon scene in Turkish forests.

When the amount of the volume to be harvested, the construction purpose, traffic density and the type of timber transportation vehicles were considered, the forest roads are grouped and built in three categories; main paved, secondary gravel or dirt or logging purposed tractor roads. More than 90% of all forest roads within the study area as well as in the rest of the country, are considered in the second category. All hauling necessities are performed over these roads. They need a stripped corridor width of 5 to 6 m to house a road bed of 3.5 to 5 m with 0.5 to 1 m side ditch. The more the forest roads are build, the worse the integrity of the forest ecosystems is influenced (Kleinschroth et al. 2016).

Figure 4. Motor-manual tree felling, tractor skidding and hydraulic operated crane assisted timber loading

Expansion of the forest roads as documented within the national quad map coverages and the later adopted spatial data management techniques, has therefore been scrutinized through geoscience capabilities in this study to see how the dearest forest region in the country has been treated in the name of sustainable forestry practices.

2. Methodology

2.1 Study Area

The forest area as managed by the Zingal Inc. was delineated through the historical records and superimposed over the current administrative units of Turkeli and Ayancik forest enterprises within the Sinop regional directorate of forestry to form the perimeter of the study area. The area encompassed 7 entire current Ayancik FE and the large parts of 2 current Turkeli FE directorates and amassed an area of 57000 ha. It is situated between 34° 18' 00" - 34° 45' 00" eastern longitudes and 41° 40' 00" - 41° 57' 00" northern latitudes. Elevation ranges between the coast and the highest peak, 1700 m (Figure 5).

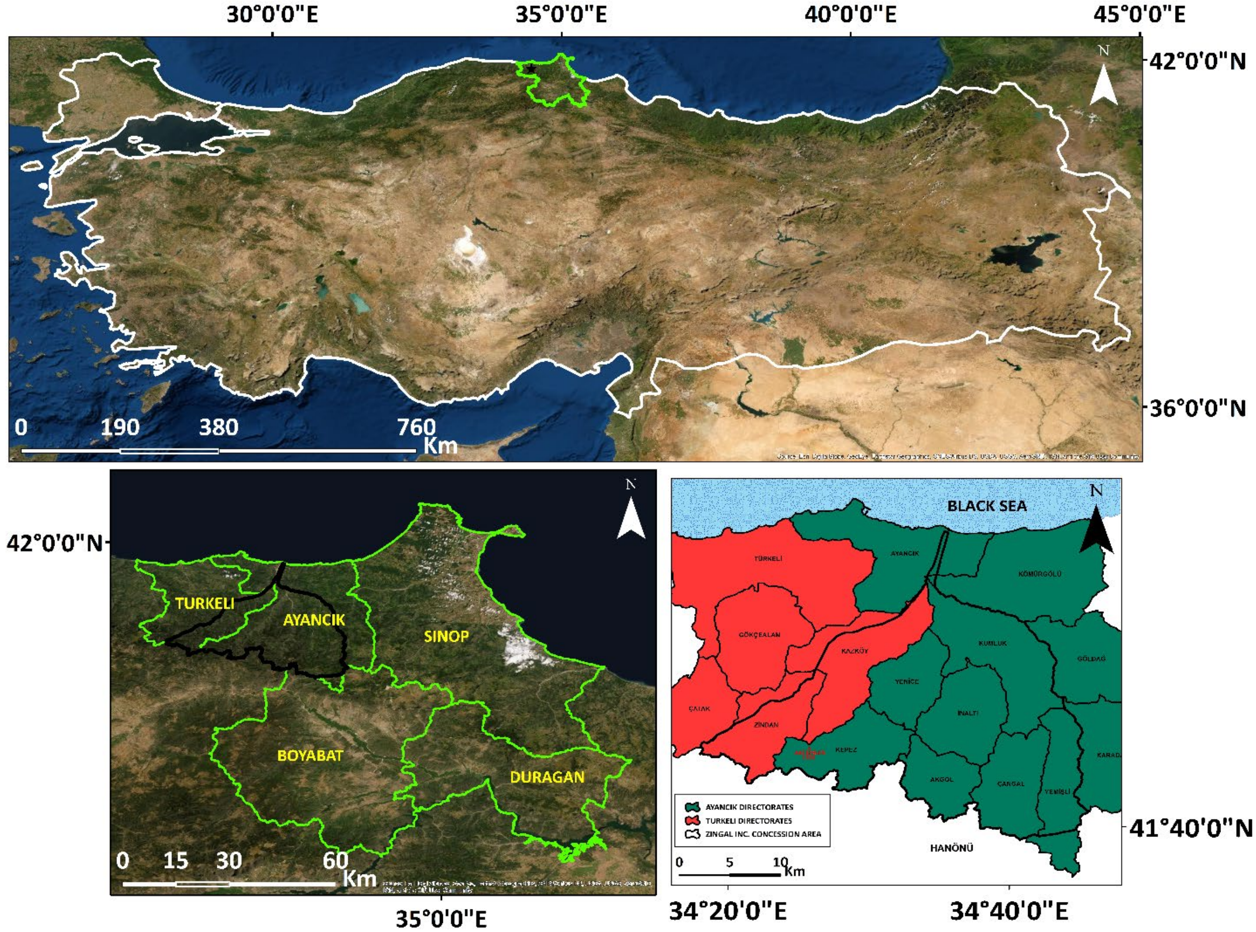

Figure 5. Location of the study area inside the regional directorate of forestry, and its extent over the current administrative units

2.2 Method

Historical records, mostly period correct and geo-referenced field maps, highlighting the operational capabilities of Zingal Inc. were used to build a geospatial coverage of the past. ArcGIS 10.7 was used in all analyses. Meticulous digitizing revealed the full extent of the Zingal Inc. logging and hauling infrastructure capacity in the 1930s and the first part of the 1940s. Additionally, 12 1:25000 scaled national quad maps were stitched together forming the study area to establish two sub-sequential era forest transportation coverages for 1959 and 1993. Quad maps were produced relying on previous stereo aerial photography capture and interpretation by the Turkish Army, mapping command. Rather popular scaling used in many countries' similar coverages provided more than enough spatial precision to extract land cover – land use preferences. Finally, the current one in use today, which has already been built and constantly updated using the spatial data management techniques, was also integrated into the study and the expanding database, so the preferred direction of forest operations in region's forestry is revealed in 4 spatial coverages spanning 90+ years. For computational convenience, the geo-referencing was adjusted for Universal Transverse Mercator (zone 36) projection over World Geodetic System 1984 datum.

3. Results

Following the declaration of independence in 1923, Turkish republic was making every attempt to improve the country's capabilities in every stage. However, the problems faced with the limited knowledge build-up and the qualified personnel shortages apparently blocked the swift development strides in forestry. Thus, one of the last remaining pristine forest areas in the country was leased for management to a foreign nation backed company. Identical to the similar operations in the rest of the world, timber production was devised based on water, rail and cable transportation systems (Figure 6) (Table 1).

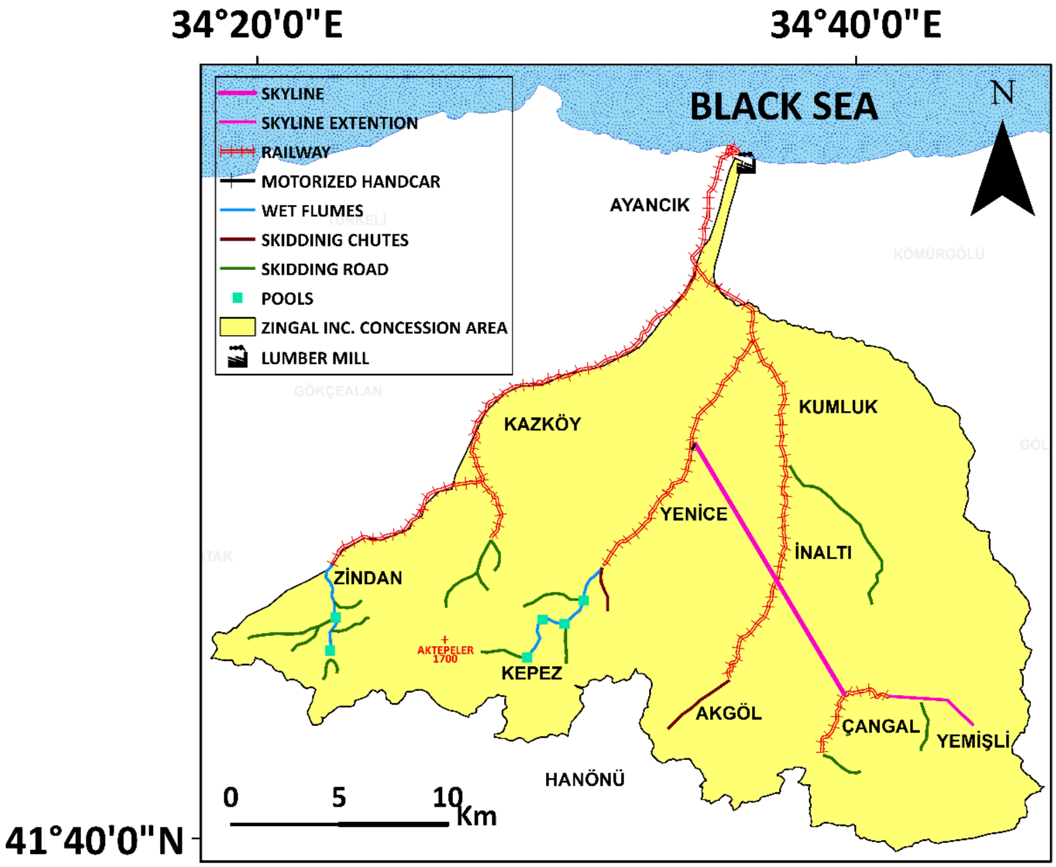

Figure 6. Zingal Inc. era forest transportation infrastructure

Table 1. Zingal Inc. transportation means and distances

Transportation method	Length (m)
Skyline	32748
Railway	95445
Skidding road	231697
Dry chutes	6420
Wet flumes	17428
Various landings	2017
TOTAL	**385755**

After the lease contract was terminated in 1945, all Turkish personnel and management preferences took charge and things started to change. 1959 produced national quad maps still included the operational parts of the former Zingal Inc. era infrastructure, and the first examples of the forest roads, called as “Dirt roads” started to emerge along with the settlement locations. It was more than likely that they probably had existed during the old times, however, there was no way of establishing where exactly the roads and villages were because no air photography capturing was available for civilian purposes in Turkey prior to the 1950s (Figure 7) (Table 2).

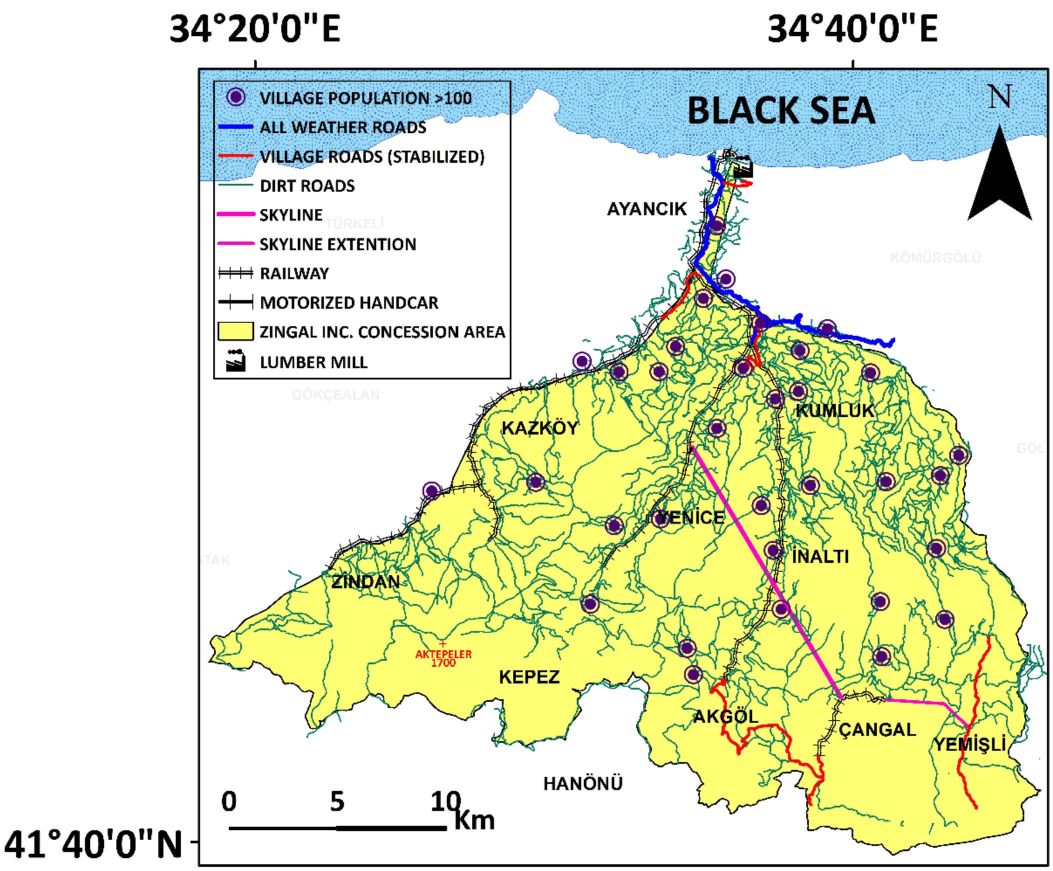

Figure 7. 1959 forest transportation infrastructure

Table 2. 1959 transportation means and distances

Transportation method	Length (m)
Skyline	17718
Railway	95445
All weather road	20260
Village road (stabilized)	33395
Dirt road	396072
TOTAL	**562890**

The real road related name differentiation came in 1993 and the forest roads were specifically denoted. By this coverage period, since all of the remaining Zingal Inc. era infrastructure were long abandoned, no such linear features were available to discern through the quad maps. Instead, rather high concentration of road building was obvious and the quality of navigable roads was on the rise (Figure 8) (Table 3).

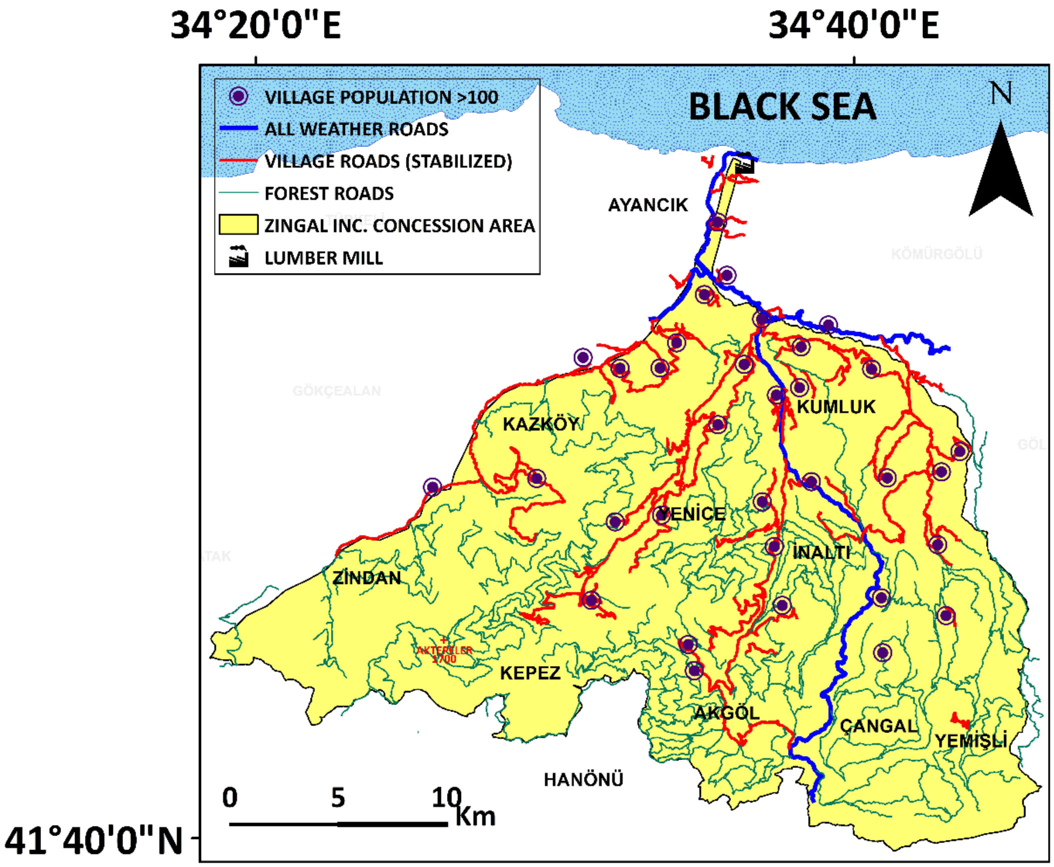

Figure 8. 1993 forest transportation infrastructure

Table 3. 1993 transportation means and distances

Transportation method	Length (m)
All weather road	55850
Village road (stabilized)	305045
Forest road	752159
TOTAL	**1113054**

Another national quad map coverage was released starting with 2008, however since the data management and handling capabilities of the regional directorates of forestry and their subordinate administrative units have professionally improved to much higher standards after 1993, the latest spatial records of the study area were acquired from the Sinop regional directorate of forestry. Thus, a current and final forest transportation system of the study area was generated (Figure 9) (Table 4).

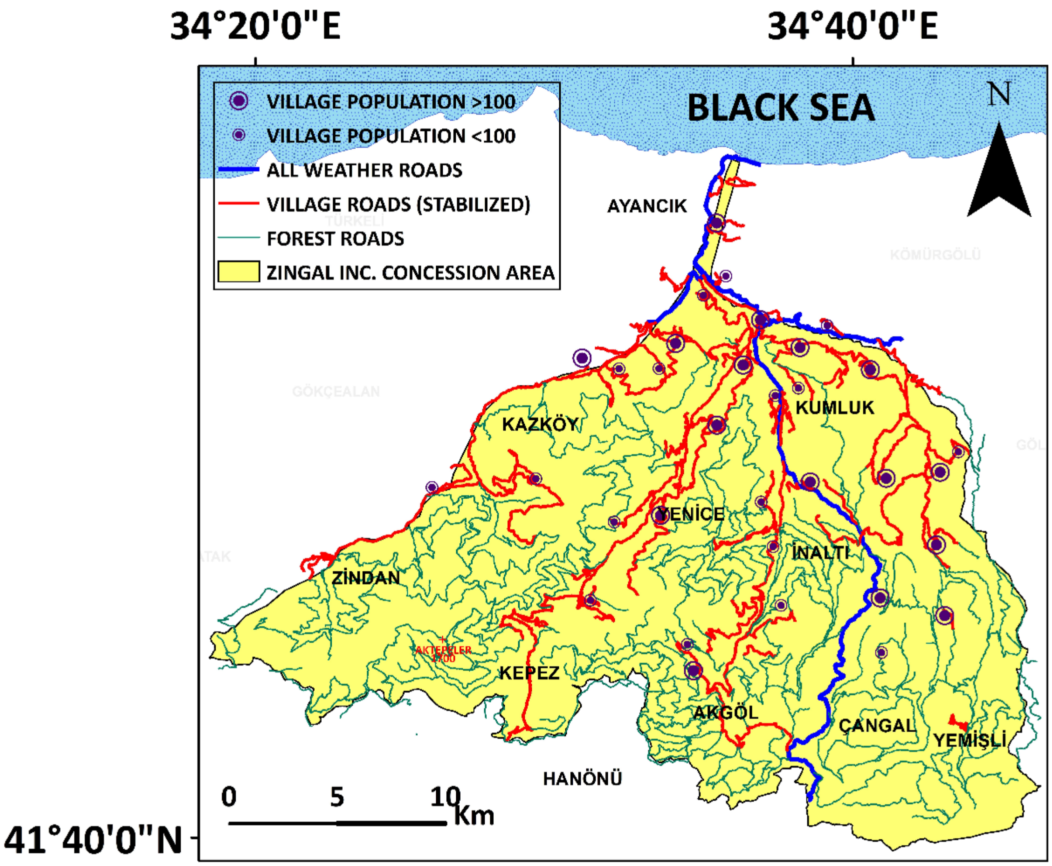

Figure 9. 2020 forest transportation infrastructure

Table 4. 2020 transportation means and distances

Transportation method	Length (m)
All weather road	55850
Village road (stabilized)	342231
Forest road	822597
TOTAL	**1220678**

4. Discussion and Conclusion

Ayancik district of the Sinop regional directorate of forestry witnessed the most comprehensive logging and hauling structuring of its day during the second quarter of the twentieth century. Due to the lack of road infrastructure, large volumes of timber produced as a result of the forest management preferences based on clearcutting approach were transported via cable, rail and water transportation means. Operation wise, it was so successful that the produced lumber was quickly shipped overseas through the harbor in arms reach of the lumber mill. However, it was depleting the standing volume without paying any attention to the stripped lands, so fast that the unfortunate contract termination came much sooner than the agreed upon period in 1945.

Although generally, the technical problems brought an end to the functionality of the skyline toward the end of the 1950s, the major blow to the railway system came after a number of major floods, which turned devastating on bare topography, destroying the tracks in large parts until 1963 (Yildiz, 2021). This would probably have convinced the authorities to invest more on the forest road building, afterwards. Nevertheless, the accumulated knowledge and know-how convinced the Turkish scholars and the authorities accepting the fact that the skyline was a revolutionary piece of logging equipment, which no other type of operational machinery could replace in such tough topographical forest areas of Turkey. On the other hand, stationary routes of the skyline(s) were seen as a handicap for their adoption for wider spread use across the country (Bayoglu, 1960). However, they surely paved the way toward mechanizing the Turkish forestry with further still stationary and improved mobile skyline systems, i.e. Wysenn, Baco, Gantner, Urus and Koller brands (Eker et al., 2001; Caglar et al., 2003; Ozturk and Senturk, 2006). Zingal Inc. skyline was similarly fashioned as the Wysenn or Gantner, but no scientific study is available to compare the efficiencies and the productivities of the past with the present circumstances. Besides, totally different types of forest management preferences, clear-cut vs. selective, left no room for comparison, either.

First comprehensive mechanization attempt in Turkish forestry came in the early 1980s and gradually continued (Demir and Ozturk, 2005; Demir, 2010). A number of the above mentioned mobile yarders were actually utilized in and around the study area. Many study surfaced focusing predominantly on the efficient utilization and management cost(s) of the yarders (Tunay and Melemez, 2001; Caglar et al., 2003; Caglar and Acar, 2005; Senturk et al., 2007; Ozturk and Demir, 2007; Caglar and Acar, 2009; Ozturk and Senturk, 2016), but they mostly failed to mention about the flexibility, which they have provided in Turkish forestry. Since the ageing yarders have not been replaced by the Forest service, they have started to be taken out of the service one by one. In the meantime, Turkish forest service has kept on building the forest roads because the primary transport has overwhelmingly been transformed to ground skidding by tractors. However, since the overwhelming majority of those tractors are simple farm tractors, which are engineered for agricultural activities on relatively leveled farm lands, they lack mobility and efficiency on tougher forest topography so the forest service keeps adding more roads to the system to shorten the distance that they would traverse to skid the timber. Since the notion explaining the fact that road building in treacherous topography is not practical for economic and ecological reasons (Robinson et al., 2010) has long been overlooked everywhere, the mechanization initiative has not taken root, except the northeastern part of the country. This could better be conceptualized when the forest road density figures inside this study's study area are viewed: 0.34 % in Zingal Inc. era, 0.45 % in 1959, 0.66 % in 1993 and 0.72 % today when only the forest road designated linear features were evaluated according to the study area extent (Yildiz, 2021) while all-weather type other roads continue being tied to the forest road networks or expanding.

Today, the vast areas of the Ayancik district are again fully stocked with lush forests, however the area housing them is continuously fragmented more every year. The approach could be understandable if the forest resources either in Ayancik or elsewhere are solely maintained for their economic returns. However, if other ecosystems services are also valued, then the road building trend must be reevaluated, and more mechanization must be integrated into Turkish forest operations to limit ecosystem deterioration further.

5. Acknowledgment

This study relied upon the findings of the work presented to the graduate school of Kastamonu University as an Msc. thesis by Ugur YILDIZ in January, 2021.

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Automated Driving on a Skid Road with a Forwarder in a CTL Logging Process

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ABSTRACT

In a fully mechanized Cut-to-Length (CTL) logging process, a harvester fells the trees and cuts them into logs of specific length according to the log quality. In the subsequent process step, a forwarder loads the logs and moves them from the logging area to a forest road. This step shows a huge potential towards automation. Within this paper, a method is presented for driving a forwarder automated on a skid road based on environmental recognition, avoiding the disadvantages of gps-based systems and their lacking accuracy under tree canopy. The presented method exploits the process flow of a CTL process, as a Lidar is mounted on the harvester, which delivers a highly accurate point cloud of the environment and works well regardless of the lighting conditions.

Applying the SLAM-algorithm 'Google Cartographer' on the collected point cloud data of the 3D-LIDAR from the Harvester creates a map, on which an offline path planning is performed. This map results firstly in a 2D occupancy grid map, showing which areas contains objects and which areas are free space. The data in the map is further processed by identifying trees using a clustering algorithm on the object points. After receiving such a simplified map, the subsequent path planning consists of two steps due to the articulated steering of the forestry machine. In the first step, a guiding path for the skid road is created by using gradient descent after creating an artificial potential field with a high potential for areas containing trees. In the second step, this path is recalculated with a simplified kinematics model of the vehicle, avoiding collisions of the forwarder with the trees adjacent to the skid road. Furthermore, the calculated path contains the steering and heading angles of the vehicle. Based on this information, the necessary steering angle of a vehicle on the map can be calculated online and sent to the machine control.

The presented method was proven simulation-based with measurement data recorded at real logging sites during thinning and will be tested under real working conditions for an 11-ton forwarder in near future. Thereby, a stump detection based on a Convolutional Neural Network resulting in an online obstacle avoidance system will be implemented by mounting an additional depth camera on the Forwarder.

Artisan Forestry: Draft Animals and Low Impact Mechanization in Upland Family Forests

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ABSTRACT

As forested mountain regions across the globe are parcellated into smaller family tracts, natural resource owners are demanding low impact, high aesthetic methods of timber harvest. By combining new and old techniques, a movement of Artisan Forestry is (re)emerging among the woodlands of Appalachia. The use of draft horses, mules, and oxen in cooperation with forwarders, small yarders, and portable milling equipment create an intriguing suite of management options. These approaches deserve a closer look by natural resource professionals who increasingly work in the wildland urban interface. Landscape scale conservation goals may also be cultivated by Artisan Forestry. But are these varied tools capable of delivering economies of scale worthy of serious consideration? Draft animals are perceived to be limited in their productivity and availability. Similarly, low impact machinery is challenged by capacity limitations. By recounting firsthand field experiences and exploring the literature we will define Artisan Forestry and establish it as a tool for sustainable forest management. We will further propose a study design for the evaluation and advancement of mixed power harvesting in Appalachia.

Keywords: draft animal power, forwarder, yarder, portable sawmilling, mountains, Appalachia

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The Potential of Mini Forestry Crawlers to Support Mechanized Harvesting Operations at Extended Machine Operating Trail Spacing

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ABSTRACT

Through wider spacing of machine operating trails, less stand area is impacted by off-road traffic of timber harvesting and extraction machinery and more productive forest area is maintained. In Germany, the national standard of FSC (Forest Stewardship Council) as well as some state forest enterprises support a spacing of 40-m of machine operating trails. Such regulations create a midfield zone outside the boom reach of the harvesters and, thus, restrict the use of fully mechanized timber harvesting and extraction operations. Moreover, the transition to continuous cover forestry with highly structured forests of multiple tree species, creates even more challenges with respect to accessibility to trees to be harvested that need to be addressed.

In our present study the analyzed production system considers the overall supply chain, but gives special focus to the use of mini forestry crawlers. At first, motor-manual felling operations concentrate on trees in the midfields of blocks between adjacent machine operating trails, and, in addition, on trees which cannot be handled during harvester processing (high DBH, widespread crown). The motor-manual felled trees are then partially bunched and pre-winched towards the machine operating trail with a remote-controlled mini forestry crawler. Afterwards, a harvester fells and processes the remaining standing trees within boom reach and finally processes the bunched trees removed from the midfield, before the logs are extracted with a forwarder.

In different studies, several aspects were analyzed: time consumption, productivity, costs, environmental impacts, and impacts on ergonomics. Moreover, the effect of bunching the trees at the machine operating trail on the harvester's productivity was analyzed. While time consumptions, productivities and costs were estimated through time studies and regression analysis, the human workload of crawler operators was assessed by a portable spiroergometric device.

Results showed that for an average load volume of 1.6 m³, the mean cycle time was 4.82 min, the productivity 7.77

m^3/PMH0, the global warming potential 0.321 kgCO_2-eq./m^3 and the costs 12.80 €/m^3 for motor-manual felling and winching from the midfield to the machine operating trail. However, pulling-out the steel cable has to be considered as vigorous work when winching distances exceed 30 m, especially in flat terrain conditions. Advantages from bunching trees at the machine operating trail resulted in increased harvester productivity, but only for broadleaved tree species.

Predicting Productivity of Skidders in Eucalypt Plantations

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ABSTRACT

Timber extraction from forest to the roadside/landing can be operated using cut-to-length, whole stem and whole tree. Skidding is one of the options for wood extraction. This paper aimed to review the available studies on work productivity of skidders in Eucalypt plantations. Reviewing the machine productivity information indicated that skidding productivity in Eucalypt plantations may be impacted by tree volume, load size, skid distance, slope of skid trail and power of the machine. Based on the reviewed literatures the machine productivity varied from 11.20 green tons per PMH0 (Caterpillar 528 operating in skidding distance of 251 m tested in USA) to 80.25 green tons per PMH0 (Timberjack 1710D operating in skidding distance of 241 m in Brazil). General productivity model was developed including variables such as skidding distance, tree size and power of machine. Future research could verify the impact of harvesting intensity/yield per ha, plantation layout (landing locations and block shape), operator experience, terrain conditions and availability of chippers/or processors at the landing in the case of hot decking on the productivity of the skidders in Eucalypt plantations.

Theme 6: Steep Slope Harvesting

Stability assessment of natural anchors for swing yarders in Coastal British Columbia

Luca Marchi, Omar Mologni, Eric Nance, Dominik Roeser, Raffaele Cavalli, Stefano Grigolato

Idaho Steep Slope Harvesting: Tracks, Tires, and Tethering

Austin Finster, Woodam Chung, Brett Morrissette

Cable tensile forces in active winch-assist harvesting: two case studies from the Pacific North West

Omar Mologni, Kevin Lyons, Eric Nance, Luca Marchi, Dzhamal Amishev, Stefano Grigolato, Raffaele Cavalli, Dominik Roeser

Opening Up and Harvesting Systems in Mountainous and Semi-Mountainous Areas of Greece

Ioannis Koukoulos, Vasileios Drosos, Georgios Tasionas, Iordanis Kasapidis, Ioannis Sismanidis,

Energy efficiency, fuel consumption, and productivity of cable yarding operations using hybrid tower yarder and electrical carriage in the North-Eastern Italian Alps

Alberto Cadei, Omar Mologni, Dominik Röser, Raffaele Cavalli, Stefano Grigolato

Conventional single-hitch vs. horizontal double-hitch suspension in cable yarding operations

Raffaele Spinelli, Natascia Magagnotti, Giulio Cosola, Stefano Grigolato, Luca Marchi, Andrea Rosario Proto, Eric Labelle, Rien Visser, Gernot Erber

A QGIS Plugin for the design of cable roads with a standing skyline configuration

Leo Bont, Patricia Moll, Laura Ramstein, Fritz Frutig, Hans Rudolf Heinimann, Janine Schweier

A Mobility Model for a Tethered Skidder

John Sessions, Jeff Wimer

The changes of cable extraction technologies in South Korea from 2000 to 2020

Eunjai Lee, Yun-Sung Choi, Min-Jae Cho, Ho-Seong Mun, Koo-Hyun Cho, Jae-Heun Oh

TVS20, a multifunction tool to up-grade an excavator into a versatile winch-based haulage equipment for hard-to-reach areas: Lessons learnt from 6 operations with the prototype

Philippe Ruch, Nicolas Vigneau, Hubert Loye, Damien Francois, Xavier Montagny, Olivier Santini, Morgan Vuillermoz

Deadman anchoring design for cable logging: a new approach

Francisca Belart, Ben Leshchinsky, Jeff Wimer

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Stability Assessment of Natural Anchors for Swing Yarders in Coastal British Columbia

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ABSTRACT

Swing yarders in running skyline configuration using either grapples or chokers is a common cable yarding practice for steep slope harvesting in Coastal British Columbia (BC). With this technique a cut block is frequently harvested by several cable roads, each one requiring proper anchors to secure guylines and haul-back lines. In old-growth forest stands, large-size trees can normally provide suitable natural anchors. Moving towards increasing harvesting of second- and third-growth forest stands, however, the identification of suitable guyline and haul-back line anchors might be a challenge, potentially increasing safety risks of cable yarding operations. Furthermore, presence of dominant species with relatively low anchoring capacity as western hemlock and red cedars rise even more the challenge. Finally, the frequent moving of the tail anchor, produces high downtimes, therefore best practice rules for their rigging are sometimes overshadowed.

The aim of this study was to investigate the behavior of natural anchors (both stumps and trees), to collect evidence of stress induced on anchors by typical cable yarders used in Coastal BC and investigate innovative anchor stability assessment technique by comparing the anchor root-plate rotations with the applied tensile forces.

Data from 29 different anchors used to secure guylines and haul-back lines were collected in early 2021 from three different logging sites in Coastal BC. Then, from the synchronization of the pulling force applied from the cable and the rotation measured at the anchor's base, main mechanical parameters such as the rotational stiffness were

evaluated and subsequently analyzed. A proper time-study allowed to also evaluate the impact of cyclic loading on the evolution of such parameters along the whole working time.

Cross comparisons between trees and stumps with similar characteristics confirmed that large trees and stumps (DBH over 70 cm) were found to be sufficient to withstand the pulling forces generated by the swing yarders up to 150-200kN without the need of tiebacks. Trees and stumps with DBH in the range between 50 to 70 cm required one or two tiebacks to safely withstand similar pulling forces. Trees with DBH lower than 50 cm needed to be extremely well rigged, supported by a pair of tiebacks and kept under surveillance during their working life. Finally, the study confirmed that the stability of an anchor can decrease rapidly over few hours of logging operations and the effects of subsequent loading cycles affects its overall response.

Idaho Steep Slope Harvesting: Tracks, Tires, and Tethering

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ABSTRACT

Steep slope timber harvesting is under scrutiny and advancement through a variety of labor and safety challenges as well as technological improvements. Timber harvesting methods on steep slopes that historically involved motor-manual tree felling and labor-intensive extraction are giving way to mechanization in steep slope harvesting for benefits of increased productivity and safety. Tether-assist technology is making these advancements of mechanization possible, with ground-based timber harvesting machines now traversing steeper terrain than previously accessible.

This study aims to compare and quantify soil disturbance impacts that occur between traditional and emerging steep slope harvesting systems with the use of tether-assist machinery. In this study, four separate steep slope timber harvesting machine configurations were used, consisting of two ground based and two cable-based extraction methods, along with motor-manual and mechanized tree felling.

A systematic approach was taken in soil sample collection to capture the differences in felling and whole tree extraction impact across each harvest system area. Sampling consisted of pre-operation and post-operation measurements taken at repeated locations on an established grid. Measurements of bulk density as well as penetrometer resistance are utilized to characterize the soil profile from 0-50 centimeters in depth, allowing for the comparison and analysis of pre-harvest and post-harvest compaction indicator values within and between timber harvest machine configurations.

The results from this study have shown differences in machine configuration impacts with each configuration contributing a unique distribution of soil impact to the harvest area. Through a variety of cable, tracked, and rubber tire equipment, this is to be expected due to the differing contact relationships and payload interactions with the soils in the harvest area.

Cable Tensile Forces in Active Winch-Assist Harvesting: Two Case Studies from the Pacific North West

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ABSTRACT

Winch-assist technology is becoming a common solution for forest harvesting on steep slope because of the connected safety benefits and performance improvements. However, cable tensile forces remain a major concern in the advancement of the technology and their investigation is lacking in the literature, particularly for active winch-assist.

This study assessed cable tensile forces of two anchor winch machines (a Falcon Winch Assist and a Summit Winch

Assist) tethering feller-directors on ground slopes up to 103% and 77%, respectively. Both studies were located in Washington (US), on second-growth forest stands. The operations were observed over four consecutive days each. Cable tensile forces were recorded simultaneously at the harvesting and anchor machines, at recording frequency up to 100 Hz. Cameras and GNSS devices enabled a time study of the operations and the recording of machine positions. The Falcon Winch Assist study focused on the dynamic analysis of the cable tensile forces, particularly at the harvesting machine. The Summit Winch Assist study focused on the impact of winch design and functionality on the observed tensile forces. Both cases show cable tensile force distribution and peaks, differences between tensile forces at the harvesting and anchor machines, and frequency exceeding recommended safety limits.

The observation of the Falcon Winch Assist showed tensile forces up to 48.5% of the minimum breaking strength of the cable, or 400 kN. Downhill movements of the harvesting machine recorded the highest peaks. Numerous local variations in cable tensile forces exceeded 50 kN in a few hundredths of a second, mainly during active movements of the harvesting machine, with a maximum variation of 300 kN in less than a second. Cable tensile forces in the Summit Winch Assist case study reached 41.5% of the minimum breaking strength of the cable, or 296 kN. Slow negotiation of obstacles while moving downhill still recorded the highest peaks, mostly due to lag and threshold settings of the winch. Because of the winch design, lower but significant peaks were also recorded during stationary work tasks. In both cases, depending on work task and machine movements, cable tensile forces were higher at the harvesting or anchor machines; however, the highest peaks per work element were always recorded at the harvesting machine. Peaks were limited to a few events and never exceeded the endurance limit of the cables. A few implementation steps for improving the safety of winch-assist harvesting operations using anchor machines are discussed.

Opening Up and Harvesting Systems in Mountainous and Semi-Mountainous Areas of Greece

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ABSTRACT

Forest exploitation and wood utilization represent a very important function within the framework of forestry activities. Greece is an extremely mountainous country, but it has at its disposal a few forests, mainly growing on degraded sites and steep terrain with reduced production potential. The condition of the forests, and consequently, the need for a careful silvicultural treatment renders more difficult the application of highly mechanized exploitation methods.

The utilization of bioenergy from wood biomass and technical timber of constructions requires its technical-economic optimal harvest.

The mountainous forests are, as a rule, and the most productive ones in our country, from where the wood products are mainly harvested-moved-transported.

Aim of this paper is to investigate an optimum opening up - harvesting system for the Greek conditions regarding efficiency, effectiveness, ergonomics, employment, environmental protection with adaptation to European standards. In this paper five opening up - harvesting systems are developed and are compared. The research results for each objective - case are interpreted and are discussed, related to the relevant literature and are presented proposals for practical implementation and prospects for future researches.

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Energy Efficiency, Fuel Consumption, and Productivity of Cable Yarding Operations Using Hybrid Tower Yarder and Electrical Carriage in the North-Eastern Italian Alps

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ABSTRACT

In the last decades, low-emission and zero-emission technologies have been applied to light and heavy-duty vehicles. Even though hybrid and full electric propulsion systems are widely studied for road vehicles and city mobility applications, there is currently a considerable knowledge gap in regard to hybrid and full electric propulsion systems applied to forest operations sector, and in particular to cable-based harvesting system. This study monitored a hybrid tower yarder equipped with an active slack-pulling electric carriage during uphill yarding operations for 30 work days, in order to evaluate energy efficiency, fuel consumption, and productivity of cable yarding operations. A total of 915 work cycles on four different cable lines were analyzed. Energy consumption and productivity were recorded by integrating long-term monitoring using Can-BUS data and direct field observations. Subsequently, energy efficiency, fuel consumption, and productivity were evaluated in terms of net energy consumption, Net EC (kWh), total energy efficiency, TEF (%), fuel consumption per unit of timber extracted (l/m^3), and productivity (m^3/PMH$_{15}$). The inhaul-unload work element consumed, on average, 63% of Net EC per work cycle, while the outhaul and the lateral skid consumed 15% and 22% of Net EC, respectively. The highest Net EC of 1.150 kWh (Mean= 0.617 kWh; SD=0.453 kWh) occurred during inhaul-unload. In contrast, lower energy consumption of 0.035 kWh (Mean= 0.172 kWh; SD=0.155 kWh) and 0.086 kWh (Mean= 0.184 kWh; SD=0.092 kWh) were recorded during outhaul and lateral skid, respectively. The electric-hybrid technology led to the reduction of the engine's running time up to 38% of the total productive time. In addition, mean TEF of each monitored cable line varied between 35% to 41%. Fuel consumption and productivity were estimated to be 0.54

l/m_3 and 4.04 m^3/PMH_{15} for the longest cable line and highest yarding distance (Mean= 380 m; SD= 94 m). In contrast, for the shortest cable line and related lowest yarding distance (Mean=80 m; SD=40 m), the fuel consumption and productivity were 0.27 l/m3 and 9.99 m^3/PMH_{15}. The estimated recovered energy, on average between cable lines, was 2.56 kWh. Therefore, the reduced fuel need was assessed to be approximately 730 l in the 212.5 PMH_{15} of observation, for a total emissions reduction of 1907 kg CO_2eq, equal to 1.89 kg CO_2eq/m^3.

Conventional Single-Hitch vs. Horizontal Double-Hitch Suspension in Cable Yarding Operations

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ABSTRACT

Two-hitch carriages have been developed to allow for full suspension of tree-length material. The use of double-hitch carriages in forest operations is not new and it is documented in the scientific literature since the late 1960s. Early double-hitch carriages were also categorized as "load beam" carriages, and the problem with them was that

they were not suited to lateral skidding and could generally reach only those loads that were placed directly under the skyline. In contrast, the new double-hitch carriages that appeared in recent years have both full suspension and lateral skidding capabilities. That is made possible by the introduction of hydraulically-powered motorized dropline winches, which were not readily available earlier on. The new double-hitch skyline carriages appeared in the European Alps several years ago and normally consist of a conventional single-hitch carriage coupled with a so-called "trailer" – i.e. a detachable secondary carriage fitted with an additional winch to power the second dropline. This study compared a standard single hitch to a two-hitch carriage under controlled conditions, namely in the same location using the same yarder with downhill extraction. The comparison included time consumption, productivity, extraction cost and skyline loading – the latter in term of mean tension, peak tension, dynamic loading and maximum cyclic loading amplitude. As expected, the two-hitch carriage required more time for loading, but was able to achieve similar productivity through increased inhaul speed. While payload was similar in the treatments, the additional weight of the double-hitch carriage resulted in higher skyline tensions. In both treatments, payload and skyline tension when the carriage was at midspan were strongly correlated. Cyclic tension was reduced by the double-hitch carriage system. A number of unique high-dynamic loads were identified that were not part of normal extraction, but they represented only 6% of the cycles and maximum tension was similar to that experienced during break-out and inhaul. This study increased the understanding of skyline tension during logging operations and the effect of carriage type. It showed that, though tension often exceeds the safe working load of the cable, it does not exceed the endurance limit for a well-designed and operated system. The significance of this study is that it demonstrates both the physical and economic feasibility of moving to tree-length extraction using the two-hitch type carriage for longer corridors, for settings with limited deflection, or areas with lower tolerance for soil disturbance.

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A QGIS Plugin for the Design of Cable Roads with a Standing Skyline Configuration

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ABSTRACT

Cable-based technologies have been a backbone for forest harvesting on steep slopes. The design 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 and stable anchor and support trees are found and that at the same time the number of intermediate supports is minimized as far as possible. In practice, the search for a solution is often iterative; especially with long cable roads, several attempts may be necessary until a good solution is found. On the other hand, for ergonomic and silvicultural reasons (work safety, damages to the forest), the skyline should be guided as high as possible.

To support this task, we developed a semi-automated cable road design tool (designed as a QGIS plugin), which is based on mechanical assumptions for the structural analysis that are "close-to-reality", contains an algorithm that checks all possible intermediate support combinations and automatically identifies the optimal solution, integrates tools and geodata within a GIS system, aiming to simplify the design process and is easy and intuitively to use. We

present its main components and demonstrate one example of application. The integration into a GIS, the implemented cable mechanics as well as the associated information for the construction a cable road was very much appreciated by the users. We will also present and discuss the result of the corresponding field tests carried out in Switzerland.

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A Mobility Model for a Tethered Skidder

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ABSTRACT

Tethered logging has rapidly been increasing in popularity in the western United States. The main application has been to use the tether to stabilize and assist a feller-buncher, permitting cutting and bunching of whole trees for extraction by cable yarding, or in some cases shovel logging.

Since the implementation of tethered harvesting into the Pacific Northwest (PNW) continual changes and updates have taken place with this system. There are several key manufacturers who are continuously changing and modifying the traditional tethered model of a tethering machine and tethered feller-buncher. One such change has been to tether a logging skidder. In areas where cable yarding equipment is not available, a tethered grapple skidder could be an alternative for moving bunched trees from the field to roadside, or in steep areas with convex slopes to avoid the use of intermediate supports.

While initially implemented in the PNW, this system has utility throughout the world in other logging regions. The PNW has historically been dominated by cable tower logging. Areas outside the PNW will have much broader access to ground-based systems than cable tower logging systems.

This paper looks to model the tethered skidder logging application. A methodology for estimating the performance of the tethered skidder is not available. A methodology for a six-wheel drive skidder is presented by extending existing four-wheel drive models for extraction uphill in steep terrain. The load that can be skidded is a function of skidder weight, soil strength, and tether tension. Tire pressure is also an important variable. The energy intensity of tethered skidders is much higher than for cable logging due to the weight of the skidder. The lighter the skidder, the lower the power requirements and the lower the energy intensity.

We seek to identify the largest log load and associated speed that the load can be brought up the hill by skidder subject to maximum horsepower contributions of the skidder, the tether winch machine, and the upper limit on slip between the wheels and the soil. There are significant challenges to using a tethered skidder on steep slopes such as weight of machine, size of load being hauled, tension required, wheel slip, soil conditions and tire interface and fuel usage. This paper looks to evaluate the efficiency of several systems and helps provide a methodology to evaluate other combinations of tethered skidder systems that could include the clambunk skidder as well as the grapple skidder.

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The Changes of Cable Extraction Technologies in South Korea from 2000 to 2020

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ABSTRACT

A cable-based extraction technology has been commonly practiced for over 150 years, particularly in North America and Europe. In South Korea (hereafter Korea), the cable yarders were introduced in the late 20th century and have continued to use method of extracting trees on steep terrain (greater than 40%; 60% of all forested areas). However, cable-based system is being expanded to push the limits of cable-based machines, such as tower yarder and swing yarder, since small private woodlots (1.92 ha of average private forest area) were owned by more than 2.1 million owners in 2020. In addition, although cable yarders are ideally suited and operated in inaccessible and environmental-sensitive areas, it is required high investment and harvesting costs, and more complicated system compared to harvesting methods on flat terrain. In recent years, Korea has sustained significant shift to its forest operation methods, particularly on steep terrain. The objectives are to evaluate the performance (i.e., productivity based on productive machine hours) alteration in Korea cable yarding operations over the two decade and discuss the impact of these changes. The performance of individual machines will considerably differ depend on pre-harvest stand quality, cycle log volume, and tower yarder sizes such as small-, medium-, and large-scale. The logistics of cable extraction operations will be discussed. Our results may lead to better-informed cable extraction decisions and advance the efficiency cable yarding system.

TVS20, a Multifunction Tool to Up-Grade an Excavator into a Versatile Winch-Based Haulage Equipment for Hard-to-Reach Areas: Lessons Learnt from 6 Operations with the Prototype

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Abstract: *Forest located on slopes greater than 30% or on sensitive soils account for 250,000 hectares in Grand Est region, including 23,000 hectares of poplar plantations. Most of this wood resource is difficult to mobilize, which impairs forest management itself on top of climate-change consequences. Foresters are also confronted to this double challenge in other French regions. On the entrepreneurs' side, hyper-specialization of forest machines and equipments, often presented as a guarantee of high performance, is not always within the reach of all companies. When markets are saturated or operating conditions become unfavourable, these machines are idle, making their depreciation uncertain. This context motivated the manufacturer Vigneau Material Forest (VMF) into developing a winch-based haulage solution, to be plugged as a multifunctional toolkit on an excavator. The TVS20 brings extra versatility to a "low-cost" machine, more than 300 of which are now accounted for in the French forest sector France, mostly as a carrier of shear heads to harvest biomass.*

The TVS20 includes: a winch installed in the blade with a pulling capacity of 20 tonnes, 200 m of cable plus a multifunction hub mounted on the boom. The latter includes a grapple, a haulback-cable and a cable-lifting pulley. It can be installed in less than 10 minutes, thanks to a fast attachment mechanism.

Time studies were carried out on 6 sites, in a wide variety of situations (flat/steep terrain, thinning/final felling, mean tree volume from 0.55 to 2.26 m³...), to measure the performance of the TVS20 and determine its operational limits. The same 14-ton excavator operated as carrier for all tests.

Overall and unsurprisingly, the most productive sites combine flat terrain, short winching distance, large average unit volume and no need to cross-cut logs on the landing. The high variability in productivity, combined with the number of operators present (from 2 to 4 depending on the site and the chosen organization), also results in a large variation in the costs. From 6.4 euros/m³ for the poplar clear cut to 44.1 euros/m³ for the extraction of hardwoods on 50% irregular slope.

This paper examines the effectiveness of the system on technical, economic and environmental aspects. Based on the lessons learnt from the first 6 test sites with the prototype, operational recommendations for an efficient use of the system conclude this study. The up-coming improvements of some of the TVS20 features, such as the winching speed, will also improve future performances.

Keywords: winch-based haulage, excavator, soil protection, steep terrain.

1. Introduction

1.1 The problem and the context

Forest located on slopes greater than 30% or on sensitive soils account for 250,000 hectares in Grand Est region, including 23,000 hectares of poplar plantations. An important part of this wood resource is difficult to mobilize, which impairs forest management itself on top of climate-change consequences. Foresters are also confronted to this double challenge in other French regions.

On the entrepreneurs' side, hyper-specialization of forest machines and equipments, often presented as a guarantee of high performance, is not always within the reach of all companies. When markets are saturated or operating conditions become unfavorable, these machines are idle, making their depreciation uncertain.

This context motivated the manufacturer Vigneau Material Forest (VMF) into developing a winch-based haulage solution, to be plugged as a multifunctional toolkit on an excavator. The TVS20 brings, thus, extra versatility to a "low-cost" machine commonly used for harvesting wood energy.

1.2 TVS 20: winch + multifunction hub developed to be mounted on an excavator

The TVS20 is a hauling accessory to be mounted on a 14 to 25 tons excavator. It is designed for hard-to-reach areas. This system consists of two elements: a winch and a multifunction hub.

- **A 20 Tons winch**

The winch is installed on the front blade of the excavator and is connected to its hydraulic power system. The winch's casing is beveled on its rear part. Hence, the blade can be raised without risk of collision with the cabin (see Figure 2). The winch weighs about 1 ton without cable. Its pulling force is 196 kN (equivalent to 20 tons). The maximum capacity of the drum allows to spool 200 m of 24 mm diameter cable. This important pulling force enables the haulage of large pieces of wood or several pieces simultaneously.

Figure 4: TVS20 mounted on a 14-ton excavator, winch on the front blade, hub in grapple configuration at the end of the boom

Figure 2: lateral view of the winch attached to the excavator’s blade

The winch’s hydraulic motor acts as a negative brake. If the winch is not operated, it is blocked; there is no freewheeling position. To unspool the cable, the winch must also be operated. Unspooling is therefore facilitated, which is a plus for the operator who pulls the cable. However, this feature may cause loops to form when the tension on the cable is not sufficient. The winch operator must therefore monitor the proper unspooling of the cable. A control window designed on the rear of the protective casing serves that purpose.

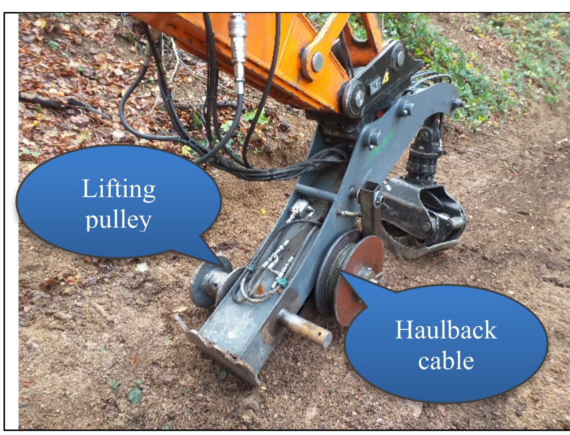
The TVS20 presented in this article is still a prototype. It should therefore be noted that:

- hydraulic activation of the winch is done manually, by opening/closing power valves behind the winch,
- the winch is only under the sole control of the pilot from his cabin
- the winch only works at slow speed, 1km/hour on average.

Up-grades (speed; winch activation from the cabin) are under preparation for the commercial version.
Choosing the cable is paramount, especially since the TVS20 is a powerful winch. The cable must be adapted to the breaking resistance of the winch, 400 kN. Synthetic cable (24 mm diameter) was chosen for the tests, mainly for safety and ergonomics reasons. However, its sensitivity to abrasion and its cost calls for special care and vigilance from the operators.

- **The multifunction hub**

The hub is attached to the end of the excavator’s boom. It is connected to the machine's hydraulic system by 7 hoses and to the electrical circuit by an electrical cable. (cf. figure 3). It can be installed in less than 10 minutes thanks to a fast attachment mechanism. It weighs 380 kg without grapple, rotator and return-cable.



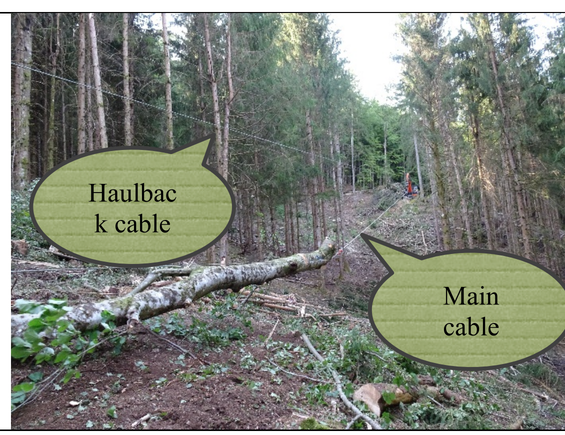


Figure 3: Multifonction hub, cable lifting pulley on the left side and haulback cable on the right side	Figure 4: haulback-cable used here on site with long haulage distance

Three tools provide TVS20 with great versatility:

- **the haulback-cable**(cf. figures 4 et 10) is used to send the cable from the landing back to the area where the chockersetters work. It prevents the operator on foot from going back and forth to recover the cable at the end of the turn, thus reducing fatigue. This cable is used with a pulley, placed at the end of the logging corridor. Its maximum length is 300 m in 8 mm diameter synthetic cable. The spooling of the haulback-cable can be controlled from the cabin by the machine operator. It works with its own driving system, yet it is connected to the main cable.
- **the cable-lifting pulley** (cf. figure 5) steers or lifts the cable and the load to overcome an obstacle or avoid standing trees. Hung-ups can thus be easily solved. The cable-lifting pulley and the haulback-cable can be used with the boom lifted or with the hub resting on the ground.
  The return-cable and its pulley are installed on the hub in about 10 minutes.
- **the grapple and its rotator** are used to handle logs near the machine. Stockpiling can thus be carried out in the direct continuity of haulage, whenever appropriate storage space is available in direct proximity to the machine. It also secures the sling stall operation by maintaining the tree, if necessary. This function is, however, only effective in the vicinity of the excavator. When the grapple is used, the multifunction hub is stuck under the boom (cf. figure 6). All common grapples can be plugged to the multifunction hub.

Figure 5 : Hub here in vertical position while using the cable-lifting pulley

Figure 6: When the grapple is used, the multifunction hub is stuck under the boom

2. Material and methods

Time studies were carried out on 6 sites, in a wide variety of situations (see Table 1), to measure the performance of the TVS20 and determine its operational limits:

- Two sites on flat and soft soils (ZH): Ash sanitary thinning (ZH1) and poplar clear cut (ZH5),
- Four sites on slope (P): logs (P2 & P4), cross-cut whole trees (P6) et whole trees (P3).

For these tests, the same carrier was used: a 14-ton Doosan excavator. The latter is usually used for whole tree harvesting with a shear head as felling accessory. Experienced excavator operators worked on the site, but none of them had previous experience in haulage with a winch.

The rigging crew ranged from 1 chockersetter (ZH1, ZH5, P2 and P4) to 2 chockersetters who took turns (P3 and P6). These operators were generally inexperienced for this type of work. As a result, the productivity results presented in this article can be significantly improved with experienced teams, including on site organization, handling and laying of cables, pulleys and slings. On the P3 and P4, there was an additional operator: a chaser on the landing to cross-cut the excavated trees with a chainsaw.

On all sites, observations on the winch capacity and time study of the different phases of work were carried out according to monitoring protocols developed by FCBA (AMREF, Cassotti-Laurier). For each turn, the time per work phase, the number of trees, their volume, the winching distance and the slope were noted (see Table 1).

Site	**ZH1**	**ZH5**	**P2**	**P3**	**P4**	**P6**
Location	Bouvancourt (51)	Soligny (10)	Beaulieu (55)	Maranville (52)	Régnault (08)	Longchaumois (39)
Practice partner	FBE	FBE	ONF	FBE	ONF	VMF
Forest type	Even-aged high forest	Poplar plantation	Uneven-aged forest	High forest transitioning to uneven-aged forest	Uneven-aged forest	Even-aged high forest
Main species	Ash	Poplar	Beech	Beech	Oak and beech	Spruce and mixed-hardwoods
Intervention	Sanitary thinning	Final felling	Thinning	Thinning	Opening of logging corridors	Removal of the hardwoods
Special attributes of the site	Swamp site	Stream in the middle of the stand + Demanding felling procedure for border trees	Largested piece of all sites	Whole trees had to be processed at the landing	Long logs had to be processed at the landing	Whole trees and cross-cut whole trees
Mean tree Volume (m^3)	1,25	2,26	1,62	0,78	0,55	0,77
Volume during time study (m^3)	137	156	57	52	57	31
Slope (%)	Flat terrain	Flat terrain	45 to 52%	49%	46 to 55%	35 to 47%
Mean hauling distance (m)	22	29	55	27	44	63
Maximal hauling distance (m)	56	47	94	56	87	114
Number of operators	1 excavator op' + 1 chockersetter	1 excavator op' + 1 chockersetter	1 excavator op' + 1 chockersetter	1 excavator op' + 1 chockersetter + 1 chaser	1 excavator op' + 2 chockersetters + 1 chaser	1 excavator op' + 2 chockersetters
Hourly Productivity (m^3/ productive hour)	**15,0**	**18,8**	**8,5**	**7,6**	**7,1**	**3,4**
Trees per productive hour(number of trees/productive hour)	13,3	8,3	5,3	9,7	12,8	4,4
% of trees hauled with the cable	55%	94%	100%	82%	97%	100%
Haulage cost Excluding felling costs **(€/m^3)**	**8,0**	**6,4**	**14,1**	**15,7**	**21,2**	**44,1**

Table 1: Main characteristics and results of the 6 test sites

3. Results and discussion

The first observation about the TVS20 is that teams became familiar with it very fast, in less than half a day.

- **A powerful winch and a stable excavator**

The 14-ton excavator never faced in trouble during the winching phases. It was well positioned in line with the logging corridor and its blade was anchored in the ground. The boom, which lifts the cable, is secured by the presence of anti-swing safety valves. The largest wood hauled at all 8 sites was an 8.2-ton beech tree, on a 52% slope over a distance of 75 m.

- **Productivities as diverse as site conditions**

Productive hours exclude breaks, breakdowns, maintenance operations and machine movements from the depot to the work area. The 6 sites explored contrasted situations (see Table 1). Thus multiple factors explain the wide variability in observed productivity (see Figure 7).

P6 is the least productive operation with 3.4 m3/ productive hour (or 4.4 trees/productive hour). It had the most difficulties: hauling distance of up to 114 m, 11% of idle time due to on-going felling carried out in parallel, rugged topography, complex directional felling required for some of the standing trees, an inexperienced team resulting in a time per tree of more than 2 minutes. The poplar clear cut on the ZH5 is the most productive site with 18.8 m3/production hour (or 8.3 trees/productive hour).

Overall and unsurprisingly, the most productive sites combine flat terrain, short winching distance (see Figure 8), large average unit volume (VUM) and no need to cross-cut logs on the landing. As soon as there is a slope (about 50% for P2, P3 P4 and 35-47% for P6), productivity is halved compared to flat sites.

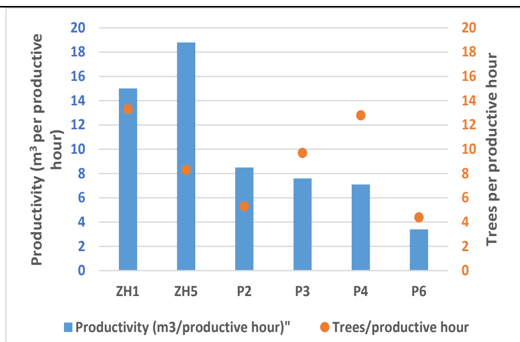


Figure 7: Productivities per site

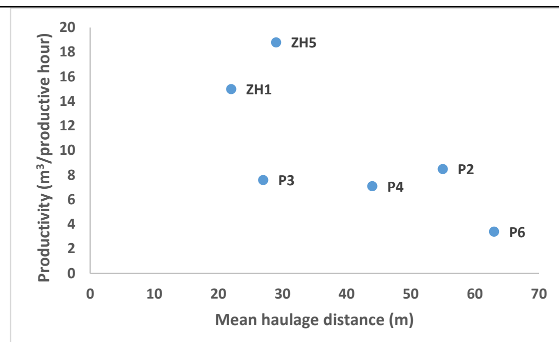


Figure 8: Productivity and mean haulage distance

However, the winching distance and slope are not the only explanatory factors. Productivity is primarily the result of the organization of the site, the haulage distance, the unit volume of the trees, the volume per corridor, the possibility to haul several logs simultaneously and the experience of the team. P3, despite a short haulage distance (27 m) is hindered by the choice to process whole trees. This does not facilitate the winching of several pieces at once, and generates significant wood processing times in the landing: 7% of the productive time is spent debranching and cross cutting the whole trees, 12% on handling logs with grapple mostly their crowns and 18% on further handling to stack the logs further away (Figure 9). Much of this time could have been saved by processing felled trees directly in the stand and leaving the crowns behind.

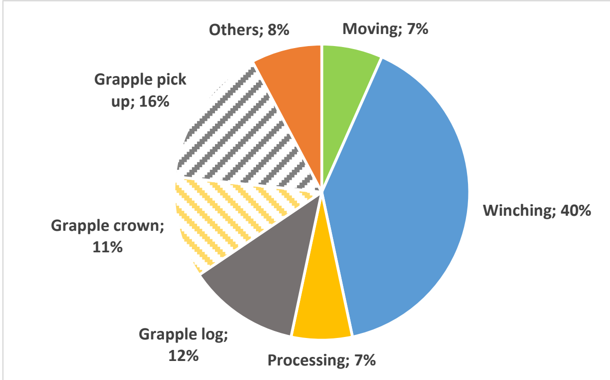


Figure 9: Time distribution per activity on P3


Figure 10: Ash logs winched out of a swamp area and ready to be transported to depot by a skidder

- **Haulage costs are also very heterogeneous**

Economic assessment was carried out on the basis of the following hourly costs:
- 90 euros per machine hour for the excavator and its operator
- 30 euros per hour per operator on foot (chockersetter, chaser).

These costs do not take into account the felling costs.

The high variability in productivity, combined with the number of operators present (from 2 to 4 depending on the site and the chosen organization), also results in a large variation in the costs (see Table 1). From 6.4 euros/m^3 for the poplar clear cut (ZH5) to 44.1 euros/m^3 for the extraction of hardwoods in P4. For other sites, the average cost is around 17 euros/m^3, from 14.1 euros/m^3 in P2 to 21.2 euros/m^3 in P4.

These high costs could be reduced by a series of measures: increased user skills, the implementation of an adapted site organization, the choice of efficient accessories (hook, sling, chockers, etc.) to reduce hanging times (on average one minute per tree on test sites).

The up-coming improvements of some of the TVS20 features, such as the winching speed, will also improve future performances.

4. Recommendations on TVS20 utilization: lessons learnt from the first 6 test sites

- Straight logging corridors must be opened, i.e. in the axis of the machine and for a distance smaller than the length of cable (maximum 200 m).
- The end log must be oriented towards the landing, or towards the main cable line. Thus, the instructions given to operators must be extremely clear. The use of maps is recommended to prevent any ambiguity about the location of logging corridors and landing places.
- A suitable forest road network should allow the machine to reach the stand and the winching places.
- The boom of this 14-ton excavator has a lifting capacity of 1.7 tons (manufacturer's data), which allows it to easily handle wood on flat areas, but may not be sufficient to handle large wood on the slope. This calls for appropriate choice of the landing and its associated storage capacity to avoid the risk of slipping the uncovered parts.
- Ideally the landing is at least 5.5 m long, for the excavator to maneuver easily. The landing must include one or more storage areas suitable for the volume of wood to be hauled from the corridor, while ensuring

operators' safety. If a second machine is present simultaneously, to transport the wood further way to the depot, it is essential to have additional space.

- The haulback-cable is optional. This choice must be made for each corridor, ensuring that the installation time of the return pulley is compensated by the gain provided by the "effortless" return of the cable to the chockersetter. It should be analyzed according to the following characteristics:
  - number of pieces to be hauled,
  - haulage distance,
  - slope and terrain roughness,
  - Accessibility to the targeted logs for the operator on foot.
- The team consists at least of an excavator operator and a chockersetter. Ideally, trees are delimbed and cross-cut before haulage. If the processing is to be made on the landing or if the logs is too long, a chaser must be mobilized on the landing. This teamwork requires a very good organization between the different people.
- Operators need to communicate remotely: the use of an efficient radio communication system is therefore mandatory. Moreover, due to the reactivity necessary for the smooth running of the operation, a permanent radio link of the "hand-free" type is strongly recommended.
- Plan to take back the woods by another machine to the landing site, delayed to avoid waiting times, simultaneously if the volumes are large otherwise.
- The risk analysis highlights three particularly high-risk situations:
  - **Crew should remain in the clear**: no operator should find him/herself between the log and the winch (risk of whiplash in case of breaking of the cable), nor downstream (risk of slipping the woods);
  - **Release of the load**: boom movement is prohibited while the operator is nearby. Auto-opening chokers are a solution to be considered for the potential gain generated on the productivity and safe release of the loads;
  - **Winch-assisted tree felling**: for tree that do not require a double winch: a cable in perfect condition is required to avoid accidental failure.

5. Conclusion

The test carried out with the prototype confirmed the interest of this type of accessory. Logs can be hauled on important slopes thanks to its powerful winch, can be handled with the grapple when reaching landing, can be easily steered and released of hung-ups. These sites show that the overall quality of the work carried out with the TVS20 is clearly dependent on the organization of the site and the qualification of the operators.

Moreover, its operational limits are not confined to strict forest operations. Environmental engineering work, such as the maintenance of riparian areas, is a market in which this type of tool can be relevant and would offer entrepreneurs an opportunity to diversify their activities, if necessary. With a modest equipment cost, this new system needs to be tested further, in order to accurately identify its operating costs in an optimized organization. The TVS 20, with its multifunction winch and hub, offers additional versatility to the excavator. It is foreseen to be offered on the market for about **65,000 euros HT excluding cable, grapple and rotator**.

Such an enhanced excavator could therefore carry out four operations:
- creation of infrastructure with a bucket and the blade,
- felling trees with a shear-head,
- hauling timber with the winch,
- handling and stockpiling logs thanks to the grapple.

The up-coming commercial version of the TVS20 is expected to show some improvements, in particular the remote activation of the winch from the cabin and a faster winch speed. This tool, intended for carriers of 14 to 25 tons, is intended to equip excavators outside France.

6. Acknowledgements

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Deadman Anchoring Design for Cable Logging: A New Approach

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ABSTRACT

Cable yarding is still a common system for transporting wood in steep terrain. In the Pacific Northwest, United States, and other regions of high-productivity forestry, reduced rotation ages for harvest have resulted in a lack of large stumps to serve as anchors for cable-yarding systems. One of the most common anchoring alternatives to stumps is buried deadman anchors. Conventional design of this system has been limited to simplified charts that account for soil resistance, as well as both shear and bending resistance, of the deadman, which is typically a buried log. However, these charts are limited to larger deadman anchors of only Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), which are likely not readily available in modern operations. Thus, revised, simplified design charts are proposed that consider a variety of different soil failure mechanisms, as well as several different wood types and bending conditions. An updated approach provides a quantitative perspective towards safe anchoring in modern forest operations.

Theme 7: Harvest Operations Planning

Rationale and Decision-Making in Choice of Effective Timber Harvesting Technology

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ABSTRACT

The global change in forestry has become more complex in the last decades by economic crises and new international environmental policies, which force timber harvesting companies to cut energy intensity and materials resource usage for control of consumptions. Analysis of the above-mentioned ecology and economic concerns, and importance of energy efficiency for timber harvesting systems has been investigated previously. Investigation of these topics with reference to indicator of productivity achieved numerous benefits during implementation of energy efficiency measures, such as structure optimization of a production process and reduction of negative impact on forest ecosystems. Therefore, energy efficiency has become critical for timber harvesting competitiveness, because it is considered as a key driver to development of sustainable forestry.

The purpose of this research is to present a common approach with set of tools for overview and usage. In particular, our results aim to become starting point in the development of more comprehensive and universally accepted set of manufacturing indicators relevant to sustainable development of forestry at national and regional levels. It is known that no set of manufacturing indicators in forestry can be final and definitive. As a result, indicators must evolve over time to fit specific actual conditions, priorities and capabilities of specific forestry enterprise.

The methodological aspects of justification in selection of timber harvesting technology take into account natural and climatic data, known technologies, and production conditions of forestry enterprises. The thematic goals, methodologies, guidelines and manufacturing indicators presented in this research are generalized and reflect experience of scientists and practitioners in various countries. This research assessed and compared timber harvesting techniques, widely used by local forest users with alternative and improved harvesting.

Different approaches to select the best options technologies have been developed for timber harvesting, including simulative and analytic approaches, which rely on multi-criteria decision analysis. This case study shows that analysis of energy efficiency is effective tool to assess, rate, and subsequently integrate in design of timber harvesting technology. The approach, which was presented in this research, based on energy efficiency indicators of timber harvesting technology for sustainable development of forestry.

Keywords: timber harvesting technology, energy efficiency, manufacturing indicators, forestry

Representation and Analysis of Logging Operation System by Queueing Theory

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ABSTRACT

A logging operation system consists of multiple work elements. Since these work elements affect each other, it is important to make them work well together in order to achieve efficient logging operations.

There is a model called the queueing model that is used to analyze jobs in the service industry and in computers. The queueing model analyzes the waiting time for each job by specifying the arrival time and processing method of the job. In the input of the queueing model, both deterministic and stochastic cases can be used, and uncertainty in the logging operation system can also be represented. A network of multiple queueing models as nodes is called a queueing network.

In Japan today, the log production is often carried out by means of a working system consisting of multiple small vehicle machines with closely spaced working roads, and it is especially important to keep the connections between the processes running smoothly.

In this study, the logging operation system is represented as a queueing network in which each work element is a queueing model. First, taking a standard logging system in Japan as an example, we mathematically determined the conditions under which the queueing network would be stable, and examined the implications of these conditions for the actual system. Then, assuming a specific forest environment, we considered the situation in which the above logging system satisfies the stability conditions, and at the same time, we examined the identification of bottlenecks in the entire logging system.

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An Efficient Decision Support Tool for Forwarding Operations

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ABSTRACT

Efficient forwarding is a key for high productivity in forest harvesting within the cut-to-length system. Planning the wood extraction on a clear-cut is a demanding task with multiple choices of route order, number and types of assortments included in a load, and how to organize the piles of assortments at the landing. It takes several years for new operators to achieve the skills of effective on-site forwarding planning, and there is a high demand for a decision support tool to help planning the work among entrepreneurs and forest companies in Sweden.

The aim of this work was to develop and test a new decision support tool for forwarding operations. Input data needed is the harvester production file, a digital elevation model, a depth-to-water map, eventual no-go areas, placement of landing and technical data of the harvester to use. The trail network is generated from the harvester data when forming a set of routes to pick up all log piles, including specific assortments and volumes. The maximum wood volume for each route is determined by weight or the cross-sectional load area of the forwarder. Up to four assortments can be loaded in one route (while using a separation bar) and a certain load order of assortments is preferred. For example, it is more efficient to put pulp logs (small diameters) at the bottom and sawlogs (larger diameter) at the top, as the mixing of assortments is reduced which will ease unloading at the landing. The route planning is solved by a set covering problem where each route is generated by both a column generation method and heuristic methods. The solutions include, in addition to routes and loading sequences, the organization of assortment piles at the landing and their sizes, depending on the total volume of each assortment.

The tool was tested on a number of clear-cuts (3-10 ha) at a large Swedish forest company, by comparing the results with detailed data from the forwarder production files. The comparison included total forwarding distance and driving time, number of routes and share of routes with multiple assortments.

Economies of Scale in Forest Harvesting Operations

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ABSTRACT

Many challenges exist for the harvest of industrial plantations, and an essential aspect of it deals with the clear-felling practice. In the last decades, there has been an increasing social pressure to reduce clear-felling as one of the strategies to balancing the social, economic, and environmental use of the land. In some countries, this balance has been achieved by new voluntary regulations promoted by certification systems, which involve spatial and size constraints to harvesting.

Despite the significant progress made on forest planning methodologies and solution techniques in recent decades, economies of scale in forest harvesting operations with spatial and size constraints have received little attention. Harvesting with spatial and size constraints has economic consequences for the plantation-based forest industry, which results in strategic or tactical plans with lower harvested volumes, and reductions in the financial value of the forestry state resulting from cutting units being harvested at suboptimal ages.

The dispersion of the harvest in a greater number of units resulting from spatial and size constraints has various operational effects, including higher investment and maintenance costs of the road network and higher establishment and harvesting costs. Regarding the latter, highly mechanized operations are the most negatively impacted on a cost per m3 basis due to the high capital costs involved and the productivity loss of the harvesting equipment due to more frequent relocations per year.

In this study, we analyzed and quantified the impact of spatial and size constraints on the economies of scale of forest harvesting operations in industrial plantations, including harvest decisions of single stands and harvesting, road construction, and maintenance costs. We have developed and tested optimization and metaheuristic-based models to conduct the analysis, using a few hypothetical scenarios and simulated landscapes.

Modeling Approaches for Harwarders in Forest Operations

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ABSTRACT

The two-machine system (TMS) have been dominant in Swedish logging operations for decades, attempts have thou been done with harwarders which integrate the harvesting and forwarding. When choosing between TMS and harwarder, potential to decrease costs is important. The purpose was to analyze and compare the machine systems potential from two tools; an advanced optimization tool (AOT) and a simpler analysis (SA). The analyses were done on a year of final fellings in a forest company region in mid-Sweden, containing information necessary for calculating costs for logging, moving between stands and travelling between the operator's home bases and the stands. The tools were used to analyze the total costs (logging, moving and travelling) for the region when only TMS were available, and the potential to decrease the total costs when both TMS and harwarders were available and number of each system that where needed. Among the differences in approach between the tools, the AOT had matching of supply and demand on several time periods where the SA only had matching on a total supply and demand. The AOT had fictional but specific machine systems, home bases and distances between stands, where the SA had calculations of summed need of machine systems and calculations of travelling and moving based on assumed average values. Differences in the results occurred, which can be explained by the differences in calculation approach, but the main results were that the two tools showed similarities in both potential to decrease total costs when harwarders where available, and distribution of TMS and harwarders. It can be concluded that the AOT is a more suitable tool when its important with a more precise and realistic analysis, and the SA is more suitable tool when the available resources for making the analysis is very limiting. It would be interesting to use the two tools for a large-scale analysis, with more focus on the machine systems potential and also possibilities following technological development such as automation.

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Optimization of Primary Extraction Routes

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ABSTRACT

There is increasing attention improving productivity in forest logging operations while reducing negative impact on soil and water streams. The position of primary extraction routes is crucial in these efforts as it has a huge impact on efficient and sustainable forwarder passages. The DSS Bestway comprises of an optimization model and method, detailed digital terrain model, depth-to-water maps and forest volume from lidar data. The information is supplemented with position of the landing(s), nature and culture conservation sites, and any known unavoidable crossings in the terrain, e.g. streams. The system has been evaluated on two large case studies.

Theme 8: Forest Roads

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Machine Vision Based Water-Logged Area Detection for Gravel Road Condition Monitoring

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ABSTRACT

When assessing forest road conditions, information about water-logged areas on gravel roads brings high practical value. Around these perimeters, lowered binding forces of the construction material can reduce the stability of the road that induces accelerated road damage. Especially, when a road is actively used to access a logging site under humid weather or thawing conditions, road wear can build up fast in these areas and make a further use of the road critical. The location or expansion of water- logged areas is thus commonly orally communicated to enable early action. Alternatively, this information could be automatically detected, offering additional possibilities for a transparent documentation and a parallel localization of the recorded damages.

In this study, a deep learning algorithm was trained to directly detect water-logged areas on forest roads from video and image data collected from a passing vehicles' perspective. As a direct application of existing algorithms, trained for sealed road damage detection on smartphone data lead to varying results, a new damage expression was defined to retrain an existing network for forest use. Next to its application value, the parameter "water-logged area" was chosen due to its high visibility and to overcome challenging light conditions, dirt, branches, and varying grain structures as typical further forest road surface characterizing influences. With the training of a YOLO v5s algorithm under varying light conditions, the training results of up to 264 pictures already showed a moderate mean average precision of 0.319, but a dominating high rate of true positive detections. With these results, the direct implementation of the algorithm in machine vision- based road condition monitoring concepts is possible, but still offers higher potential when considering additional training data, more capable algorithms, or data pre-processing.

Particularly for remote logging sites or to save the information for time shifted restoration planning on already dried-out road conditions, this approach promises direct application value.

Technical Aspects and Costs to Determine the Density of Forest Roads

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ABSTRACT

The density of inadequate forest roads causes an increase in production costs, loss of planting area and environmental impacts, and the analysis of the optimal density of roads considering relief condition, storage capacity and number of machines can support this adaptation. The general objective of the study was to determine the current (RD), optimal road density (ORD) and operational density (OD) in different conditions of land slope for the full tree harvesting system in areas with pine plantations in the South region of Brazil. The method applied was the indirect, through the minimization of the total cost, which included the sum of construction costs and road maintenance, logging, road impact mitigation and loss of planting area. The restriction of maximum wood storage capacity (MSC) in the areas was established, this was analyzed from the rate of use of forest roads and the theoretical storage capacity. In the definition of the OD, the number of extraction machines necessary to meet the annual production demand in different relief conditions was considered, plus the cost of increasing the fleet of machines in the total cost. In general, RD, ORD and OD were higher in the most declining areas and ORD and OD were lower than RD in all scenarios. In the flat areas the RD was 126 m ha-1, the ORD was 53 m ha-1 and the OD was 92 m ha-1. In the sloping areas RD was 180 m ha-1, the ORD was 65 m ha-1 and the OD was 123 m ha-1. All the ORD scenarios had a MSC less than the expected total production volume, while in OD all areas had a CME greater than the expected production volume. Forest road planning should consider the relief characteristics, as they affect road density, as well as the MSC and the ORD, which adapt the planning to local conditions and situations and make it possible to verify the feasibility of implementing the ORD and the real potential for gains in operating costs.

The density of inadequate forest roads causes an increase in production costs, loss of planting area and environmental impacts, and the analysis of the optimal density of roads considering relief condition, storage capacity and number of machines can support this adaptation. The general objective of the study was to determine the current (RD), optimal road density (ORD) and operational density (OD) in different conditions of land slope for the full tree harvesting system in areas with pine plantations in the South region of Brazil. The method applied was the indirect, through the minimization of the total cost, which included the sum of construction costs and road maintenance, logging, road impact mitigation and loss of planting area. The restriction of maximum wood storage capacity (MSC) in the areas was established, this was analyzed from the rate of use of forest roads and the theoretical storage capacity. In the definition of the OD, the number of extraction machines necessary to meet the annual production demand in different relief conditions was considered, plus the cost of increasing the fleet of machines in the total cost. In general, RD, ORD and OD were higher in the most declining areas and ORD and OD were lower than RD in all scenarios. In the flat areas the RD was 126 m ha-1, the ORD was 53 m ha-1 and the OD was 92 m ha-1. In the sloping areas RD was 180 m ha-1, the ORD was 65 m ha-1 and the OD was 123 m ha-1. All the ORD scenarios had a MSC less than the expected total production volume, while in OD all areas had a CME greater than the expected production volume. Forest road planning should consider the relief characteristics, as they affect road density, as well as the MSC and the ORD, which adapt the planning to local conditions and situations and make it possible to verify the feasibility of implementing the ORD and the real potential for gains in operating costs.

Forest Roads Optimization: People, Processes and Tools

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ABSTRACT

Klabin S/A has more than 11,000 km of forest roads to manage in its productive and environmental protection area. There is a tradeoff between reducing the number of roads and increasing the production area, and increasing operating costs for logging. The project aimed to reach the optimum point between reducing tertiary roads, increasing production areas and meeting operational and environmental restrictions. Two other factors influence to revise this equilibrium point: change in the profile of forests (less volume for sawmills, replaced by greater volume for pulp process log) and new harvesting machines, so that it is possible to reduce roads without impact on the operation. The following criteria were taken into account: road density, average machine extraction distance, amount of wood available on gravel roads, slope and type of soil. Three training sessions were carried out involving 150 employees in the operational areas (roads, harvesting, transportation) and support (planning, research, environment) and software for the optimization of forest roads was developed, called KplanR, which considers the physical, environmental, technical and financial factors for the generation of more than 80 indicators that, through simulation of scenarios, supports decision making with a high level of technical analysis for the planners decision making. The

project is in its fourth year and presents excellent results such as reducing the density of roads by 30m ha-1 year-1 and converting 200 ha year-1 of tertiary roads into areas available for planting, thus helping the company to gain productive area, reduce risks of erosion and silting, without jeopardizing the wood harvesting operation.

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Forest Road Availability - Inferences from Logging Truck Delivery Messages

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Keywords: weather conditions, bearing capacity, light weight deflectometer, rut development

EXTENDED ABSTRACT

1. Introduction

In the Nordic countries, harvesting and transport have historically utilized both winter frost/snow and summer dry periods to gain access to areas of low bearing capacity. Recent trends of increasing temperatures require, therefore, further development of supply planning processes for maintaining even year-round wood supply. New methods are needed to track forest road availability based on actual weather conditions.

The seasonal availability of forest roads in non-industrial forests is most often unclassified in road databases. Transport planning is therefore often based on the experience of transport managers or local transporters. This study aimed to capture general trends for road availability and link these to bearing capacity via commonly available data sources. The first goal was to capture seasonal trends for forest road use based on logging truck delivery messages (part 1). The second goal was to link the general seasonal trends to measured bearing capacity for selected road characteristics (part 2).

2. Approach

Part 1 – Tracking seasonal availability. For the first part of the study seasonal availability was tracked in two regions (coastal and interior Norway). The data consists of 100 000 transport messages per region over three annual cycles. Message dates and landing coordinates were joined to corresponding weather and road network data (quaternary surface deposits and DTM-based variables).

Transport messages were joined with weather data per climate and elevation zone (weekly snow depth, precipitation, and temperature). A simple research question was formulated; "For the given weather conditions, which forest road type did the weekly volumes originate from?". Transportation volumes were tracked per main deposit type (5-6 of 14 NGU codes in the data), all of which have associated texture and water infiltration characteristics. The main infiltration groups range from fluvial deposits (codes 20, 50), moraine deposits (codes 11, 12) and marine/fjord sediments (code 41) as well as organic materials (code 90).

The availability tracking focused on the frost-free periods which are most critical for maintaining the pace of wood flows. The availability trends characterize how varying bearing capacity was exploited to balance flows between seasons; either by necessity (only feasible options during difficult weather conditions) or opportunity (acceptable options during advantageous conditions).

Part 2 - Linking road characteristics to bearing capacity. Since information on road-specific characteristics in part 1 was limited to digital sources (surface deposit maps and DTM-based variables), part 2 examined the variation in bearing capacity associated with selected road characteristics. 280 road sections were sampled during the frost-free season after recent transport operations across both coastal and interior zones. Bearing capacity was estimated in MPa with a light-weight deflectometer (Zorn 3.0 10 kg) at three points per cross section (uncompacted middle sone and in each wheel track). The road cross sections were laser-mapped at 10 cm intervals across a horizontal 5 m beam. Rutting area per cross section was calculated in relation to the line from the road mid-point to the nearest unvegetated shoulder outside of each wheel track.

Section bearing capacity and rutting were then joined with the transport volumes from the most recent operation, surroundings (slope position, vegetation, drainage), planum information (surface deposit code, soil texture class, DTW) as well as data on the bearing and surface layers (thickness and material type).

3. Results

Part 1 – Tracking seasonal availability. Six surface deposits were represented in each region (11=thick moraine, 12=thin moraine, 20=glacio-fluvial deposit, 41=ocean/fjord sediment, 50=fluvial deposit, 90=peat). Transport volumes from the coastal region had a higher proportion of sediment sites (41) and fluvial deposits (20, 50). Volumes from the interior region were dominated by moraine sites (11, 12). In both cases the proportion of sediment (41) and fluvial (50) deposits was highest at lower altitudes. Three climate zones were represented in each region (coast: inner coast, mid, outer, interior: lowlands, midlands, highlands) with weekly tracking of temperature, precipitation and snow depth. For the coastal region precipitation was highest on the outer coast and winter snowpack was deepest in the inner coast. For the interior regions both precipitation and snowpack were highest in the highlands.

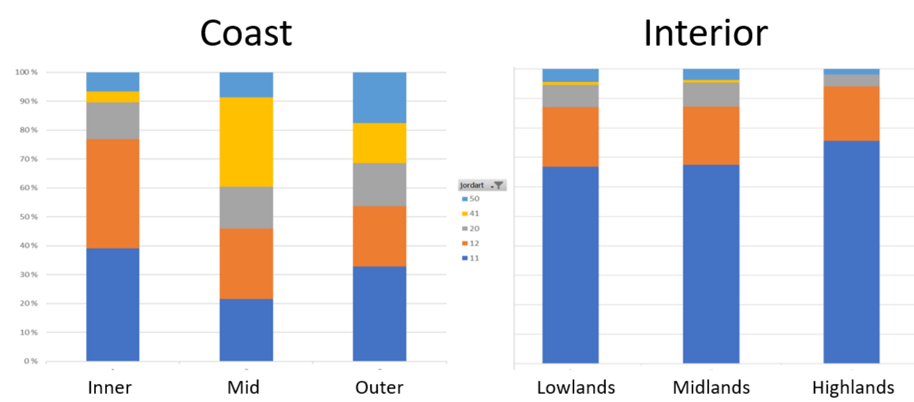

Figure 1. Distribution of transport volumes across surface deposit types with each region and climate zones.

Seasonal transport pace was tracked per week number and aggregated per season (1: spring equinox to easter, 2: easter to summer solstice, 3: midsummer to fall equinox, 4: fall equinox to winter solstice, 5: winter solstice to spring equinox). The relative transport pace (RTP) was calculated as the proportion of the annual transport volume delivered per week for the respective surface deposit types (per climate zone). The relative transport paces were then compared between surface deposit types to rank their utilization during the respective seasons (1-5). The relative transport pace is assumed to infer seasonal availability.

Multivariate principal components analysis (PCA) was used to identify general weather trends for availability. The first principal component (PC1) captures the extremes of the seasonal cycles with an anti-correlation between snow depth (+0,66) and temperatures (-0,63), as well as the correlation between deep snowpack/low temperatures and high transport paces from glacio-fluvial sites (20; +0,3). After having taken this into consideration, the second component (PC2) captures the anti-correlation of transport paces between friction and cohesion deposits (low pace for 11, 12, 20 when there is a high pace for 41) associated with periods of lower precipitation (-0,22). The third component (PC3) captures remaining variation with correlations between reduced precipitation (-0.48) and increased transport pace from thin moraines (12; +0,53) and sediment deposits (41; +0,25) as well as reduced transport pace from fluvial deposits (50; -0,55) and thick moraines (11; -0,28)

Table 1. PCA analysis of weekly weather data and relative transport rates from the respective surface deposit types.

	PC1	PC2	PC3
Temp	**-0,625**		
Precip		-0,224	**-0,479**
Snow	**0,661**		
11		**-0,455**	-0,279
12		**-0,507**	**0,532**
20	0,299	-0,284	
41		**0,599**	0,246
50			**-0,549**

For the mid zones (coast: mid-coast, interior: midlands) the surface deposits with the highest ranked transport paces are presented below.

Table 2. The highest ranked surface deposit types per season (1-5) according to their respective transport rates. Mid-coast and mid-interior climate zones.

Season	Surface deposit type with highest transport pace (RTP)	
	Coast (mid)	*Interior (mid)*
1. late winter/early spring	Ocean/fjord deposits (41)	Glacio-fluvial deposits (20)
2. spring/early summer	Fluvial deposits (50, 20)	Ocean/fjord deposits (41), fluvial deposits (20, 50)
3. late summer	Moraines (11, 12)	Moraines (12, 11)
4. autumn	Moraines (11, 12), glacio-fluvial deposits (20)	Moraines (12, 11)
5. winter	Ocean/fjord deposits (41)	Glacio-fluvial deposits (20) and thick moraines (11)

In the coastal region, ocean/fjord deposits (41) had the highest ranked transport paces in winter and early spring. For fluvial deposits the highest transport rates occurred during spring (50, 20) and autumn (20). Moraines were highest ranked during late summer (11, 12) and autumn (11, 12). In the interior region moraines had high rankings throughout late summer (12, 11), autumn (12, 11) and winter (11). Fluvial deposits were highest ranked during winter (20) and early spring (20), but even spring/early summer (20, 50).

Part 2 – Linking road characteristics to bearing capacity. A correlation matrix between all variables showed that road section rutting was best correlated with mid-road e-module (+0,308 p=0,000). Mid-road e-module was best correlated with mid-rut e-module (+0,766 p=0,000). The difference between the uncompacted mid-road compacted mid-rut e-modules was negatively correlated to the mid-road e-module (-0,321 p=0,000).

Mid-road e-module was primarily correlated to bearing layer material (-0,393, p=0,000) and surface layer material (-0,377 p=0,000). A general linear model analysis of mid-road e-module explained 27 % of variation with surface deposit and bearing layer types (n=150 road sections). The estimated single effects are shown below.

Table 3. General linear model effects of surface deposit types and bearing layer materials on mid-road e-module (MPa).

	Intercept	Surface deposit effect				Bearing layer material effect			
		11	12	20	41	1	2	3	4
E-mod (MPa)	37,6	-1,52	+0,83	+7,16	-6,47	+15.24	-3,92	-4,01	-7.31

The estimated e-modules were then grouped in 4 classes (1; <20 MPa, 2; 20-40 MPa, 3; 40-60 MPa, 4; > 60 MPa). Their corresponding distributions of surface deposit, bearing layer and surface material types are shown below.

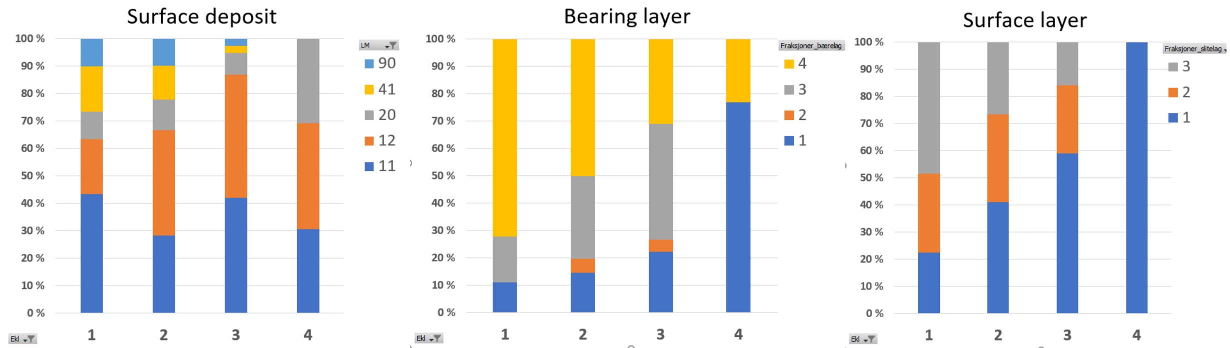

Figure 2. Distributions of surface deposit types (left), bearing layer material (middle) and surface layer material (right) for 4 classes of e-module (1; <20, 2; 20-40, 3;40-60, 4; >60 MPa).

The highest e-module classes had lower proportions of peat and ocean/fjord deposits (90, 41) up to 60 MPa and higher proportions of glacio-fluvial deposits (20) for over 60 MPa. With respect to bearing layers, the highest e-modules had a reduced proportion of unsorted gravel (4) and increased proportions of sorted gravel (3; up to 60 MPa), and crushed rock (1; above 60 MPa). With respect to surface layers the highest e-module classes had reduced proportions of sorted or crushed gravel (3/2) and increased proportions of crushed rock (1).
There was considerable variation in individual observations of mid-road e-module. However, class averages for e-module (0-20, 20-40, 40-60, 60-80, >80 MPa) and traffic volumes (<1000, 1000-1500, 1500-2000, >2000 m3) explained 79 % of variation in rut area development.

4. Concluding remarks

The study provided estimates of forest road bearing capacity with corresponding rut development and linked these to selected road characteristics (surface deposit type and bearing layer material). While there is much unexplained variation between single observations, the trends were as expected. The bearing capacities of the respective surface deposit types from Part 2 are consistent with the observed seasonal transport rates from Part 1. The observed transport rates, however, are also a result of the scheduling of harvesting operations in relation to terrain bearing capacity.
The availability trends from Part 1 characterized, therefore, how varying bearing capacity was exploited by both harvesting and transport managers to balance flows between seasonal variations in soil moisture. Soil moisture states typically range along a gradient between spring thaw, late fall rains, typical summer conditions and early summer drought. Utilization of different areas was managed either by necessity (e.g. glacio-fluvial areas for spring thaw or fall rain) or opportunity (e.g. ocean/fjord sediments during early summer drought). The utilization patterns, however, varied considerably between regions. This is driven by the respective distributions of transport volumes across surface deposit types (e.g. high proportion of volume from moraine areas in the dry interior vs. high proportion of ocean/fjord sediments in the warmer and wetter coastal conditions).

Forest Road Costing Tools

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EXTENDED ABSTRACT

1. Introduction

Forest roads are an essential part of forest harvesting operations. Their location and construction have significant impacts on harvest efficiency, environmental impact and operational costs. The complete process related to a forest road's life is one of the costliest in forestry activities (Picchio et al, 2018).

The estimation of cost for construction of low-volume forest roads is a complicated and challenging task, complicated by topography, geotechnical conditions, machinery used, and special design requirements (Layton et al, 1992). There are many methods for costing forest roads which range from coarse, fast approximations to detailed, time consuming estimates. Typically, planners are required to sacrifice cost estimate accuracy for speed or vise versa. Although this estimation technique is easy, it is a very rough estimate. It overlooks the true construction costs which are based on earthwork, material movement, and surfacing costs.

In partnership with University of British Columbia, Okanagan campus, Softree has developed "Design Time Costing", a toolset within RoadEng software which allows forest engineers to quickly and accurately calculate sub-grade construction costs for roads (Hare, 2012).

In the accompanying oral presentation, Softree explores current costing models, presents benefits derived from using design time costing capable software and discusses future areas of costing model research.

2. Current Costing Methods

To support a better understanding of current costing models, Softree conducted a survey of forest road engineers (*N*=32) to determine their costing and road construction payment methodologies.

As shown in Figure 1, when asked "Which of the following costing methods do you predominantly use?" 66% of respondents replied by indicating that they calculate their road costs by average cost per length of road or average cost per length by a ground category (slope, bank height).

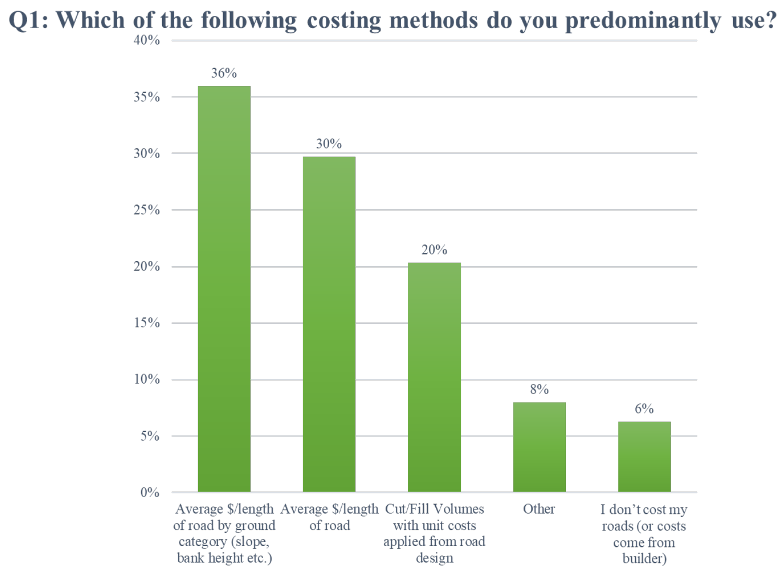

Figure 1: Responses to Costing Method Survey Question

As shown in Figure 2, when asked *"How do you most often pay your contractor for your road building?"*, only 9% of respondents utilize excavation volumes for calculating payment to their contractor.

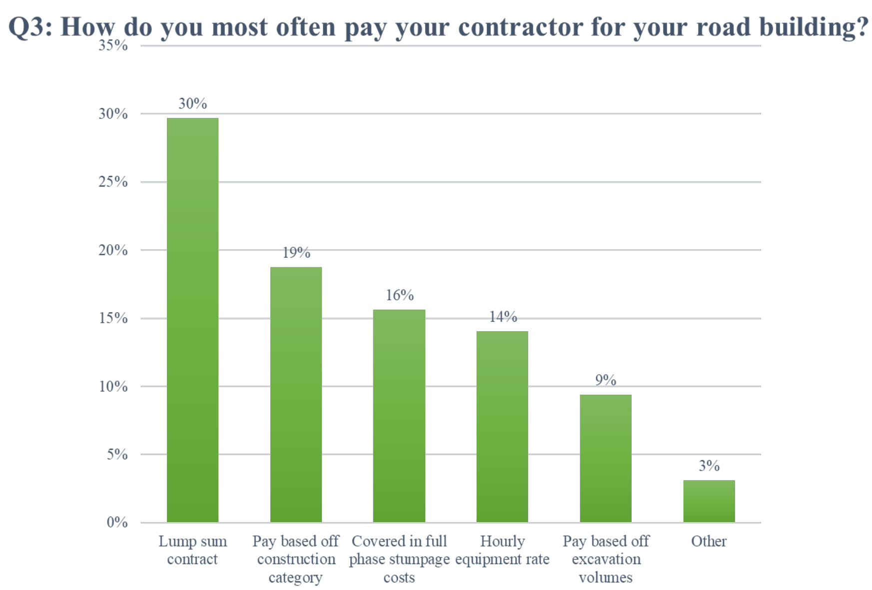

Figure 2: Responses to Road Building Payment Survey Question

3. The Challenge with Current Costing Models

In 1983, Thomas A. Ourston & Fong-Li Eh Ou identified a need for a method for estimating road construction costs with higher accuracy and less time commitment (Durston & Ou, 1983). However, based on the results of Softree's 2021 survey, industry has not moved in this direction.

The benefits of these average cost per length methods are that they are quick and reasonably easy to estimate costs. Their downfall is that they do not account for details that can have a large impact on costs.

Costing challenges can be easily demonstrated when comparing costing methods for two design options of the same short length (360 m.) in the same terrain, as visualized in Figure 3, below. Using the two most common methods as identified by Softree's 2021 survey, cost per length of road and cost per length of road by a ground category, these two roads would have been cost identically. Using a more detailed costing method based on earthwork quantities, there is a difference of ~300 cu.m of material, or roughly 30 truckloads.

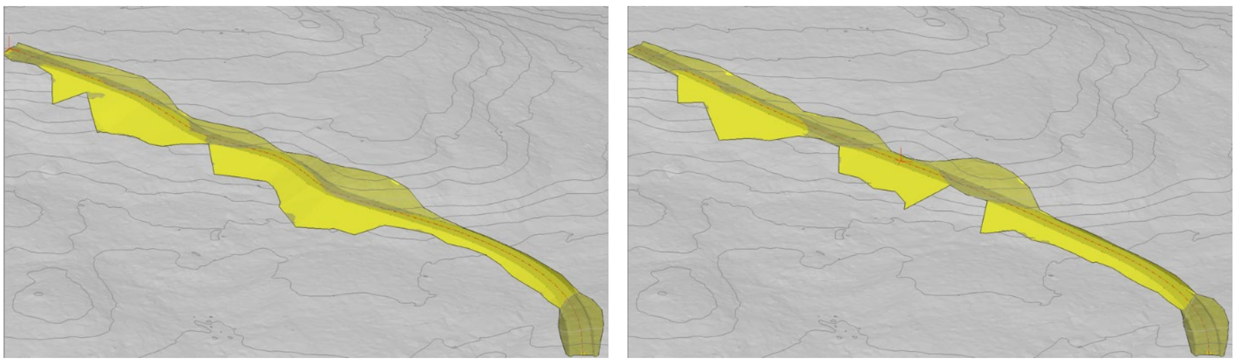

Figure 3: Different designs in same location producing very different earthwork quantities.

4. New(er) Approach

Design time costing functionality was first introduced to support alignment optimization. It accounted for subgrade earthworks (cost per unit volume) and movement costs (cost per volume and distance travelled).

Design time costing has evolved over the last 5 years and now includes:

- material movement direction constraints,
- material quality parameters,
- borrow sites, spoil sites, and side casting,
- the inclusion of other materials such as surfacing aggregate and riprap
- other user defined costs (such as culvert costs).

A flexible and easy to use costing tool allows planners to quickly evaluate existing and proposed road networks. As a result, road planners can minimize road construction costs and can evaluate the feasibility of projects early in their planning process.

5. Conclusion & Future Work

Using Design Time costing within geometric road design software presents advantages not possible with more simplified methods, including:

- Better understanding of cost drivers within a project
- Better evaluation of the risk and feasibility of a projects
- Understanding of cost impacts from design decisions
- Capability to optimize earthwork movements in the vertical alignment (profile) design

Other areas of future improvement and refinement includes mobilization costs for special equipment required to deal with specific construction techniques (such as drill and blast construction), evaluation of material movement over a road network, the calculation of road costs over the lifetime of a road (road operating costs), and the ability to assign costing parameters by polygon to further streamline evaluating many alignment options.

6. References:

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The Effect of the Triangulated Irregular Network on Solutions in Forest Road Network Layout Planning

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ABSTRACT

In this paper, we inquire into whether the use in the optimization of forest road network layout on a large dataset (> 100 thousand ha) of triangulated irregular network versus regular network can reduce the two main costs (road construction and timber transportation) and the solving time. In contrast to regular, triangulated networks have not yet much been used in the optimization of forest road network layout. The use of regular network complicates finding the optimal layout for large areas, since without additional preprocessing it will have the same number of edges between the nodes regardless of the terrain relief, and as a consequence it will be characterized by a large number of edges. Therefore the use of triangulated network which nodes can be placed over a surface irregularly, allowing a greater number of edges in those areas where the surface is highly variable, and a lower number of edges in areas with a homogeneous surface, will reduce the total number of edges and potentially reduce the solving time by reducing the feasible region. We created regular and triangulated networks using ArcGIS geoprocessing framework, taking into account the same spatial data (DEM, watersheds, forest loss areas, etc.). Triangulated datasets were generated using the Delaunay triangulation of random scattered points. The inquiry is conducted by using the authors' hierarchical method of solving the optimal forest road network layout mixed integer model. Four datasets were solved: regular network with 16 links of 250K nodes and 1.15M edges; triangulated networks with different density of nodes: 0.5 points per ha with 70K nodes and 210K edges; 1 point per ha with 140K nodes and 420K edges; 2 points per ha with 280K nodes and 840K edges. Datasets are available in the MendeleyData repository as «Dataset: Podporozhye». The results show that the use of triangulated networks with significantly fewer edges versus a regular network, yielded solutions with comparable objective function values (total road construction and timber transportation costs) on large datasets. In addition, triangulated networks allowed us to reduce the solving time. The results obtained have demonstrated the feasibility of using triangulated networks in the optimization of forest road network layout over large datasets.

Theme 9: Log Transportation

Technical-economic analysis of an in-motion weight measurements system applied to wood transportation in Italy

Stefano Grigolato, Stefano Montibeller, Stefania Minati, Raffaele Cavalli

Towards Better Environmental Performance in Timber Trucking with High Capacity Transports (HCTs) in Finland

Kalle Kärhä, Emma Kortelainen, Antti Karjalainen, Hanna Haavikko, Teijo Palander

Automated volumetric measurements of truckloads using sensing technology, computer vision, and artificial intelligence

Borja Garcí¬a-Pascual, Mauricio Acuna

A common Nordic-Baltic costing framework for road, rail and sea transport of roundwood

Dag Fjeld, Kari Väätäinen, Henrik von Hofsten, Daniel Noreland, Ingeborg Callesen, Andis Lazdins

Cost analysis of timber transportation using pgRouting

Laddawan Rianthakool, Wanchai Arunpraparut, Piyawat Diloksumpun, Nopparat Kaakkurivaara

Timber transport planning for forest trucks and semi-trailers

Peter Rauch, Christoph Kogler, Alexander Stenitzer

Stakeholder Perceptions of Potential Weight Limit Increases in Georgia, USA

Joseph Conrad

Comparison of Log Truck Crash Rates, Severity, and Contributing Factors Before and Weight Limits Increases in Two Southern States, USA

Joseph Conrad

Technical-Economic Analysis of an In-Motion Weight Measurements System Applied to Wood Transportation in Italy

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ABSTRACT

The exposure and vulnerability of European forests to extreme natural events is exponentially increasing. In the case of large damaged areas, the wood price immediately dropdown. As a consequence to reduce organizational costs, high efficiency on harvesting, transport and wood measurement is fundamental.

In October 2018 in the norther-eastern part of Italy, more than 8 million cubic meters were windthrown by the Vaia storm. One of the largest damaged forest accounts in one area more than 250000 m3 of windthrown trees.

One of the main constrain is the accounting of the extracted and sold wood volume. In particular, the need to change from a traditional manual measurement system (hand-held caliper) to an automated or semi-automated system immediately emerged. In the Italian context of the Alps, in fact, wood lots are common of an average size of fewer than one thousand m3 per site. Following the Vaia storm, wood lots become abnormally larger and the measurements of the timber extracted and sold reached values even higher than 30 thousand m3 per site. As a consequence, daily wood volumes were not suitable to be accounted with the traditional system based on caliper measurements of each single logs or with stacked volume estimation (in piles or in loaded vehicles)

An alternative method to volume measurement is based on the mass measurement and the identification of the factor to convert mass to volume. Weight data can be obtained from static or in motion vehicle measurements.

This study presents the analysis of in-motion weight measurements application able to measure automatically the weight of trucks transporting wood. In this study, the measurement site represents also the only access to the area. As a consequence, it has been possible to obtain for each vehicle data about unloaded and loaded weight, type and configuration, number of axles, the time of entering and exiting from the area and the contractor.
Data collection concerns a monitoring time of 13 months and a total of 120 000 cubic meters of transported wood.

The technical-economic analysis highlights the advantage of using this system in term of organizational costs. The break–event point with respect to the traditional system based on caliper measure of each single log corresponds to 10000 cubic meters per year to be measured and on 30000 cubic meters per year in case of volume measurements of stacked wood in piles.

Towards Better Environmental Performance in Timber Trucking with High-Capacity Transports (HCTs) in Finland

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ABSTRACT

In 2018, a novel HCT timber truck with a maximum gross vehicle weight of 92 tonnes was introduced in Finland. This 92 t HCT timber-truck combination consists of a truck and a normal timber trailer with five axles equipped with a fifth wheel at the rear of the trailer, in addition to a semitrailer with three axles. Currently, there are no published studies in which the fuel consumption of the 92 t HCT timber truck has been inspected in a long-term follow-up study. In this environmental performance study, the fuel consumption (in l/100 km, l/t and ml/tkm) of the laden 92 t timber truck was measured and compared to the performance of the normal 76 t timber truck. In addition, fuel and CO_2 emission savings, as well as potential resulting cost savings, were calculated for a future scenario where HCT (92 t) timber trucks are commonly utilized instead of normal (76 t) trucks in timber trucking from terminals to mill yards. The data was collected by a long-term follow-up study in 2019 and 2020. In total, 961 industrial roundwood payloads were transported with the 92 t truck, comprising 62,426 tonnes of timber. With the reference 76 t timber truck, the study data totalled 125 payloads and 6,374 tonnes of timber. The results revealed that the fuel consumption (in ml/tkm) of the laden 92 t timber truck is around 10% lower than that of the 76 t truck over transport distances of 100–300 km. Moreover, the calculations showed that there is a huge potential to achieve fuel and CO_2 emission savings using HCT trucks. Based on this study, it can be recommended increasing the number of energy-efficient HCT trucks in timber trucking. Consequently, lower fuel consumption and CO_2 emissions and higher environmental efficiency in roundwood transport can be achieved.

Keywords: timber truck, larger and heavier vehicles (LHVs), fuel consumption, greenhouse gas (GHG) emissions, energy efficiency

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Automated Volumetric Measurements of Truckloads Using Sensing Technology, Computer Vision, and Artificial Intelligence

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ABSTRACT

Given that wood accounts for about 1/3 of supply cost from forests to mills, it is critical to adopt correct measurement procedures and technologies that provide better volume estimates of logs on trucks and piles. Also, manual measurements of stacked logs at the roadside or on trucks are time-consuming and labor expensive, while inaccurate measurements impact the revenue obtained by haulage contractors and forest companies. Although laser scanning has become a mature and more affordable technology in the forestry domain, it remains expensive to adopt and implement operationally. Consequently, sensing technology such as RGB and stereo cameras and computer vision, and artificial algorithms have been developed and implemented as alternatives to laser scanning-based solutions.

In this research, we developed and tested two automated systems to estimate volumetric measurements of truckloads. In the first study, we tested multi-view photogrammetry and 3D image processing software to estimate the solid volume of pulp logs on Eucalyptus nitens truckloads. We investigated the accuracy in solid volume estimates obtained with photogrammetric and 3D reconstruction algorithms compared to manual methods. We proposed pipelines and guidelines for the implementation of this technology in operational conditions. Our preliminary tests show that over 85% of the variance in solid volume can be explained by the gross volume estimated with our automated approach. More tests will be conducted to validate and confirm these premilitary results.

In the second study, we tested a Convolutional Neuron Network (CNN) to detect Pinus radiata logs on trucks. Specifically, we implemented a Deep Learning (DL) algorithm in the Python language, named Mask R-CNN, to detect and identify faces (masks) of logs on trucks, which will be the basis to estimate log diameters and volumes in a subsequent phase of this project. The original data set included images from 135 truckloads (~300 logs), with different orientations, illumination, and resolution. Before training the DL models, the images were pre-processed and augmented, which resulted in a final set of 418 images. About 80% and 20% of this data set was used to train and validate the DL models, respectively. Our preliminary results show that over 95% of the log faces were detected during inference, with errors in the face area of less than 1%.

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A Common Nordic-Baltic Costing Framework for Road, Rail and Sea Transport of Roundwood

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EXTENDED ABSTRACT

1. Introduction

Transport cost calculations are fundamental for most types of transport research. Applications can range from estimating the cost benefits of developing transport technologies (e.g. increased truck GVWs) to comparing profitability between alternative infrastructure investments (e.g. rail or sea terminals). Many stakeholders rely on a favorite spreadsheet, however these vary considerably with respect to functionality, resolution and transparency. During 2019 and 2020 the NB Nord Road and Transport group has worked towards a common Nordic-Baltic costing framework for road, rail and sea transport. The goal has been to propose a general model per transport method which is user-friendly, while retaining the necessary resolution and functionality to model actual costs for specific transport orders or contracts. The project report provides: a) complete explanation of formulas, b) calculation examples and c) a corresponding Excel spreadsheet.

Because all roundwood starts its journey by truck, most of the effort has been directed towards road transport and this framework has the highest resolution. In contrast to many machine costing models which treat value depreciation as a fixed annual cost, the timber trucking model treats depreciation as a variable cost following the assumed wear of the main components (truck, trailer, loader) over their respective lifetimes, either in terms of distance driven or loads handled. As work progressed towards multimodal solutions, model resolution was reduced while still reflecting the relevant principles. Both road and rail frameworks model average resource costs over their assumed lifetimes, without the use of discounting associated with investment analysis. The modelling of resource costs is even simpler for the shipping model, where time charter rates provide representative capacity costs for the respective markets.

Validation of the respective models was done underway by comparison of calculated costs against current market prices for specific cases. As deviations were found, the models were re-evaluated and modified to better reflect the specified conditions. Each chapter also provides sources and examples for input data. The report concludes with an appendix of the corresponding spreadsheet models where the effects of key factors can be used to project future cost development scenarios.

This paper provides an introduction to the approaches followed in the framework and their assumptions. The approaches were developed to mimic the pricing structures used in the region. For the complete examples we refer to the publication and corresponding spreadsheets (report link https://nibio.brage.unit.no/nibio-xmlui/handle/11250/2723839 , spreadsheet link http://urn.fi/URN:NBN:fi-fe202101151893).

2. Costing framework for truck transport

The model is aimed at calculating the annual operating costs of timber trucking and provides performance indicators such as annual working hours, loads, transported tons of timber, driven distance etc. The user defines transport assumptions in order to compare alternative operating scenarios and their effects on costs. The model considers load and road dependent values both for fuel consumption and driving speed as well as the proportion of back-haulage. The cost accounting model includes two types of annual accounting:

A. Cost accounting with the average transport distance (traditional accounting model)

B. Cost accounting with a distribution of transport distances

The timber truck combination in the NB Nord area typically consists of a truck, full trailer and a self-loader, each defining separate investment prices (Figure 1). The payload (timber) is defined in metric tons, which is the most common pricing unit for the entrepreneur. Payload capacity can be calculated by deducting the tare weight from the gross vehicle weight. However, the average payload is generally smaller than capacity due to varying timber dimensions and fresh weight densities. Snow and ice buildup during wintertime also reduces the available load as does retaining the self-loader on-board.

Figure 1. Typical Nordic timber truck combination consisting of the truck, full trailer and self-loader.

The logic of the traditional costing model (a) is to insert and define the representative operations environment, set the values for costing indicators and then calculate the annual costs of trucking. The costs are representative for the given conditions and average transport distance of the year. Alternatively, the optional transport distance distribution model (b), calculates the cost indicators specifically for each transport distance class. For this option, the same operations specific factors are required as for the traditional costing model. However, these factors need to be inserted to each distance class (e.g. 50 km, 100 km, 150 km, etc).

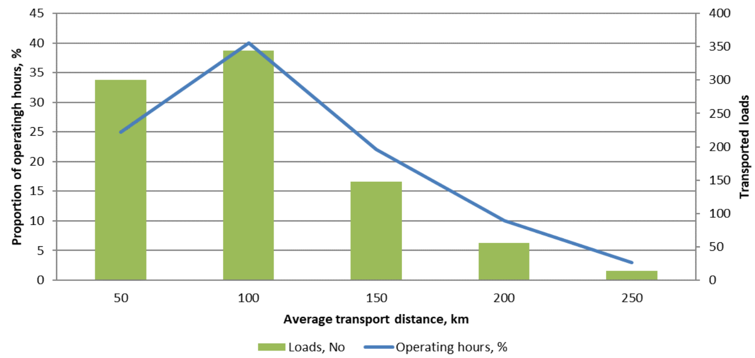

Figure 2. Example of the proportion of operating hours and loads (y-axis) for each distance distribution class (x-axis).

Costing scenarios can also be compared to case-tariffs (market prices) so profit per loads, distance class and year can be estimated. The traditional annual costing model was used to compare examples of average trucking costs between participants as a function of payload (Figure 5). The cost trend between the examples follow the variation in payload between Norway, Denmark, Sweden and Finland.

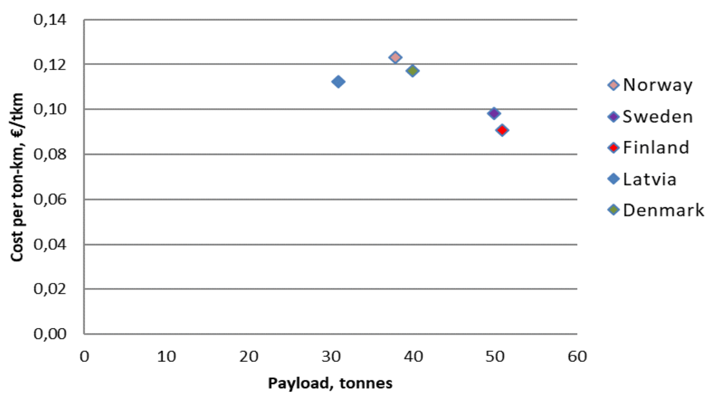

Figure 5. Examples of timber trucking costs (€/tkm on y-axis) and payload (t on x-axis) for test cases calculated with the common framework.

3. Costing framework for rail transport

Pricing for rail transport of roundwood normally assumes a system solution for mill deliveries according to a regular weekly schedule. Pricing is generally set through a tendering process between rail operator companies. A typical pricing mechanism consists of both a fixed annual price component for holding the necessary capacity dedicated to the system, and a variable price component for the exact transport volume and output delivered.

The costing of rail system solutions can become more complex as the number of resources used increase. Investment levels are higher and equipment lifetimes longer so both interest and depreciation were defined as fixed annual costs where high resource utilization is a key for minimizing the fixed costs per transported unit. The framework provides a simple calculation example for a fully electrified system running from multiple terminals (A, B, C) to the one mill. The calculation is done in three steps; 1) transport volumes and cycle scheduling, 2) annual fixed costs and 3) annual variable costs.

The cost calculations concern only the contracted freight work. Additional costs for the service buyer such as terminal infrastructure and handling are added later. For a system rail solution with high utilization rates, annual fixed costs include capital costs for all system resources as well as their regular maintenance programs. Annual variable costs are driven by operating hours, driven km and gross transport output (tkm). In the case of a larger rail operating company, locomotive engineers can be allocated to alternative systems, and are therefore defined as a variable cost.

Depending on pricing mechanism agreed in the tender, the tables above provide a cost base for pricing before the profit/risk margin has been added. Typically the periodic billings include the fixed price for holding the dedicated resources and the variable price for actual tonnage moved per period from the respective terminals. Terminal and handling costs at each end of the cycle must be added before the system cost is complete.

4. Costing framework for short-sea shipping

Pricing for short-sea shipping of roundwood is typically contracted in two ways; contract of affreightment (COA) or SPOT (individual voyages). COA pricing is most common and regulates an agreed volume per assortments between specified ports of loading (PoL) and -discharge (PoD). The freight rate (€/transported unit) is agreed between the charterer and the Owner/Operator (based on transport and loading conditions specified in the charter party with mutually agreed terms/conditions) with adjustment according to bunker price clauses and freight indexes for multiple years' contracts.

Mini-bulk vessels (length 70-120 m, beam 12-17 m, draft 5-7 m) are commonly used for short-sea shipping of roundwood in the sheltered coastal waters of northern Europe. These vessels typically carry cargoes of 2 000 – 6 000 m^3sub over distances of 100-1 000 nm (nautical miles). The vessel capacity used (< 10 000 dwt) varies between regions distances and seasons. For roundwood transport, maximum volume is generally reached before deadweight carrying capacity (dwt). Solid volume factors (m^3sub/hold volume) are therefore more convenient for calculating cargo volumes than stowage factors (hold volume/t). During typical summer conditions shallow draft/wide beam vessels allow access to shallow harbours and larger deck loads (extra 20-30 % on deck). For longer winter voyages larger ice-classed (SF1a) vessels are often used to provide more stable deliveries, but with reduced deck loads.

COA freight rates (€/m^3) can be estimated using a time charter (TC) approach. Time charter rates specify the given price (TC_{hire}) for a charterer's use of a vessel including crew and maintenance work (normal wear and tear). This bypasses the need for calculating capital costs, and links directly to actual market prices which fluctuate with available capacity. The total voyage cost includes the vessel cost plus bunker fuel, port, fairway and canal costs. In practice, freight rates also depend on the availability of alternative cargo flows in the region to reduce the distance without cargo (ballast) from PoD to the next PoL. The publication includes a general overview of the most common shipping terminology.

This report provides a simple 3-step example of TC-cost calculation for a typical voyage in the Nordic-Baltic geography. The steps include 1) vessel cargo capacity, 2) voyage time and 3) voyage cost estimation. The operating margin and any ship broker fees must also be included before the Owners/Operator can complete an offer to the charterer. The final freight rate offered is given on the terms specified in the charter party (CP) agreement, including demurrage rates payable to the shipper for delays at PoL or PoD. The agreed freight rate concerns only the Owners/Operator transport. Loading and unloading charges will often amount to approx 2 €/m^3 at each end of the voyage. Responsibility for these different costs is regulated by the INCO-terms used in the wood sales agreement.

Cost Analysis of Timber Transportation Using pgRouting

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ABSTRACT

Timber transportation of teak (Tectona grandis) from forest plantations to sawmills in Thailand are commonly using various kind of trucks such as six-wheel trucks, ten-wheel trucks, twelve-wheel trucks, and 18-wheel trucks depending on the wood load. This research was studied to analyst the transportation cost of six-wheel trucks and twelve-wheel trucks which more often used in the study area. Transportation cost analysis based on fixed cost and variable cost. The variable cost including fuel consumption costs is important factor that can be controlled to minimize the transportation cost. Shortest routes are the traditional way to reduce this problem. pgRouting is an extension to PostgreSQL and PostGIS provides libraries for the shortest path which applying in this study. Distance and slope of road were used to the transportation cost model. The results shown the shortest route and cost of transportation by six-wheel trucks and twelve-wheel trucks along that route.

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Timber Transport Planning for Forest Trucks and Semi-Trailers

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ABSTRACT

Timber transport in Austria is complicated by sudden high amounts of salvage wood and limited transport capacity of forest crane-trucks that are irreplaceable for the transport of logs out of the forest, especially under mountainous conditions. Introducing semi-trailer transport increases both local available timber transport capacity, but also planning efforts to secure an effective interaction of forest crane-trucks, semi-trailers and first prime movers. Therefore, a discrete event simulation model was developed to support finding optimal truck fleet configuration based on performance indicators. Results provide cost efficient solutions in terms of robust forest crane-truck, semitrailer and first prime mover combinations for timber transport managers in form of transport planning tables.

Stakeholder Perceptions of Potential Weight Limit Increases in Georgia, USA

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ABSTRACT

Georgia and other states in the US South have far lower gross vehicle weight (GVW) limits than other US regions and timber producing countries. Low weight limits result in higher transportation costs, more log trucks on the road, and higher fuel consumption and emissions than would otherwise be necessary. In 2020, Georgia log trucks were allowed GVW of up to 38,102 kg (84,000 lbs.) on five-axle tractor-trailers. In the US Northeast, Midwest, and West, many states allow approximately 45,359 kg (100,000 lbs.) GVW on 6–8 axle tractor-trailers. Recent interest in weight reform in the state prompted research to evaluate the perceptions of stakeholders on potential GVW limits and log truck configurations. Telephone surveys of 30 loggers, 32 forest industry representatives, and 42 county road officials were conducted to better understand their attitudes towards timber transportation and their support or opposition to four alternative log truck weights and configurations. The four alternative GVW limits and configurations included five axles, 39,916 kg (88,000 lbs.); six axles, 41,271 kg (91,000 lbs.); six axles, 45,359 kg (100,000 lbs.); and seven axles, 45,359 kg (100,000 lbs.). These weight limits and configurations were chosen because they are legal in at least one US state and would accommodate the tree-length timber transported in Georgia. Unique questionnaires were developed for each population with overlapping questions that allowed for comparisons. The telephone interviews lasted approximately fifteen minutes and were conducted during summer and early fall of 2020. The majority of forest industry representatives and logging business owners stated that current weight limits were too low, while the majority of county officials stated that current weight limits were too high. Loggers and forest industry supported the five-axle 39,916 kg (88,000 lbs.) configuration. Loggers opposed both 45,359 kg (100,000 lbs.) configurations while forest industry opinions were mixed. Local government officials opposed all alternative truck weights and configurations. Opposition to the proposed configurations focused on safety, implementation costs, and infrastructure impacts. Loggers, forest industry, and policymakers should seek solutions that reduce transportation costs and emission while protecting public infrastructure and highway safety.

Comparison of Log Truck Crash Rates, Severity, and Contributing Factors Before and Weight Limits Increases in Two Southern States, USA

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ABSTRACT

Reducing the frequency and severity of log truck crashes is essential to prevent further increases in log truck insurance premiums, attract drivers to the sector, and improve the public image of loggers and forest industry. States in the US South have among the lowest gross vehicle weight (GVW) limits for log trucks in the US and globally. Opponents of increases in GVW limits cite highway safety concerns among their arguments. The southern states of North Carolina and Virginia increased their weight limit for log trucks from 38,102 kg (84,000 lbs) to 40,823 kg (90,000 lbs) in 2012 and 2015, respectively. Crash reports were obtained from state authorities in these two states for all log truck crashes occurring between 2009 and 2019. Log trucks were defined as vehicles classified as a cargo body type "log". Log truck crash rates, severity, contributing factors, crash locations, and vehicle conditions were compared before and after the increases in weight limits in both states using Wilcoxon rank sum non-parametric tests at $\alpha = 0.05$. Log truck crashes per million tonnes of timber harvested increased by 134% in North Carolina and 29% in Virginia between 2009 and 2019. Crash rates began rising prior to the increases in GVW limits and continued rising after the increases. Crash severity, as measured by estimates of vehicle damage and percent of disabled vehicles, declined by non-significant ($p > 0.10$) amounts after the increases in weight limits. Exceeding safe speed for conditions, improper turn, failure to yield right-of-way, and following too closely were common contributors to log truck crashes before and after the weight limit increases. Most crashes occurred in rural areas and on two-way, non-divided highways. Approximately 10% of log trucks involved in crashes had at least one defect, with tire and brake violations among the most common defects. Changes in GVW limits for log trucks appear to have had minimal impact on log truck crashes in the two states. Proactive safety measures such as driver education, implementation of safety technology, and improving the condition of log trucks should reduce log truck crashes in the US South.

Theme 10: Environmental Impacts

Fuel Consumption, Greenhouse Gas Emissions, and Energy Efficiency in Cut-to-length Logging Operations: A Case Study in Finland

Hanna Haavikko, Kalle Kärhä, Asko Poikela, Mika Korvenranta, Teijo Palander

Vehicle -induced disturbances of forest soils - a deeper look

Hans R Heinimann

Spatio-temporal prediction of soil strength using open access data and a Random Forest model

Marian Schönauer, Kari Väätäinen, Harri Lindeman, Robert Prinz, Dariusz Pszenny, Martin Jansen, Joachim Maack, Bruce Talbot, Rasmus Astrup, Dirk Jaeger

Evaluating possibilities for developing dynamic soil moisture maps using hydrological modelling

Sima Mohtashami, Tomas Thierfelder, Lars Eliasson, Johan Sonesson

Assessment of Rut Formation via Cross-sectional Profile and 3D Digital Model

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Comparison of soil damages between forwarding and skidding during wood extraction

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Tethering forest machines in flat terrain: effects on wheel slip and rut formation

Lorenz Breinig, Bastian Hinte, Henrik Brokmeier, Marian Schönauer, Stephan Hoffmann, Dirk Jaeger

Modelling rut formation on peatland related to soil conditions and forwarder design

Jari Ala-Ilomäki, Harri Lindeman, Blas Mola-Yudego, Robert Prinz, Kari Väätäinen, Bruce Talbot, Johanna Routa

Forestry Best Management Practice Implementation and Erosion Rates by State and Regulatory Approach in the Southeastern United States

Brent Hawks, Michael Chad Bolding, Wallace Michael Aust, Scott Barrett, Jonah Fielding

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Fuel Consumption, Greenhouse Gas Emissions, and Energy Efficiency in Cut-to-length Logging Operations: A Case Study in Finland

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ABSTRACT

The aims of the study were 1) to clarify the forest machine fleet energy-efficiency as related to the engine power; 2) to determine the fuel consumption and greenhouse gas (GHG) emissions from cut-to-length (CTL) logging operations, including relocations of forest machines by trucks; and 3) to investigate the energy-efficiency of CTL logging operations. The study data consisted of Stora Enso Wood Supply Finland's industrial roundwood harvest of 8.9 million m^3 (solid over bark) in 2016. The results illustrated that forest machinery was not allocated to the different cutting methods based on the engine power. The calculated fuel consumption totalled 14.2 million litres (ML) for logging 8.9 million m^3, and the calculated fuel consumption of relocations totalled 1.2 ML, for a total of 15.4 ML. The fuel consumption proportion for harvesters was 52.5%, forwarders 39.5%, and forest machine relocations 8.0%. The average calculated cubic-based fuel consumption of logging was 1.6 L/m^3, ranging from the lowest for final fellings of 1.2 L/m^3 and highest in first thinnings at 2.8 L/m^3. The calculated fuel consumption from machine relocations was, on average, 0.13 L/m^3. The calculated CO_2 eq. emissions totalled 40,872 t, of which 21,676 t were from cutting, 16,295 t were from forwarding, and 2,901 t from relocation trucks. By cutting method, the highest calculated CO_2 eq. emissions were in first thinnings (7,340 g CO_2 eq./m^3) and the lowest were in final fellings (3,140 g CO_2 eq./m^3). The calculated cubic-based CO_2 eq. emissions in the forest machine relocations averaged 325 g CO_2 eq./m^3. In conclusion, the results underlined that there is a remarkable gap between the actual and optimal allocation of forest machine fleets. Minimizing the gap could result in higher work productivity, lower fuel consumption and GHG emissions, and higher energy efficiency in CTL logging operations in the future.

Keywords: carbon dioxide equivalent (CO_2 eq.), wood harvesting, forest machines, machine relocations

More information: Haavikko, H., Kärhä, K., Poikela, A., Korvenranta, M. & Palander, T. 2021. Fuel Consumption, Greenhouse Gas Emissions, and Energy Efficiency of Wood-Harvesting Operations: A Case Study of Stora Enso in Finland. Croatian Journal of Forest Engineering, Accepted.

Vehicle -Induced Disturbances of Forest Soils – A Deeper Look

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ABSTRACT

It has been generally accepted that off-road vehicle traffic is the main source of soil disturbance in land-use activities, such as forestry and agriculture. The effects are often subsumed under the umbrella of "soil compaction", which does not address the whole range of disturbances from slightly deformed to remolded service disruptions. Additionally, the ultimate goal of soil disturbance studies is to assess and evaluate the effect of physical soil deformation on the health of soil ecosystems. The purpose of the presentation is (1) to revisit the mechanical stress propagation in the soil under wheels based on elastic theory; (2) to characterize the mechanical strength of soils for the unsaturated phase, which is different from classical so mechanics; (3) to propose a set of bioindicators that can detect and monitor critical changes in the soil ecosystem functions.

We follow a risk management approach, the assessment process of which has 3 main components. First, it characterizes the mechanical actions of vehicle traffic in terms of stress distribution. Second, it assesses the vulnerability/resistance of the exposed soil. And third, it assesses the consequences of soil stresses and deformations on soil ecosystem functions. While a lot of soil disturbance studies report physical parameters only, such as bulk density, etc. We propose a different set of parameters: (1) CO2 content of the pore air, (2) soil air volume, (3) degree of saturation, and (4) the characterization of microbial soil communities. This set of parameters could bring us closer to establish links between vehicle strains and ecological relevant effects. The parameters respond rapidly to stressors and conserve as "early warning" indicators of effects.

Spatio-Temporal Prediction of Soil Strength Using Open Access Data and a Random Forest Model

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ABSTRACT

Milder winters and extended wetter periods in spring and fall limit the amount of time available for carrying out forest operations on soils with satisfactory bearing capacity. Thus, damage in the form of rutting and compaction is reported to be becoming more widespread. The prediction of soil strength, and therewith stand trafficability has become one of the most central issues in the planning of mechanized harvesting operations.

The present work looks at ways of improving the depth-to-water (DTW) algorithm, used for trafficability modelling. DTW reveals a modelled depth to a simulated water layer, whereas a close proximity to this layer indicates a high susceptibility to damage. So far, maps created using the DTW algorithm are static, limiting the applicability and accuracy for use in forest operations. Aiming towards an improvement of accuracy and appropriate emulation of variations of soil strength, we integrated temporal open access data. A joint TECH4EFFECT survey was designed for six study sites in Finland, Germany and Poland, where repeated in-field measurements of soil strength and soil moisture were conducted using a penetrologger and TDR, respectively. Measured values of soil strength were compared with the predictions derived from four DTW maps, representing different moisture conditions. Although the observed accuracy across the study sites was adequate, with 74% of true predictions, 70% of values with low soil strength deviated from the predictions made. In the second step of analysis, open access data of soil moisture (temporal) and soil characteristics, was added, fitting a linear model to the occurrences of low or high values of soil strength. Overall accuracy was not improved (72%), but class error for low soil strength was reduced from 70% to 42%. The same data, which was integrated into the linear model was used to train the tree-based learner Random Forest. The resultant accuracy of predictions was high, showing 80% of true predictions and a low error class for low soil strength of 20% only.

We are confident, that open access data can be used to clearly improve the prediction of soil strength and offer a way for adequate trafficability mappings. It is shown, that global geophysical data reveals useful soil moisture estimates, which contribute to an evidence-based consideration of operational conditions. By the training of a Random Forest, we were able to successfully combine static spatial information with temporal data, leading to more accurate predictions of soil strength.

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Evaluating Possibilities for Developing Dynamic Soil Moisture Maps Using Hydrological Modelling

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ABSTRACT

The risk for rut formation during forestry operations has been increased since mechanization of forestry operations in 1950s in Sweden and has been intensified by a warmer climate in recent decades. Rutting is displacement of the soil to the sides or middle of the tracks and occurs when machines apply compression or shear forces to moist or wet soils. Higher water retention in flat areas, erosion, and sediment transport to adjacent water environments in steep areas, are some of the negative effects of rutting, that challenge the forestry in Nordic regions.

Having knowledge about both spatial and temporal variation of soil moisture can assist forest planners to reduce the risk of rutting. This can be achieved by knowing "when" a proper time is for cutting off a site, and "where" the highest bearing condition exist in the site using dynamic soil moisture maps. We have evaluated the possibilities of developing dynamic soil moisture maps using a hydrological model, e.g., Swedish Hydrological Prediction for Environment (S-HYPE). The S-HYPE model, mainly developed to simulate flow channels and circulation of nutrients, provided us soil variables like moisture content, temperature, and frost depth.

Field collected data about ruts and logging roads in 27 logging sites, was used to analyze the variation of "rut depth" and "proportion of logging roads with ruts" across the sites. Regressors from three main categories: field-surveyed data, spatial data available as digital maps, and S-HYPE data were examined to improve description of the rut formations.

Applying partial least square analysis (PLS) revealed that using field and spatial data regressors resulted in extraction of two significant components explaining 7,9% of the variations of rut depth within the stands. Inclusion of S-HYPE variables, however reduced the explanation of the rut depth variation to 2,9%, using a non-significant component. Analyzing "the proportion of logging roads with ruts" in a linear mixed model identified "road type" and "ground protection measures" as significant factors ($p < 0.0001$) with adjusted R2 value as 67%. The model's

explanatory power (adjusted R2 value) fell to 39% when S-HYPE data, together with field-surveyed data, were examined as regressors.

The results of our study indicated that none of the S-HYPE variables, given current spatial resolution, cannot improve description of rut formations. However, their use for adapting depth-to-water (DTW) maps to temporal changes of soil moisture content may be a way to develop more dynamic soil moisture maps for forestry applications.

Assessment of Rut Formation via Cross-sectional Profile and 3D Digital Model

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ABSTRACT

Rut formation is a clearly visible and easy to measure indicator to assess the impact of forest operations on soils. Uncertainties exist in assessing rut depth from driving on forest soils. The study aims to better understand rut formation assessment accuracy as a pre-condition for a continuous rut formation measurement during forest operations and the development of a fast and easy method to measure this indicator.
Within two studies in Brandenburg, Germany, and Saxony-Anhalt, Germany, ruts were assessed via cross-sectional profiles and 3D digital models based on common photographs. The photos were processed using Photo Modeler Scanner and GIS software.
The ruts were formed by a rubber-tracked forwarder, passing up to 20 times on the secondary podzols and sandy humus gley soils. In sum, 15 plots were analyzed, each in order of 0, 1, 4, 8, 12, 16, 20 machine passes. The calculated volumes of an ideal horizontal area of 2.0 x 1.8 m were further statistically analyzed, for both, the cross-sectional profile and the 3D digital model.

The final method, analysis and the results will be presented during the conference.

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Comparison of Soil Damages Between Forwarding and Skidding During Wood Extraction

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ABSTRACT

Intensive forestry operations may cause soil compaction, plastic soil disturbances and rutting, which are responsible for undesirable effects on soils, vegetation and water bodies. Despite the numerous studies aimed to identify the main factors affecting soil damages, it still remains unclear whether wood extraction methods and driving direction may affect the impacts of forest machines. In this context, the overall objective of this study was to compare physical soil parameters for assessing compaction (i.e., bulk density and soil penetration resistance) and rutting (3D soil models obtained by images collected using drones and Structure from Motion photogrammetry) caused by forwarding and skidding. The effects of wood extraction in different transporting directions (flat, up- downhill and in a curve on flat terrain) was also tested. In this study the same forest machine (i.e., a forwarder) was used during both skidding and forwarding, in order to maintain machine parameter constant (e.g., wheels size and tire pressure). In forwarding, the machine was used as an ordinary forwarder for transporting the logs. The forwarder was loaded with 5.5 m long logs for a total of 9,817 kg. In skidding, the main part of 16 m long trunks (for a total 7,849 kg) was fixed with chains on the forwarder back to simulate a clambunk. Our findings showed that the direction of extraction did not affect soil damage severity (bulk density) during forwarding on a 15% slope. On the contrary, in order to reduce soil compaction, downhill is preferable to uphill skidding. The results showed that the pressure on the ground caused by vehicles can be distributed horizontally, thus highlighting the effect on soil also between the wheel tracks. The soil bulk density in the tracks in forwarding increased by 38-40% and 15-25% between the wheel tracks. The comparison of the area affected by soil impacts showed the larger area in skidding than forwarding due to the effect of dragged logs. The soil displacement in skidding trails (6.36 m3 per 100 m of trail) was significantly higher than in forwarding (1.83 m3 per 100 m of trail) driving uphill. The comparison of driving in a curve and in a straight line highlight that curvature caused the larger soil damages. In conclusion, these results show important information on soil impact, which can be a useful criterion for choosing a proper wood extraction technique.

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Tethering Forest Machines in Flat Terrain: Effects on Wheel Slip and Rut Formation

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ABSTRACT

Tethering ground-based forest machines has been widely adapted for harvesting operations in sloped terrain as a means of increasing machine gradeability by providing additional tractive force and thereby reducing slippage and soil disturbance. When operating in flat terrain, however, traction assistance of forest machines is usually not utilized, even though slippage may contribute considerably to rut formation and productivity loss on sensitive soils. Since little is known about the potential to reduce rut formation due to forwarder traffic by tethering the machine on level ground, this was tested in a pilot study. An 8-wheel forwarder with a total mass of 28.6 metric tons, neither equipped with bogie tracks nor wheel chains, was repeatedly driven over a two-section test track along a skid trail on a virtually flat forest site with soil developed from loess sediment. Traction assistance by an external winch was applied on the second track section during each machine pass. Cable tensile force and wheel slip were recorded during machine passes, while rut depth was measured with a laser scanner after each pass. When driving tethered, raising cable tensile force from about 10 kN to approximately 50 kN as the number of machine passes progressed from 1 to 15 kept wheel slip below 1.5%. At the same time, wheel slip increased from 2% to 8% when driving unassisted. Observed mean rut depths after 15 machine passes were 8.6 cm for the section travelled with traction assistance and 12.3 cm for the section travelled unassisted, but the effect of traction assistance was not found to be significant. Considering the substantial cumulative load exerted on the test track, the observed rut depths were rather shallow, and the level of wheel slip occurring during unassisted machine travel was low as well. This might be attributable to pre-compaction of the soil as indicated by comparably high initial bulk density and penetration resistance in the upper 30 cm of soil.

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Modelling Rut Formation on Peatland Related to Soil Conditions and Forwarder Design

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ABSTRACT

Current trends on wood extraction are expanding the ranges of soil conditions encountered by forest operations. In Northern Europe, the challenging trafficability of peatlands can be aggravated further due to anticipated warmer climatic conditions affecting soil characteristics during forest operations. The present study aims to analyze rut formation related to track design and vehicle configuration on trails with no slash mats on peatland. Five forwarders; four 8-wheeled and one 10-wheeled, with different configurations are studied on different plots in Eastern Finland. The forwarders were driven loaded with approximately 5,100 kg of pulpwood with an average length of 4.56 m. Straight versus curved sections of the trail, as well as number of passes, soil shear modulus, peat depth, among others, were included in a mixed effect model, using N=760 rut depth observations. The results show that rut depth decreases exponentially with soil shear modulus, increases linearly with the number of passes and it is not affected by the trail section configuration. The predictive power of the model was R2=0.55 and it incorporated important differences between the machines tested: old generation Ponsse Elk with Fomatec tracks showed the lowest rut

formation, followed by old generation Ponsse Elk with Fomatec tracks equipped with add-on track shoes, Ponsse Buffalo with KOPA high flotation tracks and Ponsse Elk 10W with Olofsfors mixed tracks, while Ponsse Elk with long wheelbase rear bogies and Olofsfors high-flotation tracks showed the deepest rut formation. Despite differences observed, all track and forwarder designs performed overall satisfactorily in terms of vehicle mobility, and the choice of track or forwarder under the given test conditions was not critical, as none of them performed vastly inferior in comparison to the others. On soils with a lower strength, however, the importance of track shoe coverage of the total track-soil contact area may increase, although increased track shoe coverage will also lead to increasing track mass and increasing vertical loading to the soil. Vehicle dynamics on peatland is still far from being fully understood and the paper highlights the complexity of the interactions of the variables studied while providing a valid modelling tool with applications in planning of forest operations and simulation.

Forestry Best Management Practice Implementation and Erosion Rates by State Grouping and Regulatory Approach in the Southeastern United States

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EXTENDED ABSTRACT

1. Introduction

Forestry Best Management Practices (BMPs) have been developed and implemented cooperatively by state and federal agencies, researchers, forest managers, harvest operators, private landowners, and industrial forest organizations to minimize nonpoint source (NPS) pollution associated with forest operations (Edwards et al., 2015, Phillips and Blinn, 2004, 2007). When forestry BMPs are not adequately utilized, high rates of erosion can occur and can be potentially delivered to streams as sediment (Arthur et al., 1998). Sediment has been the most common NPS pollutant addressed by BMPs in forestry for decades (Yoho, 1980).

State BMP programs can be classified as non-regulatory, quasi-regulatory, or regulatory. Non-regulatory states utilize education, incentives, and third-party certification programs to encourage BMP implementation in addition to the standards set forth by the Clean Water Act (Ice and Stuart, 2001). Quasi-regulatory states normally have a state law concerning sediment with enforcement capabilities, but do not typically require specific BMPs (Cristan et al., 2016). Lastly, regulatory states typically have forest practice acts that require the application of certain BMPs during and after forest operational activities (Phillips and Blinn, 2007).

Although several studies have reported BMP implementation rates and erosion rates separately, this is one of the few studies that assessed these variables on the same harvest sites across several US states. This study was designed to compare BMP implementation rates and erosion rates across state groupings and BMP program types, and to determine if significant differences exist across these categories. Additionally, BMP recommendations will be provided to improve implementation and to mitigate potential erosion.

2. Materials and Methods

This study evaluated BMP implementation percentages and erosion rates on skid trails, stream crossings, forest roads, decks, and harvest areas at 116 recent harvest sites, which were closed out within eight months prior to evaluations, in the southeastern United States so that comparisons could be made across state groupings and BMP program types. Audit questions from the 13 state forestry agencies in the southeast were used to evaluate BMPs. The "13-state average" BMP implementation rate was presented in this study so that comparisons could be more easily understood across the categorizations. Additionally, the Universal Soil Loss Equation as modified for forestry (USLE-Forest) (Dissmeyer and Foster, 1980) was used to estimate erosion at all features as this model has been commonly used in forestry research.

Sites were categorized into three state groupings, Gulf (n = 27), Interior (n = 20) and Atlantic (n = 69). State groupings are based on geography, with the Gulf region including Florida, Alabama, Mississippi, Louisiana, and Texas, the Interior consisting of Oklahoma, Arkansas, and Tennessee, and lasty the Atlantic which includes Virginia, North Carolina, South Carolina, and Georgia. Although Florida shares similarities to both Gulf and Atlantic states, all sites evaluated in Florida were more similar to operations in the Gulf states. Harvests in states with non-regulatory programs (n = 51) and quasi-regulatory programs (n = 65) were also categorized. Virginia, North Carolina, South Carolina, Florida, and Alabama have quasi-regulatory guidelines, while Georgia, Mississippi, Louisiana, Texas, Oklahoma, Arkansas, and Tennessee are classified as non-regulatory states (Cristan et al. 2018). Kentucky is the only state in the southeast with regulatory guidelines (Cristan et al. 2018), but no harvests were evaluated in Kentucky because state officials could not provide any sites that met the study's criteria.

JMP® (SAS Institute Inc., 2021) was the statistical software used for analyses of study data. An alpha level of 0.10 was used during the analysis because it reduces the likelihood of making a Type II error and is appropriate for operational evaluations (Stefano, 2001). Because data were non-normally distributed, the non-parametric Kruskal-Wallis tests were used to determine significant differences. If significant differences were detected, mean separations were conducted via Steele-Dwass tests.

3. Results and Discussion

Overall BMP implementation was significantly higher in the Gulf grouping (93.5%), followed by the Atlantic (89.1%), and Interior (89.0%) groupings. The Atlantic grouping's weighted average erosion rate (4.7 tons/acre/year) was approximately twice as high as the Gulf (2.4 tons/acre/year) and Interior (2.3 tons/acre/year). The Atlantic grouping averaged significantly lower skid trail implementation rates (79.8%) compared to the Interior (84.4%) and Gulf (89.8%) and had a mean skid trail erosion rate (24.9 tons/acre/year) approximately three times higher than Gulf and Interior states. It is reasonable to believe that this might be due to the prevalence of more challenging, mountainous terrain in Atlantic states and/or fewer BMP incentives from forest certification programs for mountain operators.

Table 1. BMP implementation rates (%) and Erosion Rates (tons/acre/year) for six forest operational features based on three state groupings (Atlantic, Gulf and Interior). Connecting letters report based on the nonparametric Wilcoxon p-values and the Steel-Dwass All Pairs comparison is also presented vertically as a connecting letter report.

Forest Operational Category						
State Grouping	Stream Crossing	Deck	Skid Trail	Haul Road	Harvest Area	Overall Weighted Average
13-State Average BMP Mean BMP Implementation Rate (%)						
P-value	0.1616	0.0689	0.0006	0.3390	0.0924	0.0055
Atlantic	90.7a	91.9b	79.8b	91.1a	93.9b	89.1b
Gulf	84.2a	94.7a	89.8a	95.0a	98.7a	93.5a
Interior	78.4a	92.4ab	84.4ab	90.5a	97.4ab	89.0ab
Mean Erosion Rate (tons/acre/year)						
p-value	0.4373	0.5178	0.0141	0.0087	0.0796	0.0670
Atlantic	7.0a	5.7a	24.9a	12.4b	2.6a	4.7a
Gulf	8.7a	3.4a	8.4b	16.2a	0.9a	2.4a
Interior	7.2a	2.0a	7.6b	12.1ab	1.4a	2.3a

Overall BMP implementation rates were similar in non-regulatory states (90.6%) compared to quasi-regulatory states (89.7%). These overall implementation rates are consistent with those calculated in Cristan et al. (2018) for non-regulatory (90.2%) and quasi-regulatory (90.2%) categorizations. However, mean stream crossing BMP implementation rates were significantly higher in quasi-regulatory (90.6%) compared to non-regulatory (83.9%) states where erosion rates were marginally higher. Mean skid trail BMP implementation rates were significantly higher for non-regulatory states (86.1%) compared to quasi-regulatory (80.1%) states, and quasi regulatory states also had significantly higher erosion rates for skid trails (22.8 tons/acre/year) compared to non-regulatory (12.8 tons/acre/year).

Table 2. BMP implementation rates (%) and Erosion Rates (tons/acre/year) for six forest operational features based on two BMP program types (Non-Regulatory and Quasi-Regulatory). Connecting letters report based on the nonparametric Wilcoxon p-values and the Steel-Dwass All Pairs comparison is also presented vertically as a connecting letter report.

Forest Operational Category						
BMP Approach	Stream Crossing	Deck	Skid Trail	Haul Road	Harvest Area	Overall Weighted Average
13-State Average BMP Mean BMP Implementation Rate (%)						
p-value	0.0701	0.0688	0.0105	0.7317	0.0782	0.1837
Non-Regulatory	83.9b	93.7a	86.1a	91.6a	97.7a	90.6a
Quasi-Regulatory	90.6a	91.7b	80.1b	92.2a	94.0b	89.7a
Mean Erosion Rate (tons/acre/year)						
p-value	0.2279	0.2912	0.0471	0.0006	0.6266	0.4090
Non-Regulatory	7.7a	4.9a	12.8b	17.6a	1.8a	3.4a
Quasi-Regulatory	7.0a	4.4a	22.8a	10.0b	2.1a	4.1a

4. Conclusions

All harvest sites inspected in this study were examined by state forestry agency employees at the time of tract closure and prior to our evaluations, which ensures that operators BMP implementations were complete. Therefore, it is clear that some operators did not implement the appropriate level of recommended BMPs before closure, thus explaining increased erosion rates. In general, results identified differences in BMP implementation and erosion rates across state groupings and BMP programs in the southeast, especially at stream crossings, skid trails, and haul roads. Skid trail and haul road approaches leading to stream crossings may benefit from additional BMP practices such as additional water diversion structures, application of slash, and utilization of portable bridges to better protect water quality (Dangle et al. 2019).

5. Acknowledgement

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Theme 11: Forest Biomass and Bioenergy

Mulching of harvesting residues after clearfelling in Pine and Eucalyptus stands; a comparison of productivity, costs, and CO2 emissions

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Harvest Residue Emissions Estimates and Bioeconomy Opportunities in British Columbia

Eric Nance, Sheng H. Xie, Ben Hudson, Dominik Roeser, Werner A. Kurz

Flexible planning model to manage fire risk in forest-to-bioenergy supply chain

Reinaldo Gomes, Alexandra Marques, Paulo Fernandes

Investigation & Comparison of Three PTO Chippers for Small-Scale Operations

Sabrina St-Onge

Linking Forests and Cities: Market Impacts of Biomass Heating and Sustainable Forest ManagementWood Fuel Logistics and Carbon Performance

Brandon Bung, Dominik Roeser, Gary Bull, Jamie Stephen, Sheng Xie

Forest biomass collection from systematic mulching on young and dense stands in Spain

Eduardo Tolosana, Teresa de la Fuente, Rubén Laina, Mihail Manea, Pedro Pérez, Raquel Bados, Gonzalo Piñeiro

Projecting Future Procurement Potential of Forest Resources Using Swedish Forest Inventory Data

Kalvis Kons, Dimitris Athanassiadis

Quantifying the Life Cycle Impacts of Forest Logging Residue Logistics

Xufeng Zhang, Jingxin Wang, John Vance

Evaluation of an improved concept enabling large-scale storage of Wood chip and bark

Erik Anerud, Anders Eriksson

Fuel quality and dry matter losses of stored wood chips - Influence of cover material

Erik Anerud, Dan Bergström, Johanna Routa, Lars Eliasson

Comparison of cost-efficiency of innovative and conventional supply systems for small trees and shrubs in Sweden, Finland, Slovenia and Spain

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Mulching of Harvesting Residues after Clear-felling in Pine and Eucalyptus Stands; A Comparison of Productivity, Costs, and CO2 Emissions

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ABSTRACT

Plantation forestry typically involves the use of fast-growing tree species managed in relatively short rotations, mostly shorter than 20 years, and in dedicated pulpwood stands, only 6-8 years. Given that land available for plantation forestry is a limited resource, there is a strong incentive to maximize production on the available land base. Traditional methods of residue measurement have included windrowing, spreading and / or burning. All are associated with a unique set of advantages and disadvantages, including cost, nutrient or organic matter loss, as well as sometimes significant delays linked to the availability of production factors or in the case of burning, suitable conditions within a limited season.

Mulching offers a solution for the comminution of residues almost immediately after harvesting. Reducing the period of time between successive rotations contributes to maximizing land utilization, especially so in short rotation forestry. However, mulching requires significant inputs in terms of capital, motor power, maintenance, and fuel and lubricants, and this should naturally be justified by the benefits of the treatment.

The aim of this study was therefore to quantify the costs, productivity rates, and CO2 emissions.

Two field studies were carried out in low-lying Eucalyptus stands on sandy soils and two on higher elevation Pine stands on clay rich soils. Comprehensive residue volume estimates were carried out immediately before mulching using the line intercept method for scattered residues, while stump volumes were measured directly on all sites. The Eucalyptus trials done on 36 ha (89 acres) with a wheeled Cat 586c base machine fitted with an FAE 300U mulching head. The Pine residue mulching trials were done on 42 ha (104 acres) using a wheeled Tigercat M726G mulcher. Both are horizontal drum mulchers. Both machines weigh approximately 15 tonnes without the attachment and both are powered by 350 hp (260 kw) motors and were considered highly comparable. Time and motion studies were carried out in order to calculate productivity in preparation, mulching and turning, while supplementary data was collected in monitoring fuel consumption. Mulch quality was assessed separately.

This paper will present the productivity levels achieved as a function of residue volumes on the ground, the unit costs of the respective mulching treatments, as well as the emissions associated with mulching in each of the trials.

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Harvest Residue Emissions Estimates and Bioeconomy Opportunities in British Columbia

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ABSTRACT

Slash-pile burning is a common forest management practice in British Columbia (BC) where the residual fiber created during roundwood harvesting (harvest residue) is piled and open burned in cut blocks. Burning of harvest residues is justified as a tool to reduce fuel load and wildfire risk. However, this low efficiency combustion produces significant greenhouse gas (GHG) emissions, releases harmful particulate matter, and depletes the nutrient stores and wildlife habitat of recently disturbed ecosystems. Current estimates of slash-pile burning emissions, derived from the Carbon Budget Model of the Canadian Forest Service (CBM-CFS3), suggest that 5 mega-tonnes of carbon dioxide equivalent (Mt CO2e) are emitted annually in BC. However, there is concern that this estimate may be under-representing emissions, as there has been little research on the volume of harvest residues being generated in the province, the frequency of burning treatments, and the GHG profile of the resulting emissions. Furthermore, opportunities to utilize these residues in the bioeconomy are somewhat limited by our narrow understanding of the availability and quality of residual wood fiber contained in slash piles.

A preliminary review, along with a sensitivity analysis, has identified Harvest Utilization (HU)- the volumes, spatial distributions, piece sizes, and qualities of harvest residues- as a primary source of uncertainty in the current slash-pile burning emissions estimate and a key knowledge gap for future GHG mitigation strategies and bioeconomy opportunities. A systematic literature review will be carried out on the current state of HU in BC, targeting the volumes and distributions of residual fiber left for various stand and harvest characteristics, as well as an exploration of alternative uses for these residues. Datasets from timber harvesting operations across the province will then be collected and analyzed to (1) calibrate HU estimates for specific regions, species mixes, and harvesting systems, and (2) provide information on fiber quality and piece size distributions for various harvest residue categories. These

updated parameters will then be used to model the potential bioeconomy and carbon benefits of diverting harvest residues that would otherwise be open burned, for alternate use scenarios.

The results of this research are expected to improve current GHG emissions estimates of slash-pile burning, illustrate the potential carbon benefits and bioeconomy opportunities of better managing and utilizing this residual wood fiber, and serve to inform future mitigation programs or policies that target emissions reductions in the forest sector.

Flexible Planning Model to Manage Fire Risk in Forest-to-Bioenergy Supply Chain

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ABSTRACT

In forest-based supply chains, and others related with the exploration of natural resources, managing risk and uncertainty in the procurement stage is key, affecting downstream decisions related with logistics and inventory management, and production planning.

This research was motivated by the variability in the availability of wood that is affected by fires, storms, diseases, and other drastic unforeseen events. But most importantly, there is a significant degree of uncertainty in estimating the quantity and quality of the raw materials that will be available for harvesting in a certain forest site at a certain time, especially if long planning horizons are considered. There is spatial variability, some forest sites are located in regions more productive than others, and seasonality, over the year, operations execution is conditioned by the weather conditions. We propose a modelling approach of burning volume in a region to estimate the large amounts of wood with a lower quality that become available in a region as a result of a forest fire. This raw material should be harvested shortly and delivered to the mill to avoid devaluation, taking priority over other unburned regions and often requiring much more harvesting and logistics resources than otherwise. The rationale is that having flexibility to adapt supply chain design and operations along time according to current resource availability, can be instrumental for gain economies of scale and reduce operational costs. The study intends the development of a flexible planning model that suggests when and what piles of forest residues to collect, where to deliver the material, which teams and equipment to allocate, which intermediate storage nodes can be open and closed along the time horizon, adjusting to raw materials availability, and the possibility to postpone operations from the supply nodes to these intermediate nodes. Our approach was applied in a case study of a logistics operator and the results show an increase in the profitability of its business and the efficiency of operations to different disruption scenarios. This paper supports strategic decisions such as the opening of intermediate yards for storage and chipping contributing to better risk management.

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Investigation & Comparison of Three PTO Chippers for Small-Scale Operations

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ABSTRACT

Small-scale European chippers are largely unknown to North America. However, in the past decade or so, to address global and national Climate Change objectives, governments of Canada (National, Provincial, and municipal) adopted carbon emission reduction regulations and released subsequent funding aimed at reducing GHG emissions from fossil fuels. Consequently, a spike (alas, still tentative!) in wood chip boilers and combined heat and power (CHP) installations occurred across Canada. Given the plenitude of biomass availability and the widespread of small and medium size communities and towns, Canada is perfectly positioned to grow a scale bio-energy sector dramatically, at all scales, from small to industrial.

The objective of this study was to compare the productivities and wood chip quality attributes (moisture content and size distribution) of three small-scale chippers employed in processing a variety of typical Canadian feedstocks: logging residues, burnt logs and stem tops, SRWC stems and branches. The scope is to inform Canadian and North American stakeholders about the technical and economic parameters of small-scale European chippers and wood chip qualities produced by these chippers from typical North American feedstocks.

Size distributions resulting from all trials indicated that, if sharp knives were used and the chippers were regularly maintained according to manufacturer's schedules, all tested chippers and feedstocks can produce wood chips that meet the most stringent wood chip quality specifications of a small-scale CHP unit and for other heat and CHP applications. The results of these trials are encouraging. They proved that the chippers were well capable of producing chips that met the specifications of the most stringent bio-energy applications. However, using the right size and type of chipper for the right feedstock is critical to the success of any bio-energy application.

Linking Forests and Cities: Market Impacts of Biomass Heating and Sustainable Forest Management

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ABSTRACT

Canada has committed to reducing anthropogenic greenhouse gas emissions by 30% by 2030 relative to a 2005 baseline but has only achieved a reduction of less than 2% to date. As home to 10% of the world's forest, Canada's forests play a major role in carbon sequestration. However, Canada has largely overlooked the emission reduction opportunities using forest biomass for larger-scale urban heating plants and district energy systems. This technology combination has been deployed extensively in Europe, particularly in Nordic and Germanic countries. However, a challenge to adoption of large-scale biomass heating in Canada has been concerns surrounding the life cycle carbon performance of biomass and long-term forest sustainability. Using a case study approach, this project aims to address these concerns through determining the implications of managing forests for fuels, the market impact of a biomass-to-heat supply chain and carbon performance. The case study, broken down into three phases, focuses on the delivery of wood chips from central Ontario to a potential biomass energy center in Haliburton. The first phase will be a detailed analyses for the head load demands of 4 distinct systems in the Municipality of Dysart et al in Haliburton. The second phase will establish a baseline scenario according to the existing forest management practices, low-grade timber stock and the market climate for Haliburton Forest and Wildlife Reserve. The third phase will be a comparison between the baseline and shifting the focus towards managing Haliburton Forest for wood fuel. The results are expected to demonstrate the enhancement of active sustainable forest management, the delivered cost of wood fuel for the individual systems and their carbon implications.

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Forest Biomass Collection from Systematic Mulching on Young and Dense Stands in Spain

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ABSTRACT

The forest fire danger potential is expected to increase due to a warmer climate on the Mediterranean region. On the other hand, an increase in biomass demand is expected in a growing bioeconomy. Therefore, improvements in forest fire prevention and efficient technologies and working methods for biomass harvesting become critical, especially in young and dense forest stands.

Mechanical mulching with biomass recovery not only would reduce the risk of forest fires and its severity on those stands, but also would contribute to the development of the bioeconomy by providing renewable resources to the industry. A chain mulcher is the conventional technology used in the mechanical systematic mulching, leaving the

cut biomass on the ground. As alternative to the conventional mulcher, two different technologies were tested in four different young and dense forest stands in the Northwest of Spain, the mulcher-bundler BioBaler WB55 and the mulcher-collector Retrabio. The Biobaler is a harvesting and baling technology designed to continuously cut and process the biomass into 1.2 m wide by 1.2 m diameter bales, which facilitate the biomass forwarding and further handling operations. The Retrabio is a vehicle with a grinding head, that collects and crushes the biomass, and a 24 m3 container, where the crushed material is stored.

Surface and weight productivities, collection efficiency, cost, stump heights and damages to the remaining trees were analyzed for both technologies, and compared to the conventional mulcher. The cost and productivity of the selective clearing by operators with portable brush cutters on the strips unaffected by the systematic mechanized mulching were also analyzed.

The average Biobaler biomass collection productivity was 1.54 ODt (oven dry tonne)·PMh-1 (productive machine hour) and the surface productivity was 0.82 ha·PMh-1 on natural regenerated pine stands (initial biomass 10.1 ODt·ha-1). Although the surface productivity was slightly higher for the Biobaler than for the conventional chain mulcher, the economic balance of the treatment was costlier for the Biobaler.

The average Retrabio biomass collection productivity was 1.86 ODt·PMh-1 and 1.17 ODt·PMh-1 on willow coppices (initial biomass 30.6 ODt·ha-1) and natural regenerated pine (initial biomass 8.3 ODt·ha-1) stands, respectively. The surface productivity was 0.55 ha·PMh-1 and 0.67 ha·PMh-1 on willow and pine stands, respectively.

Projecting Future Procurement Potential of Forest Resources Using Swedish Forest Inventory Data

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ABSTRACT

In the last 20 years, the use of forest biomass for energy production and sawlog and pulpwood production has increased by 68%, 11%, and 31% in Sweden. As Sweden is trying to achieve net-zero greenhouse gas emissions by 2045 the high demand for biomass can be expected also in the future. Therefore a method to project the amount of spatially available biomass assortments for industries was developed. The available amount of different forest assortments was estimated and visualized in a web-based tool using forest inventory data and nationwide projection analyses of available biomass for 2035-2039. In 2035 – 2039 the most biomass and roundwood will be available in Northern Southern Sweden. Results also indicate that already existing harvesting intensity is very high compared to the available biomass in the future. The industry can expect noticeable more available biomass due to improved regeneration material and climate change closer to 100-year period. With increased competition between large pulp mills and biorefineries, the supply areas can exceed 200+ km to satisfy raw material demand. The long-distance and high-volume supply chain requirements will demand further improvement in transportation solutions nationally and cross-border in the Baltic Sea Region.

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Quantifying the Life Cycle Impacts of Forest Logging Residue Logistics

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ABSTRACT

Forest logging residue could be utilized as a renewable feedstock for bioenergy products to promote bioeconomy and reduce greenhouse gas emissions for sustainable development. To quantify the environmental impacts, a life cycle assessment (LCA) model was developed using the TRACI 2.1 methodology focusing on the supply chain processes from harvesting to the gate of a processing facility. The environmental impacts of the unit-processes of biomass sorting and treetop processing, chipping, micro-chipping, grinding, baling, transportation, biomass screening was first assessed with the functional unit of one oven dry tonne of processed biomass. Then the environmental impacts of potential logistics alternatives configured by various unit processes were further analyzed. In addition, the uncertainty of biomass logistics LCAwas also investigated via the Monte-Carlo simulation.

The results indicate that, the global warming potential (GWP) impact of the logistics of one oven dry tonne of forest logging residue varies from 42.00-69.87 kg CO2 equivalent depending on logistics alternatives and transportation distance (30-70 miles). Biomass harvesting presents highest GWP impact. Specifically, the life-cycle GWP impacts for chipping, micro-chipping, grinding, baling, screening are 3.06, 7.04, 8.52, 8.03, 1.18 kg CO2 equivalent, respectively. In addition, the potential logistics for hog fuel has a higher GWP impact than that for high-quality biomass feedstock (uniformed and small-size chips), majorly due to its higher energy consumption in biomass grinding.

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Evaluation of an Improved Concept Enabling Large-Scale Storage of Wood Chip and Bark

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ABSTRACT

A developed bioeconomy needs improved storage concepts for wood chips and forest industry by-products since more storage is expected and the number of requested assortments increases. Today, solutions for coping with storage related problems such as dry matter losses and risk of self-ignition is based separating assortments in smaller piles and avoiding large-scale long-term storage of chips. A safe and efficient storage solution would open for wood chip production all year round and not being limited to just-in-time production during the cold heating season with large demand. This implies a less vulnerable system with larger buffer capacities, a less stressful working environment for chipping and transport contractors and a sounder yearly machine utilization is expected. This study evaluated storage outcome for wood chips and bark when using an improved storage concept with assortment separation using concrete walls and a semipermeable sheet for coverage. The new concept enabled efficient area utilization and increase fire safety at the same time as storage outcome was improved in terms of moisture content, dry matter losses and temperature development compared to conventional open-air piles.

Fuel Quality and Dry Matter Losses of Stored Wood Chips - Influence of Cover Material

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ABSTRACT

Irregular seasonal demand from heat- and combined heat and power plants means that outdoor storage of forest fuels is an inevitable step in the forest fuel supply chain. Storage of fresh comminuted biomass render substantial dry matter and energy losses. Covering can protect wood chips from rewetting, leading to a higher net calorific value and lower dry matter losses, and thus increase the amount of available energy. This study examined the combined effect of covering material on fuel quality and the amount available energy from wood chips stored in a full-scale pile. The combined changes in fuel quality and dry matter loss reduced the amount of accessible energy by 9.8% in the uncovered part, by 5.6 % when covered with water proof or light semi-permeable cover materials and by 1.0 % when covered with a thicker semi permeable material. Fuel quality of wood chips can be improved by covering the piles during storage but the gain is affected by the type of cover material. Seasonal storage in properly covered chip piles facilitate an increased annual utilization of chippers and chip trucks which reduces overall biomass supply chain cost.

Comparison of Cost-Efficiency of Innovative and Conventional Supply Systems for Small Trees and Shrubs in Sweden, Finland, Slovenia and Spain

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ABSTRACT

There are large amounts of underutilized small-diameter trees and shrubs across Europe that could be sustainably harvested to boost the growth of the bioeconomy. Main sources for these residual biomasses are first thinnings of dense forests, overgrown farmland, and clearing operations to maintain infrastructure (roads, power lines, etc.) and prevent forest fires. However, high supply costs make it difficult to bring these biomasses to the market at a competitive price, limiting their utilization and requiring of efficient supply chains. The aim of our study was to compare the cost-efficiency of three innovative systems for industrial supply of small-diameter trees and shrubs, versus conventional, reference systems. The innovative systems consisted of: 1) a harvester Komatsu 901 equipped with an upgraded version of the accumulating felling head Bracke C16, using a novel working method (boom-corridor thinning); 2) the "Retrabio" system, consisting of an integrated harvester and chipper; 3) the "Biobaler" system, attached to a farm tractor, able to cut, compact and produce round bales of biomass. The conventional systems consisted of: 1) the same type of harvester and accumulating felling head, working with a reference working method (selective thinning from below); 2) motor-manual work with a chainsaw or brush saw; 3) mechanized clearing with a chain mulcher. The economic analyses will consider the operations in the supply chain from the stand to the end-user, including harvest, extraction, comminution and transport to industry. Input data to perform the analyses (such as machine productivity) will be obtained from the performed field trials in Sweden, Finland, Slovenia and Spain within the framework of the project "Smallwood" (http://www.smallwood.eu/), and complemented with data from the literature. Comparisons will be performed within countries, considering the assessed machine systems in each stand type. Results will be presented at the conference.

Biomass Harvesting Amidst Market and Policy Constraints: Perspectives of Foresters and Loggers in the Northeastern United States

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ABSTRACT

Woody biomass is a renewable material that can help satisfy energy and other consumption needs across the United States. An extensive forest resource with small-sized trees and dense stands makes the Northeast US a promising source of biomass but harvesting biomass has been a recent challenge in the region because of the reduced economic feasibility of the operation. The main objectives of the study were a) to identify and compare the different circumstances, motivations, and constraints for harvesting biomass in the northeast US; b) to see if the responses varied between different profession and experience categories; and c) to understand the perspectives of foresters and loggers to reduce the current constraints in biomass harvesting. An online survey of foresters and loggers in the region obtained a total of 300 responses. The results showed that biomass harvesting is mostly done to satisfy the landowner objectives (93% favored) and for aesthetic values (85% favored). Among the perceived applicability of biomass utilization, the most positive response was for bioenergy (92% favored) followed by institutional heat (93% favored). However, there was less favoring for the emerging products such as biochar and liquid biofuel which was 71% and 69% favored respectively. A majority of the respondents agreed that lack of markets and trucking distance, favored by 94 and 91% respectively, were the largest constraints in biomass harvesting. There were no significant differences in the responses between profession and experience categories, showing the main opportunities and constraints have been collectively agreed upon by both groups. The recommendations provided by the majority of respondents strongly emphasize the need for better and diverse product markets and more policy incentives for biomass harvesting. Further, many emphasized that harvesting biomass and small diameter timber is an essential part of improving forest health and economic viability in this region of the US.

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Evaluating the Productivity and Costs of Five Energy Wood Harvesting Operations in the Lower Mid-Atlantic Region of the US

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ABSTRACT

Woody biomass is an important feedstock for renewable energy production in the United States. While there are other sources of woody biomass for energy production, one of the main sources with potential for increased usage is forest harvesting residues. Harvest residues are a potential by-product for most standard forest harvesting operations, and some operations utilize this material for energy wood. Energy wood is often the lowest value product generated from a harvest, yet it requires additional processing such as chipping or grinding. Thus, more economics of energy wood production are a research need. This study evaluated five energy wood harvesting operations in the Lower Mid-Atlantic region of the United States. Each of two Appalachian Mountain harvests and three Coastal Plain operations were observed for 4-7 days and productivity data were collected on each harvesting function using time-motion and activity sampling methods. The Mountain operations used tracked feller-bunchers to access steep terrain combined with smaller rubber-tired grapple skidders and knuckleboom loaders. Coastal Plain operations used larger rubber-tired feller-bunchers, grapple skidders, and knuckleboom loaders. Operations used chippers of varying sizes for comminution and trucks with chip vans for secondary transportation. All operations integrated energy wood production into their existing roundwood operation. Productivity and costs of each operation were estimated, and equipment mixes and harvesting methods were evaluated to determine efficiency. Interviews were also conducted with each logging contractor to understand operating strategies and decision making. Results were compared to provide a holistic view of common energy wood harvesting operations across the region. This research will provide stakeholders with a valuable comparison of typical energy wood harvesting operations in the Lower Mid-Atlantic region of the United States which can be used to make better-informed decisions regarding the efficient and economical harvest of energy wood.

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Innovative Duplex Spiral Chipper - Trials for Comminution, Fuel Properties, Storability, Technical Drying, Conveyability and Combustion of a Novel Wood Fuel

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Abstract: The Effiter 20.30 is an innovative duplex-spiral chipper that produces novel fuels ("Effits") that strongly deviate from conventional wood chips in their particle size, particle form and in their lower share of fines. These fuels might offer advantages during storage, artificial drying and combustion. Five different assortments (whole trees of European poplar from short rotation coppice, stemwood of Norway spruce and European beech, forest residues from hardwood and softwood) were comminuted with the Effiter and a reference drum chipper. During chipping, the Effiter produced coarse particles with a pre-broken structure and significantly lower shares of fines (< 3.15 mm) compared to a conventional wood chips (Effits: 2.1 w-% ± 2.7 vs reference fuel: 4 w-% ± 1.0). The novel chipper reached lower throughput rates in all trials (Effits: 4.0 t_{dm}/h ± 1.8 vs reference fuel: 6.5 t_{dm}/h ± 2.9), as well as higher fuel consumption due to differences in chipper size class. Natural drying during five months of storage performed better with Effits compared to conventional wood chips and dry matter losses were decreased (Effits: 6.5 w-% ± 7.8 vs reference fuel: 11.6 w-% ± 7.0). The Effits showed lower air pressure resistance during artificial ventilation than the reference chips but proved to be more energy demanding on a conventional screw-conveyer. Combustion trials in a 20 kW boiler showed no clear differences in emissions (CO, NO_X, TPM) between the two chipping variants. Overall, the novel fuels produced with the Effiter 20.30 might be an interesting alternative to conventional wood chip production especially for private forest owners with a high fuel quality demand and limited access to artificial drying systems.

Keywords: wood chips, fuel production, fuel quality, storage, combustion, drying

1. Introduction

Small and decentralized heating systems that use solid biofuels are an important part of the German heat transition from fossil fuels to renewable energies (BMWI, 2020; FNR, 2017). Especially in rural areas, wood chip boiler < 100 kW are often installed for the purpose of sustainable heat production. Small-scale combustion units have high demands on fuel quality to ensure failure-free, energy efficient, and low-emission combustion. Relevant fuel quality parameters are e. g. a suitable moisture content, a low ash content, low shares of fines and a suitable particle size distribution (Kaltschmitt, 2016).

In Germany, operators of small-scale wood chip boilers are often farmers or private forest owners that produce their own fuels. Their fuel supply chain is frequently integrated into their own forest operations and many boiler operators carry out most of the necessary steps during fuel production such as harvesting of the wood, logging, transport, storage, chipping, drying and / or screening of the materials.

During private chipping operations, small and less expensive chippers are often used for comminution. These chippers are usually PTO-driven and are constructed with the aim to produce wood chips with a high and defined fuel quality, especially for combustion in small-scale heating plants. The particle size and particle shape of the produced wood chips as well as the fuel quality in general depend on the raw material, on the skills of the chipper operator and, to a large extend, on the chipping technology (Kuptz, 2015). For instance, machine parameters such as chipper type, cut length, knife sharpness, feeding system, output system or the dimensioning of chipper screens of a drum chipper strongly affect particle size and particle form. The same parameters affect fuel consumption and throughput rate during production (Kuptz, 2015).

Technical innovations might strongly improve energy efficiency and fuel quality during wood chip production and during the subsequent processing steps (drying, storage, combustion). One of such recent developments is the novel and innovative duplex-spiral chipper Effiter 20.30 (*Figure 1, left*) of the Bavarian company Alvatec GmbH & Co KG. This system is a small PTO-driven chipper (required power: 40 to 70 kW) that applies two simultaneously operated chipping spirals on the same shaft with opposing screw threads, one elongated cylindrical screw (No. 1 in *Figure 1*, *middle*) and a flat screw (No. 2). The shaft rotates at a speed of 270 revolutions per minute. The resulting fuels (called "Effits") (*Figure 1*, *right*) differ largely from conventional wood chips in their physical fuel properties such as particle size and particle shape, i. e. they consist mainly of rather large particles with a pre-broken structure and a very low share of fines.

Due to their unique particle form, the Effits promise advantages during drying, storage and combustion compared to conventional wood chips. Thereby, the Effiter 20.30 is especially designed for rural fuel production by local farmers or private forest owners that want to produce high quality fuels for their small-scale boilers.
The aim of this study was to compare fuel production using the Effiter 20.30 with a conventional reference drum chipper. Time studies were applied to analyze chipper throughput rate and energy consumption. The produced fuels were investigated regarding fuel quality, storage stability, transportability in conventional screw conveyors, drying behavior during artificial drying and combustion behavior in a small-scale wood chip boiler.

Figure 1: ***left:*** *The Effiter 20.30 duplex-spiral chipper powered by a conventional farm machine;* ***middle:*** *Duplex spiral of the Effiter 20.30 with the cylindrical screw on the left (1) and the flat screw on the right (2) as seen from the inspection hatch;* ***right****: Effits from stemwood of Norway spruce (photo: Tobias Hase, StMELF)*

2. Material and Methods

Five different raw materials were chipped at TFZ during spring 2019 using the Effiter 20.30 and a reference drum chipper. The materials comprised whole trees from poplar (*Populus maximowiczii* × *Populus nigra*, clone "Max 3") from a three-year old short rotation coppice (SRC), stemwood (diameter from 15 to 30 cm and length of 2 m) of Norway spruce (*Picea abies*) (STW-S) and European beech (*Fagus sylvatica*) (STW-B), as well as mixed forest residues from coniferous softwood (FRC-SW) and from deciduous hardwood (FRC-HW). The nomenclature is given in *Table 1*. An "E" was added to the variants produced with the Effiter 20.30 and a "R" was added to the reference fuels.

Table 1: *Fuels used during this study incl. abbreviations*

Fuel batch	Effiter (E)	Reference (R)
Poplar	SRC-E	SRC-R
Stemwood Spruce	STW-S-E	STW-S-R
Stemwood Beech	STW-B-E	STW-B-R
Forest residues soft wood	FRC-SW-E	FRC-SW-R
Forest residues hard wood	FRC-HW-E	FRC-HW-R

Raw materials derived mainly from forest areas around Straubing (± 70 km) in Lower Bavaria, Germany. For each variant (raw material × chipper), at least 10 to 20 lcm (loose cubic meters) of fuels were produced, generating a total volume of about 120 lcm for all five raw materials. A conventional PTO-driven drum chipper was chosen as the reference. The model has eight cutting knives, a blower output system, and a maximum in-feed width of 400 × 670 mm. The chipper was equipped with a screen with a hole size of 35 × 40 mm. Both machines (Effiter 20.30, reference) were equipped and maintained with sharp cutting knives during all trials. Chippers were operated using the same tractor for each material, i. e. a Kubota M8560 with 67 kW for producing fuels from poplar SRC, stemwood of Norway spruce and both forest residue batches, or with a John Deere 6135R with 100 kW for the stemwood of European beech. All raw materials, except forest residues, were fed into the chippers manually. In the case of forest residues, feeding was performed by crane.

During all chipping operations, time studies were performed to evaluate throughput rate and fuel consumption. Mass and volume of the produced fuel was determined in an agricultural trailer after comminution. The energy demand was determined by measuring the diesel consumption of the tractor using an external fuel tank that was placed on a scale and continuously monitored. The share of energy required for comminution in relation to the energy content of the final product was calculated using the calorific value of the diesel fuel used and the calorific values of the fuels produced but also fuel consumption of the tractor and the produced fuel mass. After chipping, fuels were sampled representatively according to ISO 18135 and fuel properties were analyzed according to international standards for solid biofuels (*Table 2)*.

Table 2: *Investigated parameters, associated units, and the respective ISO standards*

Fuel quality parameter	Unit	ISO standard
Moisture content	w-%	18134-2
Particle size distribution (fine fraction)	w-%	17827-1
Bulk density	kg/m³	17828
Ash content	w-% d.b	18122
Fuel particle class	-	17225-4 (2021)

Storage behavior and changes in fuel quality during storage were evaluated for all ten fuels in open, small-scale storage containers with a filling volume of approx. 0.6 m^3 (ca. 1100 × 900 × 570 mm). Side walls of the storage containers were insulated using rigid foam insulation panels (30 mm) to create a microclimate similar to large storage piles. All containers had a perforated bottom (hole diameter 20 mm) to ensure air circulation. Containers were stored outdoor in a rain and wind protected shelter for 23 weeks. Container mass was determined every 21 days. Previous research projects at TFZ showed that although results from container trials cannot be transferred to outdoor storage piles directly, these containers simulate trends in the storage of wood chips in large storage piles rather well (Hofmann, 2017).

In addition to container storage, both Effits and the reference fuel of spruce stemwood were stored in an outdoor storage pile of approx. 15 lcm (3 ×5 ×2 m), each, for 23 weeks. Twelve balance bags (approx. 5 l) were filled with sample material and placed into each pile at defined points (pile center, pile surface, etc.) to monitor the changes in fuel quality parameters and dry matter losses over the storage period. The piles were covered with a vapor permeable fleece (PolyTex, Zill GmbH & Co. KG) to avoid rewetting. Temperature profiles were recorded both in the containers and in the piles using temperature sensors (Datalogger testo 175-H1, Testo AG; interval: one hour).

Artificial drying was performed directly after the chipping process (*Figure 2, left*). All fuels were dried to a moisture content of about 15 w-% in a self-constructed batch drying systems consisting of two containers with a filling volume of approximately 2 lcm each (1650 × 950 × 1320 mm). In this setup, an adjustable blower is used to ventilate the drying boxes from below through a perforated floor with adjustable air flow rates. To improve drying, ventilation air was heated up using an external heater (18 kW). The temperature measurement of the drying air takes place at the entrance of each box. To automatize the drying process, each drying box is equipped with load cells and the drying system shuts down automatically when the calculated target weight (calculated by using initial fuel moisture content and initial fuel mass) is reached. During drying, process parameters of the drying system, i. e. the temperature of the drying air, the drying duration, the volumetric air flow rate (TERZ 94, RMG Messtechnik GmbH, Germany), the changes of fuel mass in each box and the energy consumption of both the blower and the heater were constantly monitored. The efficiency of the drying process is calculated by relating the actual energy used for heating and ventilation to the calculated energy required for the evaporation of the water in the 30 to 20 w-% range of drying.

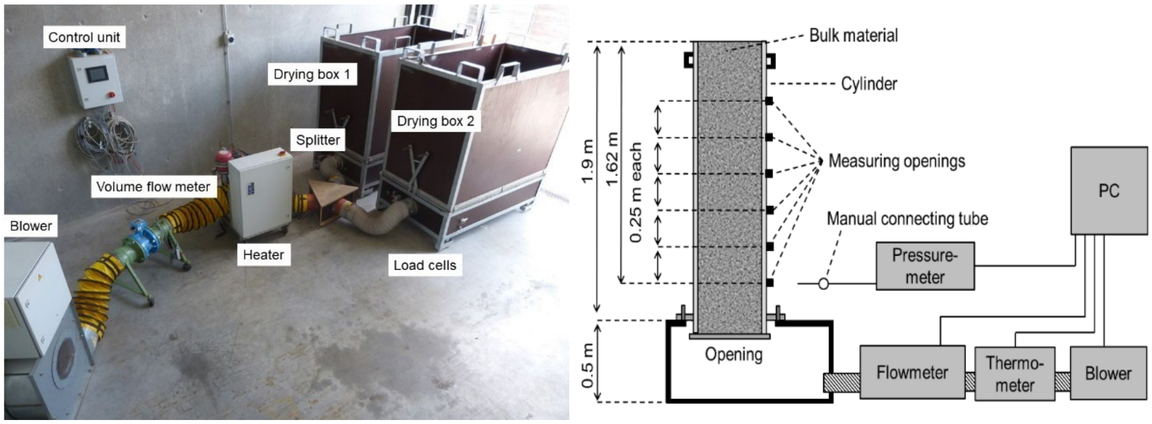

***Figure 2: left:** Experimental setup of the batch drying;* ***right:** Schematic design of the air pressure resistance test stand used at the TFZ*

Air pressure resistance during ventilation was evaluated experimentally in a custom-built flow cylinder. *Figure 2* (*right*) shows a schematic drawing of the test stand. The cylinder has a height of 2 m and a filling volume of 0.4 lcm. Air pressure resistance (0 to 2500 Pa) was determined by measuring changes in static pressures (P26 (0-100 Pa, 100-500 Pa and 500-2500 Pa) Halstrup-Walcher GmbH, Germany) at six defined positions in the cylinder at varying air flow rates. The air flow was increased in 10 % steps from blower idle (0 %) to 100 %. The airflow was measured continuously (TERZ 94, RMG Messtechnik GmbH, Germany). Each sample was measured twice, whereby the cylinder was emptied and refilled between the experiments. Detailed information on how air pressure resistance was calculated from the data is given in Kuptz et al (Kuptz, 2021).

Transportability of the dried fuels in screw conveyors of small-scale boilers was tested using a specifically designed test stand at TFZ consisting of a fuel bunker equipped with a conventional screw conveyor (Ø = 100 mm) (*Figure 3, left)*. The test stand was placed on a platform scale (Mettler-Toledo GmbH, MT KD600) and bunker weight was constantly monitored to determine fuel mass flow. Fuel transport was simulated using a dynamic boiler performance cycle. Each conveying test lasted for 80 minutes and conveyor performance was decreased automatically every 8 min from 100 % to 10 % in 10 % steps. The required power of the screw conveyor and thus the total amount of energy as well as exceedances of the nominal power of the conveyor motor were measured in 1 s intervals. Analyses of the particle size distribution and particle form (ISO 17827-1, n = 1) was performed for each fuel before and after the trials to identify changes in the physical fuel structure due to the transportation process.

All dried fuels with a moisture content of approx. 15 w-% were combusted in a small-scale wood chip boiler with a thermal output of 20 kW. 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 3, right* shows a schematic drawing of the combustion test stand and the arrangement of the measurement devices.

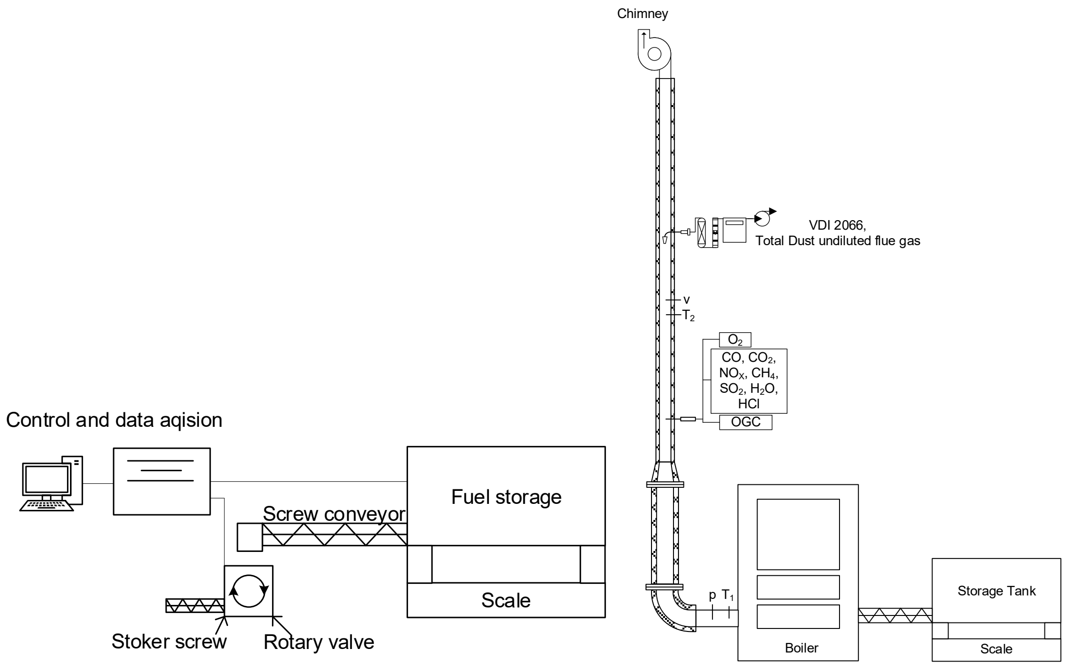

Figure 3: left: *Schematic drawing of the transportability test stand used at the TFZ;* ***right:*** *Schematic drawing of the combustion test stand used at the TFZ (position of measurement points: T -= temperature, p = pressure, v = velocity)*

The heat consumption was permanently regulated to a nominal load of 20 kW (± 8 %) 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, 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 isokinetically sampled following VDI 2066-1 applying a filtration temperature during sampling of 160 °C and the filter pre- and post-treatment temperature of 180 °C and 160 °C, respectively. Also, solid depositions in the sampling line were collected after each measurement day by washing with acetone and subsequent evaporation.

The boiler was operated at a constant flue gas draught of -10±2 Pa as it is suggested by the boiler manufacturer. The diameter of the flue gas duct and the connection pipe was 150 mm. The 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 80 mm. For each combustion trial, the boiler was pre-heated to nominal load for approx. 1.5 h followed by a continuous nominal load operation. Five TPM measurements lasting 30 minutes each were conducted within the 5 h operation. After each combustion experiment all ash was removed from the boiler. If differences between mean values are stated as significant the data was always tested to normality (Shapiro-Wilk). Significance was tested using either a t-test or a Mann-Whitney-test. Correlation in data was tested with the Pearson correlation. The level of significance was always set to $p<0.05$. If higher significance levels were reached it is indicated.

3. Results and discussion

3.1 Throughput rate and energy consumption

Throughput rate per ton dry mass (t_{dm}) during chipping with the Effiter 20.30 was lower compared to the reference chipper and required a higher amount of energy (*Table 3*).

Table 3: *Throughput rate, energy consumption and share of comminution on energy content in wood chips during fuel production with the Effiter 20.30 and the reference chipper (n = 1)*

Variant	Throughput rate t_{dm} / h	Specific fuel consumption L / t_{dm}	Share of comminution on energy content in wood chips %
SRC-E	2.1	4.4	0.9
SRC-R	2.6	3.2	0.6
STW-S-E	2.9	4.5	0.9
STW-S-R	4.5	2.9	0.5
STW-B-E	2.9	6.0	1.2
STW-B-R	5.4	3.6	0.7
FRC-SW-E	1.6	5.5	1.0
FRC-SW-R	2.7	3.3	0.6
FRC-HW-E	1.3	5.9	1.1
FRC-HW-R	2.1	2.9	0.5

The highest throughput rates were achieved during the chipping of stemwood. Approx. 2.9 t_{dm}/h were produced with the Effiter for both stemwood assortments while the reference chipper produced 4.5 t_{dm}/h for Norway spruce and 5.4 t_{dm}/h for European beech, respectively. As the reference chipper is from a larger chipper size class (>100 kW) compared to the Effiter, differences in throughput rate might derive from a generally higher chipping power, but also from the maximal stem diameter of both machines. Chipping with the reference chipper allowed for a maximal stem diameter of 400 mm while with the Effiter 20.30, a maximal stem diameter of 200 mm could be processed. Thus, higher shares of wood could be fed into the reference chipper at a given time interval resulting in the overall higher throughput rates.

In the case of forest residues, both chippers were fed by a crane. The lower throughput rate compared to the manually fed stemwood and SRC wood might thus be related to the crane operation that strongly decreased the feeding rates of the FRC batches. Another reason for the lower throughput rates of FRC might be the much lower mass per volume compared to stemwood so that the feeding operations of the chipper resulted in lower mass input of fuel at a given amount of time. Additionally, the increased bulkiness of FRC wood compared to stemwood due to twigs and branches might cause mechanical resistance during feeding and chipping (Kuptz, 2015).

The results shown here are related to mass (d. b.). When throughput rates are related to volume, the Effiter still performed lower compared to the reference chipper but the differences were smaller (data not shown). This might be explained by the lower bulk density and therefore the higher bulk volume of the Effits compared to conventional wood chips (see section 3.2), leading to overall larger volumes at comparable fuel masses.

Results on specific fuel consumption and thus percentage of comminution on the energy content in the wood chips matched results on throughput rates in that the Effiter consistently required a higher amount of fuel per t_{dm} and therefore required higher shares of energy for the chipping process. The differences were most pronounced for forest residues. The data collected show that the difference in specific energy consumption of the two machines increases at increasing chipper idle times (e.g. during chipping of FRC batches). This is due to the construction of both chippers. The Effiter, which is driven purely by the torque of the tractor, requires a higher amount of fuel during an idle period compared to the reference chipper, which required less power from the tractor in these periods due to the mass of the chipper drum and the installed flywheel that were already in motion.

3.2 Fuel quality

The moisture content of the comminuted fuels was > 30 w-% and therefore in a range (in which microbial activity could still be expected during storage (*Table 4*) (Kaltschmitt, 2016). However, some of the materials were not freshly cut due to the tense drought situation and calamity stress during summer of 2019 in Germany, which is reflected in moisture contents between 30 and 35 w-%. These lower values may cause lower dry mass losses compared to fresh fuels. Ash content in the Effits was slightly lower (*Table 4*).

In all cases except for forest residues from coniferous softwood (FRC-SW), the Effits contained a lower share of fines (i. e. particles < 3.15 mm, *Figure 4, left*) compared to the respective reference fuel. This effect was strongest in case of stemwood of Norway spruce (STW-S). Here, the average fine fraction in the reference fuel was 36 times higher compared to the Effits (STW-S-E). The significantly lower shares of fines in Effits compared to the reference fuels fits to expectations regarding fuel production in that the Effiter 20.30 comminutes the materials in a more cutting motion and at a much lower cutting speed than the reference chipper leading to less breaking of the particles during the chipping process.

Table 4: *Fuel quality parameters (Mean values ± SD)*

Variant	Moisture content w-% (*n = 10*)	Ash content w-% d.b. *(n = 1 to 5)*	Particle size class (*n* = 3)
SRC-E	58.8 ± 0.004	1.5	-
SRC-R	58.3 ± 0.011	1.8 ± 0.015	P31s
STW-S-E	53.7 ± 0.013	0.8	-
STW-S-R	55.0 ± 0.026	0.9 ± 0.0008	P31s
STW-B-E	33.3 ± 0.012	0.7	P45s
STW-B-R	37.9 ± 0.049	0.7 ± 0.0013	P31s
FRC-SW-E	36.6 ± 0.025	0.7	P45s
FRC-SW-R	34.0 ± 0.027	0.8 ± 0.0008	P45s
FRC-HW-E	35.5 ± 0.032	1.4	P45s
FRC-HW-R	36.9 ± 0.008	2.0 ± 0.0044	P45s

In case of forest residues from softwood (FRC-SW), the fine content of the Effits was higher compared to the reference fuel (*Figure 4*). In contrast, results on particle size distribution during storage trials (section 3.3) or artificial drying (section 3.4) always displayed lower fines in FRC-SW-E compared to the reference fuel (storage: Effits = 3.5 w-%, reference = 8.0 w-%; artificial drying: Effits = 1.0 w-%, reference = 4.5 w-%). Thus, the here displayed higher fine fraction in FRC-SW-E might be due to unrepresentative sampling of an overall heterogeneous raw material (forest residues) and the relatively small sample size (*n = 3*) for the determination of particle size distribution.

The generally observed higher shares of fine particles in forest residue fuels can be attributed to the higher share of small particles such as needles, leaves or small branches in the unchipped raw materials (Kuptz, 2015).
Previous studies suggest that a fuel with a low percentage of fines and a high percentage of coarse particles provide for better ventilation during storage and thus for better natural drying (see section 3.4) (Kuptz, 2021) and advantages during combustion (see section 3.6) (Schön, 2019).

Two of the five Effits assortments could not be classified in any of the specified particle size classes (P45s or smaller) according to DIN EN ISO 17225-4 (2021). The remaining three assortments were assigned to P45s. The reference batches could be classified into either P31s or P45s (*Table 4*). Thus, the results on particle size distribution measured by horizontal screening and classification according to ISO 17225-4 suggest that the very large Effits particles might cause problems in the fuel supply system and during combustion in small heating systems. Whether or not this is actually true will be investigated in the following sections focussing on transportability (section 3.5) and combustion (section 3.6).

In all cases, mean bulk density (*Figure 4*, *right*) of the Effits (154 ± 25 kg / m^3, d. b.) was significantly lower compared to the reference wood chips (168 ± 29 kg / m^3, d. b.). For SRC-poplar, stemwood from Norway spruce and forest residues from hardwood, bulk densities of the Effits were about 10 kg/m^3 (d. b.) lower compared to the reference fuel while for stemwood of European beech and forest residues from coniferous wood, this difference amounted up to 21 kg/m^3 (d. b.). The lower bulk densities in the Effits might be due to their changed particle size distribution, i. e. their higher proportion of large particles compared to the reference fuels. This should result in a higher volume of free air voids in the Effits bulk material and, thus, to a higher porosity of the fuel. Consequently, bulk density is expected to strongly influences process parameters during fuel processing such as air pressure resistance during storage or artificial drying (Kuptz, 2021). Highest bulk density was measured for stemwood of European beech. The observed differences among individual raw material were expected due to higher gross density of the hardwood species.

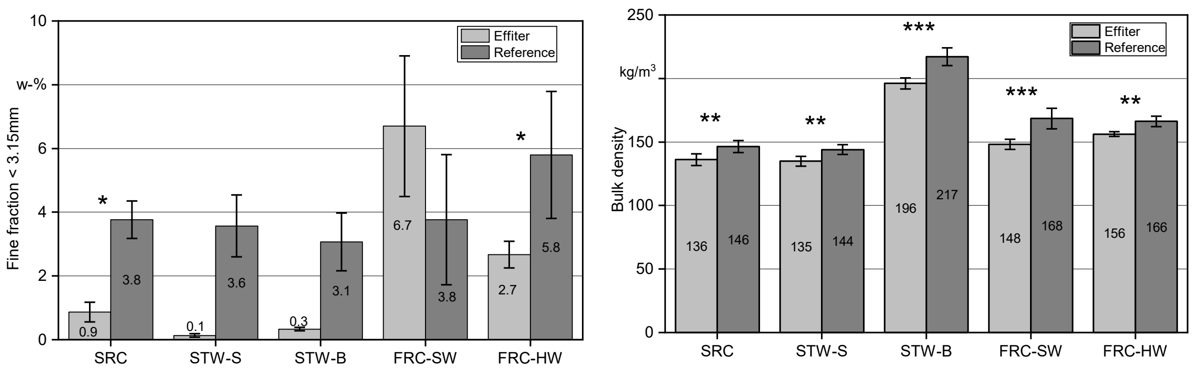

Figure 4: left: *Mean fine fraction (particles ≤ 3.15 mm) in the fuels ± standard deviation (n = 3). * represents significant difference (* p ≤ 0.05; ** p ≤ 0,01; *** p ≤ 0,001) between Effits and reference (t-test and Mann-Whitney-test)**; right:** Mean bulk density (on d.b.) for the fuels after chipping ± standard deviation (n = 5). * represents significant difference (* p ≤ 0.05; ** p ≤ 0,01; *** p ≤ 0,001) between Effits and reference (t-test and Mann-Whitney-test)*

3.3 Storage trials

In most cases, storage of the fuels in containers for 23 weeks led to a strong decrease of the fuel moisture content (*Figure 5*, *left*). Values after storage varied between 16 w-% (STW-B and FRC-SW) and 30 w-% (SRC) for Effits and 18 w-% (FRC-S) and 42 w-% (STW-S) for the reference fuels. In all cases, Effits had a significantly lower moisture content after storage compared to the conventional wood chips ($p \leq 0.05$, t-test) and the reduction in moisture content (ΔM) after 23 weeks of storage due to natural drying in containers was always higher for Effits compared to the reference fuels (except FRC) (*Figure 5*, left*; Table 5*).

Four of the five Effits batches from container trials had a moisture content < 20 w-% after storage (*Figure 5*, *left*) Thus, drying in containers was sufficient for the use of these fuels in most small-scale heating systems that often require optimal moisture contents of 15 to 20 w-% for low-emission combustion. For the reference fuels, this was only the case for forest residues from coniferous softwood.

Table 5: *Reduction in moisture content (ΔM) after 23 weeks of storage in container*

Fuel	ΔM w-%	p-value (t-test)
SRC-E	28.3	<0.001 (significant)
SRC-R	23.6	
STW-S-E	36.0	<0.001 (significant)
STW-S-R	10.6	
STW-B-E	18.4	<0.001 (significant)
STW-B-R	13.2	
FRC-SW-E	23.2	<0.001 (significant)
FRC-SW-R	14.2	
FRC-HW-E	15.7	0.2 (not significant)
FRC-HW-R	16.2	

The monthly dry matter losses in the small-scale storage containers varied between 0.3 w-% (STW-B) and 3.1 w-% (SRC) for the Effits and between 1.1 w-% (STW-B, FRC-SW and FRC-HW) and 4.1 w-% (SRC) for the reference fuel. In all cases, the monthly dry matter losses were 0.8 to 2.6 % lower for the Effits compared to the conventional wood chips (*Figure 5*, *right*). This coincided with higher temperatures ($\Delta T > 3$ K) in the reference containers (data not shown), indicating an increased microbial activity and a lower ventilation within the reference samples (Hofmann, 2018; Jirjis, 2005; Jylhä, 2017).

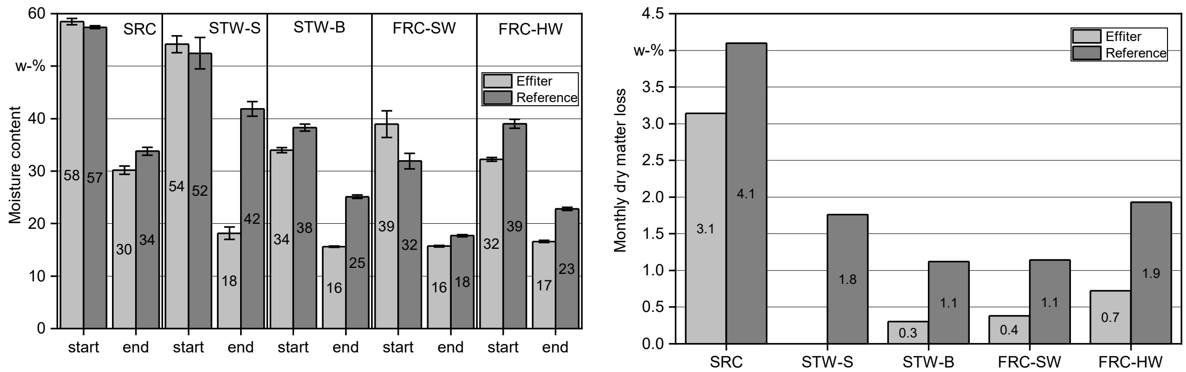

Figure 5: left: *Mean moisture content in the fuels before and after storage in container ± standard deviation (n = 5)* ***right:*** *Monthly dry matter loss for the stored fuels, (n = 1)*

In case of STW-S, calculation of monthly dry matter loss amounted up to -0.8 w-% (i.e. dry matter gain) due to calculation uncertainties that results from variation in moisture content determination. Although this value must be considered illogical and is therefore omitted from *Figure 5 (right)*, a positive effect of Effits fuels compared to the reference fuels is obvious.

Since some of the fuels showed a moisture content of less than 40 w-% at the start of the storage trials, it can be assumed that the microbial degradation processes and consequently dry matter losses were slightly inhibited during storage. Thus, in fresher materials, monthly dry matter losses might be even higher.

The trend from container trials could be replicated in storage piles, i. e. lower pile temperatures during storage, significantly lower moisture contents after storage (31 w-% vs. 47 w-%; $p \leq 0.05$; t-test) and lower dry matter losses (0.9 w-% vs. 1.3 w-%) for the Effits compared to the conventional wood chips. The moisture content of the fuels after storage in piles was not suitable for an optimal performance of many small-scale boilers. Moreover, fuels from storage piles showed a higher heterogeneity after storage compared to fuels from containers.

3.4 Artificial drying

In contrast to the storage trials, differences among fuel batches during artificial drying were rather small. The calculated efficiency of the self-constructed batch dryer (related to the energy required for drying of fuels from a moisture content of 30 to 20 w-%) is shown in *Table 6.* Dryer efficiency ranged from 42.56 % to 61.72 % and was often slightly higher for Effits compared to the respective reference fuels when the same dryer settings (volumetric air flow, heat, etc.) were used for drying.

Air pressure resistance (in Pa / m) was strongly reduced during ventilation of Effits compared to the reference fuels in four of five cases (see *Table 6)*. The lower air pressure resistance is due to various fuel parameters such as the novel particle structure with its coarse particles and lower share of fines. Particle size and particle form directly influence on the pore volume (i.e. the porosity) and thus the size, structure, and abundance of free air voids within a bulk material. This alters laminar and turbulent air flow through a material (Kuptz, 2021), affecting both natural and artificial drying. In case of artificial drying systems, process parameters (air flow rate, air temperature, etc.) may be further adjusted to optimized drying by ensuring that the air leaving the dryer is always saturated. This would require considerably more drying trials with constant adaptation of these parameters. Still, based on the results in the air pressure resistance, it can be assumed that the drying of Effits has considerable potential for optimization and that the parameters of the respective drying system should be optimized for the novel fuel.

Table 6 *Pressure resistance at an air flow rate of 0.5 m/s and dryer efficiency*

Variant	Pressure resistance at a volumetric air flow rate of 0.5 m/s in Pa / m	Dryer efficiency (30 to 20 w-% moisture content) %
SRC-E	293	42.6
SRC-R	464	-
STW-S-E	298	46.7
STW-S-R	429	46.7
STW-B-E	255	47.1
STW-B-R	487	42.2
FRC-SW-E	488	56.6
FRC-SW-R	676	54.5
FRC-HW-E	824	61.7
FRC-HW-R	686	59.7

3.5 Transportability

The transportability of the coarse Effits particles in common screw conveyors of commercially available small-scale combustion systems (screw conveyor Ø = 100 mm) was possible but required a higher energy input and led to a higher number of peak loads that exceeded the nominal power of the conveyor motor compared to conventional wood chips in four out of five cases (*Table 7*). This might result from an increased mechanical stress for conveyor systems during boiler application.

The coarse Effits particles were easily broken down by the conveyor screw due to their pre-broken structure. At the same time, breaking of the coarse particles led to an increase in the fine particle fraction (i. e. particles ≤ 3.15 mm). This resulted in a particle size distribution of the conveyed Effits that was almost identical to that of the reference fuels before fuel transport (data not shown). Thus, no strong differences in emission behavior due to differences in fuel particle size distribution were expected.

Table 7: *Performance data of the transportability trials*

Variant	Fuel mass (d.b.) kg	Peaks exceeding the nominal power (550 W) s	Maximal power W	Energy consumption Wh
SRC-E	126	22	595	334
SRC-R	161	0	455	294
STW-S-E	101	315	844	362
STW-S-R	114	4	595	342
STW-B-E	130	415	878	370
STW-B-R	206	242	812	360
FRC-SW-E	188	13	680	322
FRC-SW-R	192	1	560	316
FRC-HW-E	147	8	743	281
FRC-HW-R	186	161	716	296

3.6 Combustion trials

CO emissions during combustion (at STC, i. e. dry flue gas at 0 °C, 1,013 hPa and 13% O_2) ranged from 55 (FRC-S-R) to 287 mg/m^3 (STW-S-R), (*Figure 6*, *left*). All values remained below the German emission threshold of 400 mg/m^3 (13% O_2, 1. BimSchV, Step 2) (BMU, 2010). For some fuels (STW-S, FRC-HW), CO emissions were significantly different when Effits or the reference fuels were applied. However, no general trend between chipping variants could be observed.

High CO emissions indicate incomplete combustion. In this study, CO correlated well with moisture content ($R^2=0.58$) with a significant ($p<0.05$; pearson correlation) correlation. This might be due to cooling of the combustion chamber when fuels with a higher moisture content are applied (Kaltschmitt, 2016; Schön, 2019). STW-S-R had one of the highest moisture contents (19.9 w-%) and achieved the highest CO emissions during combustion (287 mg/m^3) while FRC-SW-R had one of the lowest moisture contents (11.8 w-%) and the lowest CO emissions (55 mg/m^3) (data not shown). Thus, the observed differences in CO emissions most likely relate to differences in fuel moisture content rather than to the applied chipping technology.

NO_X emissions ranged from 148 (STW-S-E) to 336 mg/m³ (FRC-HW-E) (*Figure 6*, *right*). Currently, NO_X is not limited for this boiler class according to German legislation. NO_X emissions strongly differed between raw materials. Significant differences between different chipping techniques (Effits, reference) were observed for SRC, STW-B and FRC-HW but no general trend could be observed.

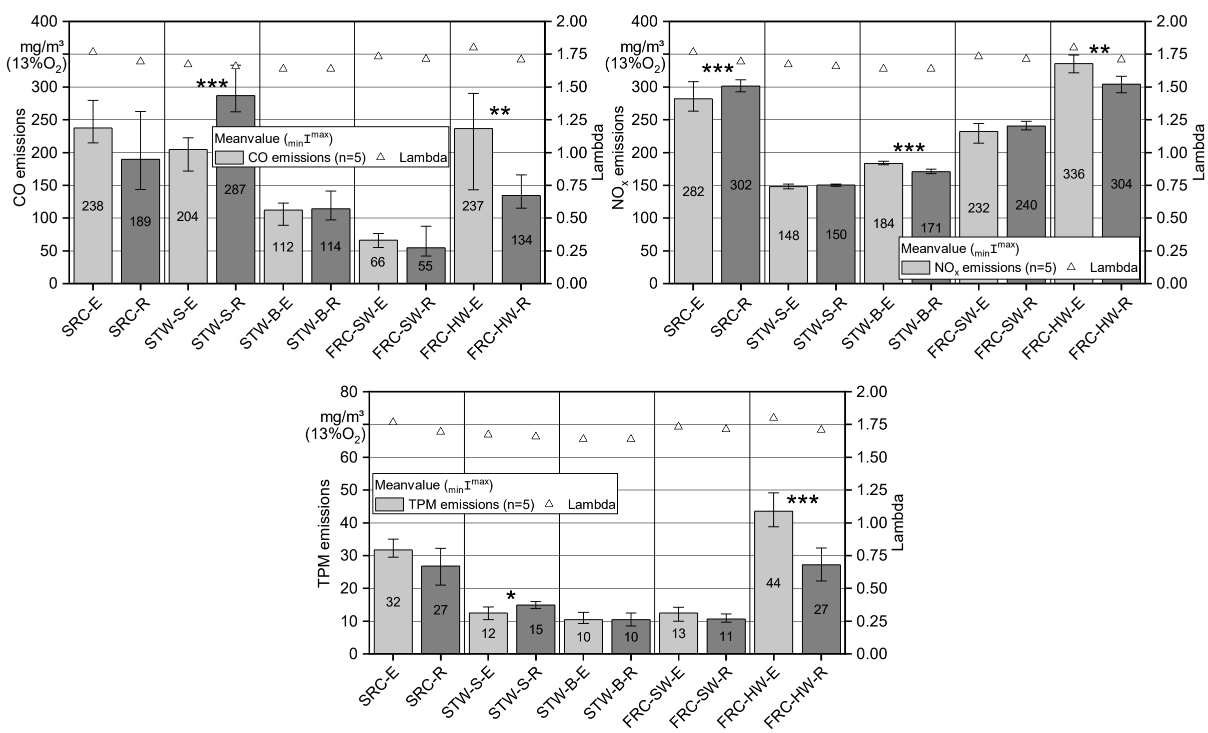

***Figure 6: left:** Mean CO emissions (± min/max values) during combustion trials in a 20 kW wood chip boiler (n = 5). **right:** Mean NO_x emissions (± min/max values) during combustion trials in a 20 kW wood chip boiler (n = 5). **bottom:** Mean total particulate matter (TPM) emissions (± min/max values) during combustion trials in a 20 kW boiler (n = 5). * represents significant difference (* p ≤ 0.05; ** p ≤ 0,01; *** p ≤ 0,001) between Effits and reference (t-test and Mann-Whitney-test)*

NO_x emissions usually can be attributed to N content in fuels (Schön, 2019) explaining the higher NO_X emissions with increasing shares of N-rich plant parts such as bark, needles/leaves and small twigs in FRC or SRC (Kaltschmitt, 2016) (*Figure 6*, *right*). Moreover, the results on elemental analysis show a clear linear and significant correlation between the N-contents of the fuels and the NO_x emissions during combustion ($R^2 = 0.81$; $p<0.001$; pearson correlation) (data not shown). Thereby, N content was lower for many reference fuels compared to the respective Effits, probably due to differences in stem diameter during chipping and therefore due to differences in the ratio of bark to wood.

TPM emissions ranged from 10 (STW-B-E, STW-B-R) to 44 mg/m³ (FRC-HW-E). Three of the five raw materials (STW-S, STW-B and FRC-SW) showed TPM emissions below the German emission threshold of 1. BImSchV (BMU, 2010) for small-scale wood chip boilers < 1 MW (i. e. 20 mg/m^3 at STC) (*Figure 6, bottom*). Significant differences between Effits and reference fuels were measured during combustion of STW-S and FRC-HW but no general trend could be observed.

Schön et al (2019) investigated the effect of the fine content on wood chip combustion by mixing woody fines of the same chemical composition to regular wood chips, i. e. by altering particle size distribution but not the share of aerosol forming elements. In their study, TPM emissions increased with increasing fine content. In contrast, no trend could be observed during this study whether Effits (i. e. fuels that are generally low in fines) or the reference fuels were combusted. This might be due to the previously observed breaking of the coarse Effits in screw conveyors and the associated change in particle size distribution / the increase in the share of fines (see section 3.5). Thus, the results indicate that other influences such as moisture content (leading to soot formation due to incomplete combustion), ash content or the amount of aerosol forming elements might be more relevant to explain the observed TPM emission behavior (Schön, 2019).

Overall, combustion trials indicated that there is no clear trend between the type of comminution (Effiter / reference) and the emissions of CO, NO_X or TPM. During combustion in the 20 kW boiler, no mechanical problems, e. g. clogging of screw conveyors or fuel bridging occurred that could be attributed to the novel structure of the Effits. However no improvement but also no disadvantage for combustion could be identified whether Effits or conventional wood chips were applied.

4. Conclusion

The Effiter 20.30 had lower throughput rates, a higher energy consumption and a higher share of the energy of comminution during fuel production compared to the reference chipper. This might be due to different chipper size classes and variation in stem diameters during chipping. Due to the reduced throughput rate compared to industrial scale chippers, the machine might be most suitable for small-scale fuel production, e. g. for farmers or private forest owners that want to produce fuels from their own forests or short rotation coppices.

Fuel production with the Effiter 20.30 resulted in fuels with very low fine contents that had a coarse and pre-broken particle structure compared to conventional wood chips. This led to advantages during storage (better drying, lower dry matter losses) and artificial ventilation (lower air pressure resistance). Thus, the novel fuel structure makes the Effiter especially interesting for fuel producers with no access to artificial drying systems, i. e. that want to apply natural drying during pile storage. At the same time, small batch drying systems such as drying containers that are often applied at biogas plants in rural areas usually operate with thicker fuel beds compared to continuously moving dryer (e.g. belt dryer). These small-scale dryers might benefit from the improved ventilation due to the coarse particle structure.

During this study, no clear benefits could be observed regarding artificial drying in the self-constructed batch drying system. However, no adjustments were performed regarding volumetric air flow rate and drying temperature. These parameters might be improved to further adjust the drying process in that the dryer exhaust air should always be saturated. Further trials are required to optimize the drying efficiency of a batch drying system using Effits.

For large scale fuel production, a bigger Effiter size class might be developed. Especially for the setup of industrial scale wood chip storage piles, the duplex-spiral technique might be an interesting approach to improve storage behavior. Further trials are required to test the duplex-spiral technique on storage at a larger scale.
No improvement but also no disadvantage could be observed regarding the combustion behavior of Effits compared to conventional wood chips. This might be due to further comminution of the fuels in small screw conveyors that are commonly used in small-scale boilers. Additional trials are recommended on combustion systems using screw conveyors with a larger diameter or a walking floor, i.e. that do not alter fuel particle structure of the Effits by breaking of the coarse particles. This might lead to reduced TPM emissions during combustion as long as the fine content of the fuels remains low. Moreover, these novel fuels might be especially suie for combustion in small-scale decentralized wood gas CHP plants that require coarse, high-quality fuels with very low fine contents.

In conclusion, the Effiter 20.30 is an interesting and novel approach for chipping that applies an innovative chipping technique. Currently, it might be considered most suitable for local farmers and private forest owners to supply their own small-scale wood chip boilers, but further fields of application might be developed.

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Estimating Available Unused Dead Wood Materials for Heat Generation in Mongolia: How much Coal can Unused Dead Wood Materials Substitute?

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ABSTRACT

In this study, we estimated the technoeconomic availability of three types of dead trees, namely commercially fallen, normally fallen, and standing, in Mongolian subgroups. For dead trees of three major Mongolian tree species (Siberian larch, Scotch pine, and Asian white birch), lumber, firewood, and unused material as sources of energy were quantified and operational costs (marking, felling, skidding, transporting, loading/unloading, processing, and stumpage prices) were estimated. As a result, most Mongolian subgroups were profitable, and suitable for the harvest of unused materials. Moreover, unused materials of dead trees can substitute nearly 5.45 million tons of coal, although it is not sufficient to meet the 0.6 years of coal demand across Mongolia. However, in some places, unused dead wood materials can completely substitute coal for decades. Therefore, although the heat utilization of woody biomass is not suitable for Mongolia as a whole, it is feasible in specific regions where forest resources are abundant, such as some Mongolian sub-provinces. Promoting the use of dead trees can reduce the risk of damage caused by wildfires and pests, which are serious problems in Mongolia, and keep the forests healthy. Furthermore, unused materials can generate new income opportunities, and the forest land can be well prepared by removing dead trees to promote planting for sustainable forest management. Finally, dead trees can be used as a resource until transition to sustainable forests with living trees.

Forest Residue Harvesting and Logistics

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ABSTRACT

Logging operations produce a large amount of forest residuals as a byproduct of their normal operations. In an attempt to increase profits, loggers can collect, process, and transport these residues to energy producers in the form of wood chips. These wood chips can then be burned to produce energy. However, the harvesting and processing of forest residues poses both financial and logistical challenges. The first objective of this study is to formally establish the production rates and costs associated with forest residue harvesting and on-site processing in the southeastern United States. Additionally, biomass chipping operations remove the slash that a typical logging operation would scatter about the site. Accordingly, the second objective of this study is to quantify the environmental impacts that forest residue chipping operations have on the site. These objectives were accomplished by means of gross time study methods and several environmental impact assessment tools, such as the USLE equation and state-specific BMP compliance surveys. Three operations were visited in the course of this study: two in Florida and one in Georgia. Production rates were determined for all three.

Poster Presentations

Acoustic analysis of forestry work

Richard Parker, Brionny Hooper, Brooke O'Connor

Biofeedback on forestry machine operators

Brooke O'Connor, Richard Parker, Brionny Hooper

Assessment of physical risks in emergency vehicles used in rural areas, Northern Brazil

Roldão Carlos Andrade Lima, Luciano José Minette, Stanley Schettino, Glicia Sivania Pedroso Nascimento, Denise Ransolin Soranso, Wanderson Lyrio Bermudes

GNSS Positioning and Accuracy of New Dual- and Tri-Frequencies Smartphones under Forest Canopies

Thomas Purfürst

Automating the characterization of log inventories at roadside

Samuel Pilote, Daniel Beaudoin, Eric R. Labelle

Simulation tool to analyze the silvicultural results of conceptual autonomous tree planting machines: a sub-study of the Swedish AutoPlant project

Jussi Manner, Anders Eriksson, Linnea Hansson, Back Tomas Ersson

Comparing the cost of cardboard box concepts that increase the productivity of tree planting machines: a case study from southern Sweden

Back Tomas Ersson, Jussi Manner, Lars-Göran Sundblad

Does the damage caused by harvester head feed rollers have an impact on the moisture content of wood?

Karol Tomczak, Arkadiusz Tomczak

Saplings extractor for mechanized planting

Radomir Ulrich, Ladislav Zverina, Lubos Stanek

Performance of small-sized harvesting system for single tree selection thinning of Quercus acuta using an excavator-based grapple machine and a winch-mounted mini-forwarder

Yasushi Suzuki, Tetsuhiko Yoshimura, Kai Moriguchi, Yoshifumi Hayata, Mitsuharu Urabe, Kiyomitsu Imayasu

Log shape segmentation by deep learning for autonomous log loading

Kengo Usui

Towards as usable roll-over protection system for quadbikes

Carola Häggström, Björn Edlund, Thomas Kronholm, Tomas Nordfjell, Peter Lundqvist

A new type of renewable energy source derived from forestry

Radomir Ulrich, Lubos Stanek, Ladislav Zverina

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Kazuhiro Aruga, Yoshino Tsukahara, Yusuke Matsuoka

Can the terrestrial laser scanner become a widely used tool for estimating biomass production from hybrid poplar crops?

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Acoustic analysis of forestry work

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ABSTRACT

Large forestry machines make considerable noise when working. Some forest managers and supervisors have stated that the sound of a cohesive, productive and efficient forest operation is different from one that is not. "A harmonious operation sounds more harmonious". We are using acoustic analysis techniques to explore this concept and try to determine if there is a quantitative relationship between sound and work. In addition, the analysis of sound may provide information on productivity and skill of the operator. For example, a novice machine operator may use the machine throttle more aggressively than an expert and so sound differently. The novice may also drop logs or work more slowly than an expert so their acoustic signature may be different. Acoustic analysis is common in the condition testing of machinery to detect bearings that are wear out or unbalanced rotating components. The military have used acoustic techniques to detect the presence and type of vehicles in terrestrial and aquatic environments. We will draw on that knowledge and explore the feasibility of analyzing the sound from forest operations.

Biofeedback on forestry machine operators

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ABSTRACT

This experiment aims to assess operators' muscle load and stress in forestry machines during harvesting operations using electromyography sensors. This research continues past research conducted by Scion (New Zealand Forest Research Institute) to evaluate EMG biofeedback in forestry operations in New Zealand. This work is conducted as part of a Master's project in collaboration with Scion and Waikato University with funding from the Forest Growers Levy in New Zealand. The forest industry in New Zealand has shifted to predominantly mechanised harvesting and processing with a growing trend of tethered or cable assist logging. Operators use levers to control the machine's mechanisms and sit for long periods in one position. These workstations can be challenging for muscles and cause ongoing shoulder and neck pain. This project investigates these workstations and the operators' stress and tension levels with the additional effect of working on a gradient. Preliminary measurements will compare muscle load variation between machine operators working on flat vs steep (<20deg slope) terrain in logging operations. Electromyography (EMG) is used to study electrical signals in the muscles. Wearable EMG sensors were used to transmit data on target muscle groups in real-time via a wireless link to a recording device. Additionally, Biofeedback was explored to visualise and improve the machine operator's awareness of their muscular tension. Biofeedback comprised a real-time muscle activity display, allowing operators to observe the activity of their monitored muscles and consciously manage the contraction and relaxing of these muscles.

Assessment of physical risks in emergency vehicles used in rural areas, Northern Brazil

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ABSTRACT

Emergency vehicles are of fundamental importance for human health, acting in the rescue of victims of an accident and in the transport of patients. Considering these vehicles as a workplace, the team of professionals is susceptible to exposure to various occupational risks, especially if these vehicles operate in rural areas. This work aimed to assess physical risks in emergency vehicles operating in rural areas. The methodology was carried out in the Amazon region, northern Brazil, in type B emergency vehicles (basic support vehicle) that work in urgent and human health emergencies. The evaluation consisted of measuring occupational heat levels inside the vehicle with the use of a Thermal Stress Meter, measuring ambient light levels with a Portable Digital Luxmeter and measuring doses of noise exposure by workers with Digital Dosimeters. As a result, it was obtained that the vehicles had levels of exposure to heat with maximum temperatures of 31.4 deg C, which, according to national legislation, should not be carried out on the job without creating control measures. The levels of illuminance were considered poor, requiring the installation of new points of artificial light. Regarding noise levels, they are in accordance with the legislation.

GNSS Positioning and Accuracy of New Dual- and Tri-Frequencies Smartphones under Forest Canopies

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ABSTRACT

It is no longer possible to imagine our everyday life and work without determining our current position. The positioning also became increasingly important in forestry and especially in forest operations. The easiest way is to determine a position is to use a smartphone, which is almost always available. Nevertheless, what accuracy do such smartphones actually achieve, especially as technological development in this area progresses rapidly? The research aimed to evaluate the position accuracy of the new generation of dual- and tri-frequencies smartphones under forest canopy conditions.

A total of ten smartphones with integrated GNSS modules and one high-end receiver were used in the tests. The smartphones were selected according to different criteria. In order to obtain a comparison, older models and newer models and models with single and dual-frequency receivers and models used in practice ('outdoor/forest mobile phones') were combined. Four of the ten smartphones provide dual-frequency reception (Xiaomi Mi8, Mi8pro, Mi10) with their internal chips, and one smartphone provides triple-frequency reception (Huawei P40).
A holder was set up for the ten smartphones and the high-end GNSS receiver, and it was mounted on a tripod. The tripod was aligned precisely with the center over terrestrially surveyed geodetic survey points where the exact absolute position with cm accuracy was known. The measurements were carried out under different stand and reception conditions.

The reception qualities of the various smartphones vary greatly. There is also a clear trend towards newer devices and multi-frequency devices having higher accuracy. However, there is also significant variability under different conditions. The average accuracy of smartphones varies between 1.42 and 8.14 m (CEP). Detailed results are presented on the poster.

Automating the characterization of log inventories at roadside

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ABSTRACT

Few companies use scalers to obtain reliable information on roadside inventories due to a labor shortage. If in the past the sawmill could count on a large inventory in its log yard in order to manage the supply of the production lines and meet its production plan, today the majority of factories have little inventory and must coordinate transport activities to those of the sawmill. This coordination requires reliable information on the availability of log assortments. This project aims to develop an automated procedure for characterizing log piles along roadsides by exploiting data from harvesting equipment.

The procedure is based on the processing of harvesters production data (.pri / .hpr) and shapefiles (.shp) containing the GPS tracks of the forwarders. The procedure was automated in ArcMap using the ModelBuilder tool. The model makes it possible to recreate each tour of the forwarders, to identify the logs collected and transported in each tour, and their unloading point at roadside. The results can be viewed directly in ArcMap where log piles are located on the road network and an attribute table describes the characteristics of the logs in each pile (species, product, length class and diameter class distribution, stem count, and volume). The procedure accuracy is currently under investigation. Logs are being inventoried along harvesting trails and then in log piles at roadside. It is necessary to differentiate measurement errors from the harvesting head from errors of log allocation to log piles with the developed procedure.

Preliminary results indicate that the pile locations are being accurately identified within the procedure. Log allocations to piles at roadside present some mismatches. Predicting the allocation of a group of logs at the same time is easier than making a prediction for a single log, because some errors cancel each other out. It should be noted that for better results, it is important that harvesting heads be properly calibrated to reduce measurement errors in the .pri/.hpr files and avoid poor description of logs. After having demonstrated the concept, it will be necessary to automate data preparation to fully automating the process.

Simulation tool to analyze the silvicultural results of conceptual autonomous tree planting machines: a sub-study of the Swedish AutoPlant project

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ABSTRACT

Today's commercially available tree planting machines provide good silvicultural results, but they cannot economically compete with mechanized site preparation followed by manual tree planting. Consequently, tree planting machines plant <5% of all seedlings within Nordic forestry. Because the labour costs of manual tree planting are steadily increasing, there is a clear need within Nordic forestry to mechanize tree planting to prevent overly high regeneration costs in the near future. The development of fully autonomous planting machines is of special interest. Hence, we created a general simulation tool to analyse the potential of conceptual autonomous planting machines.

Obstacles, both above and below the ground surface, are one of the main reasons preventing large-scale break-through of today's mechanised tree planting machines. Undoubtedly, these obstacles will be the main challenge also for autonomous planting machines. The inclusion of such obstacles in the simulation tool is therefore essential. In our simulation tool, an obstacle can be a stone, root or stump, and they all come in different sizes and in varying frequencies. Together these obstacles constitute a total obstacle quota.

The future's autonomous planting machines should be capable of detecting obstacles. Our simulation tool sets (by default) stumps as detectable objects above ground, and roots as non-detectable objects below ground. Meanwhile, bigger stones are (by default) detectable objects above the surface and smaller stones are non-detectable objects below the surface. However, these default settings are easily adjustable so as to analyse different machine generations with different detecting capabilities. In addition, the size of the digging tool (i.e. area requirement) and the minimum distance between planted seedlings can be adjusted.

The outcome of the simulations includes all the traditional measures such as planted seedlings/ha, time consumption, distance driven, etc. Additionally, it includes spatial distributions (coordinates) of both successful planting attempts

(i.e. planted seedling) and failed planting attempts. It might happen that the landowner is not content with the simulated planting results or that legislative requirements concerning regeneration are not met. In such cases, specific machine settings can be readjusted. For instance, on stony soils, the minimum distance between the seedlings probably should be decreased to sustain the desired stocking rate (seedlings/ha). In practice, this means that seedlings will be planted, at least to some extent, in groups. Meanwhile on obstacle-free soils, the situation is opposite: seedlings can be evenly distributed all over the site.

Comparing the cost of cardboard box concepts that increase the productivity of tree planting machines: a case study from southern Sweden

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ABSTRACT

There is a strong need to mechanize tree planting in Nordic forestry. Today, tree planting machines plant <1% of all seedlings in Swedish forestry. The planting machines that are commercially available (mainly the crane-mounted Bracke Planter on excavators) currently plant trees with higher quality but more expensively than mechanized site preparation (mainly disc trenchers mounted on forwarders) with subsequent manual planting. Because they are designed for manual tree planting, today's seedling handling systems are one of the bottlenecks keeping tree planting machines from becoming economically competitive with manual tree planting. However, cardboard concepts that would speed up seedling reloading on the Bracke Planter 196 seedling carousel have been proposed. The question then raised was: could the time savings offered by these seedling supply concepts pay for the added packaging and investment costs?

The objectives of this study were to: 1) analyze the cost-efficiency of three conceptual seedling supply systems involving cardboard boxes of varying packing densities; and 2) compare their total costs with those of today's two most common seedling supply systems in southern Sweden.

All systems were based on cultivating seedlings in Hiko v93 cultivation trays. The first system entailed seedling handling in cultivation trays between the nursery and planting machine, while the other four systems involved transferring seedlings from cultivation trays to cardboard boxes at varying densities and dimensions for transport to the planting machine. Data (time consumption values, costs, measurements, capacities, etc.) were acquired from manufacturers, nursery personnel, contractors, transportation companies, etc. Costs were then calculated and tallied up.

The results showed that cultivation trays (Hiko) seem to be the most cost-efficient packaging system for excavator-based tree planting machines. Because of low packing densities, the three proposed cardboard box concepts did not seem to be cost-efficient. Indeed, to save on transport and packaging material costs, seedlings in boxes should be shipped lying down with intertwined stems/green parts. And as long as the hourly cost of excavator-based mechanized tree planting is relatively low (because of low-tech planting machines, i.e. Bracke Planter) and primary transport distances are short (because of few contracted planting machines), even the highest-density cardboard box

concept seemed to be cost-inefficient. However, the cost-competitiveness of the high-density cardboard box concepts would increase if we had made the analysis for continuously advancing planting machines with high hourly costs and manual seedling loading (e.g. a tree planning machine like the recently developed Plantmax).

Does the damage caused by harvester head feed rollers have an impact on the moisture content of wood?

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ABSTRACT

The surface of roundwood harvested by the harvester is usually damaged mechanically. Stems are moved using powerful hydraulic feed rollers, which are fitted with spikes for obtaining sufficient traction on the log surface. The absolute and relative damage levels may change with season, like moisture content of wood in living trees. It is difficult to explain if and to what extend wood moisture content has a severe impact on the stem damage, but we can explain if and how feed rollers affect changes in wood moisture content. In the long run, this may help understand why the use of harvesters causes greater amount of blue stain on the logs compared to trees harvested motor-manually. This study aimed to determine the effect of feed rollers pressure on the wood moisture content (MC) changes on pine logs.

Samples for the determination of MC were taken from 30 fresh felled trees, from two sections along the trunk. The first section was far from 1 m from the base of trunk, the second was far 10 m. In each section two samples were collected using Pressler increment borer (ca. 4 cm length). One in a place damaged by a spike of feed roller, and the second from the undamaged surface Additionally, the wood damage depth was measured using the depth gauge of a digital caliper. In total 120 samples were collected, 60 from damaged spots and 60 from not damaged ones.

Average moisture content of undamaged wood was app. 70%, when MC of damaged ones was characterized by app. 60%. In this case statistically significant difference was found. In case of samples collected from 1st section MC value was greater in undamaged wood by app. 7%. In second section difference was app. 13%, and greater value was noticed also in undamaged wood. Statistically significant difference was found only between samples collected from 2nd section. Average depth of damage was 3.88 mm.

Therefore, it can be predicted that the decrease of moisture content causes faster drying of wood in the damaged spots and then harvester head rollers would contribute to faster formations of blue stain by indirectly creating optimal conditions for development. Confirmation of this theory in the future will provide an opportunity to address development of fungi, which are causing decrease of wood quality.

Saplings extractor for mechanized planting

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ABSTRACT

Drought and the effects of insect pests have a huge impact on the landscape, the forests and their owners. Therefore, research and development of a cultivation machine that would be flexible, reliable and universally environmentally friendly, is a great opportunity to accelerate the change in tree species composition. And this is in favor of mixed forests with a higher proportion of deciduous trees, which are more resistant to weather fluctuations and climate change. The forestry technology market lacks logging and cultivation machinery, as well as adapters, that would be operationally and economically efficient, environmentally friendly, applicable in hard-to-reach terrains and affordable for small forest owners, greenness managers and entrepreneurs of cultivation machinery.
For this reason, a small multi-purpose machine with high performance and flexibility for picking up and replanting of saplings in seedling forests on calamitous clearing areas, was developed at the Faculty of Forestry and Wood Technology of Mendel University in Brno. The extractor enables the use of the production potential of saplings in seedling forest stands, which are often very difficult to access and growing in heavy unprocessed soil with a high content of roots and stones. The saplings are picked up without significant damage and their replanting on calamity areas is carried out with minimization of rides and damages to the subsoil. This newly developed technology enables the rapid renewal of calamitous clearing areas, or its replenishment, with the help of saplings from seedling forest species, which are more resistant and stronger than the saplings grown in forest nurseries.

A new prototype of a saplings extractor, which penetrates horizontally into the soil around the picked up sapling by pressure and rotational movements, and thus enables the collection of trees up to 250 cm in height with a large hemispherical ball of soil and root (diameter: 80 cm, depth: 40 - 50 cm) is manufactured by MISTRA s.r.o. The same technology is used to prepare a place for planting of saplings. The benefit of this extractor is that with its small dimensions (as mentioned above) and weight (approx. 750 kg) it enables one to gently pick up a sapling from seedling forest species, with a sufficient ball of soil and root even from hard-to-reach terrain. Testing of the new technology took place in cooperation with the engineering manufacturer MISTRA s.r.o.
and the Faculty of Forestry and Wood Technology at Mendel University in Brno.

Performance of small-sized harvesting system for single tree selection thinning of Quercus acuta using an excavator-based grapple machine and a winch-mounted mini-forwarder

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ABSTRACT

After "fuel innovation" in 1950s in Japan, much of broad-leaved forests, in other words "Satoyama forests" have been abandoned and left unused although they provided firewood and charcoal timber as well as precious saw timber species for houses and furniture. Some of too matured broad-leaved forests, especially with dominant oaks, are attacked by oak disease insects. Appropriate thinning is required to prevent such disease and enhance landscape esthetics. Because large-sized harvesting systems are not matched for normally low profit operations of broad-leaved forests, small-sized harvesting systems would be one of possible solutions. A trial small-sized harvesting operation was carried out in Kochi University Forest using an excavator-based grapple machine and a winch-mounted mini-forwarder combined with motor manual felling and narrow spur road network. A 30 m x 30 m plot was established in a broad-leaved forest with dominant species of Quercus acuta in volume and Camellia japonica in number. Nine sets of large Quercus acuta stumps were harvested in three patterns of logging: direct grappling at roadside, uphill winching, and downhill wincing, for three sets of stamps each. Highest productivity was obtained for direct grappling while productivities of both uphill and downhill winching were almost the same. In the downhill winching operation, the trees should be fell toward upward in order to make following winching be easier concerning widely spread crowns of fell trees. Cost balance of the operation would be acceptable for self-employed private companies, while the balance would be deficit for full employment logging enterprises. As of harvested

timber usage, almost half in volume should be used for biomass fuel, one third in volume could be used for timber, and the remains would be used for production of firewood.

Log Shape Segmentation by Deep Learning for Autonomous Log Loading

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Abstract: The autonomous forest machinery was focused on the aspect of increasing productivity or eliminating machine operators as a bottleneck. Previous studies on autonomous forest machinery include automation of existing forest machines and development of new forest robots. However, few studies have been observed in loading/unloading logs using existing forestry machinery. These technologies were also necessary for collecting logs by forwarders in the CTL system and loading logs into trucks. Therefore, to properly load logs, it was necessary to recognize each log individually and grab single or multiple logs. Nevertheless, few studies strive to recognize logs individually. Hence, this study focuses on the log handling, grabbing and loading of logs after bucking. We also proposed a technique for detecting individual logs and estimating the shape of the log, which is necessary for autonomous log handling. Additionally, instance segmentation using Mask R-CNN was used as a detection technique for logs. Furthermore, we captured images from logs at multiple locations (Ibaraki and Gunma prefectures) with a stereo camera. In this process, we not only acquired data from multiple places to ensure the robustness of detection that can adapt to environmental changes, but we also extended the dataset using RandAugment as a form of data augmentation. Results of the training revealed that the mAP was at least 0.65 and the intersection of union (IoU) was 0.74 in multiple places. In contrast, compared to the model without RandAugment, the mAP increased by 0.43 points. We suggested as well that log detection by instance segmentation can be applied to multiple places. Moreover, to estimate the shape of the log, we masked the point cloud obtained from the stereo camera with detected images of the logs. Thus, discriminating between log lengths was possible, which helped our system classify the logs into 3 m and 4 m types with 96% accuracy.

Keywords: autonomous forest machinery, instance segmentation, log detection, log loading, detection

1. Introduction

Recently, autonomous forest machinery was adopted to focus on the aspect that increases productivity or eliminates the machine operator as a bottleneck. However, previous studies on the use of this autonomous forest machinery focused mainly on autonomous driving (Ringdahl et al., 2011; Hellstrom and Ringdahl, 2006). Few technologies were also known about the autonomous loading and unloading of logs. Nevertheless, these technologies remain necessary for transporting and loading logs by forwarders and trucks in CTL systems. Alternatively, manufacturers have partially reported some technologies to support operators of these forestry equipment (John Deere, 2021).

As highlighted by Visser et al. (2021), information on robotics in forest operations is primarily found in the »grey literature« (i.e. websites). Thus, it was developed to partially assist the loading and unloading of forestry machinery. However, these technologies simplified the control of existing machines, which were insufficient for complete and autonomous loading and unloading operations due to the absence of sensing technologies that recognized these logs from external environments. Only a few reports on developing these sensing technologies have been reported as well, except for that of Usui et al. (2019). Therefore, this study will focus on sensing technologies for the full and autonomous loading of logs.

In a fully automated log loading operation, it is necessary to correctly recognize the external environment, detect the individual positions of the logs, and generate a trajectory and motion for the grapples to handle single or multiple logs. To detect individual trees, LiDAR and image-based techniques have been proposed. Especially, laser scanning using TLS and Hand-held LiDAR in addition to SfM-based image data acquisition has been widely used for forest resource estimations (Bauwens et al., 2016; Hunčaga et al., 2020; Hyyppä et al., 2020; Wallace et al., 2016; Iglhaut et al., 2019). However, these methods include not only the extraction of individual trees but also the measurement of tree diameters and height.

Furthermore, these studies acquire huge point clouds and extract features of standing trees from the data obtained. Therefore, collecting detailed points required multiple perspectives for an individual tree. Additionally, large number of points needs much processing time. In contrast, the autonomous log loading process requires individual tree detection methods performed in real-time. However, it is difficult to obtain laser point clouds and images from multiple or back-side viewpoints of logs because sensors were used to capture the points installed on the moving machinery. Hence, it was adequate to obtain point clouds in one shot rather than scanning multiple viewpoints each time for the autonomous log loading process since the positions and numbers of logs changed during the loading and unloading process.

To solve these problems, we adopted deep convolutional neural networks (CNN), which have recently become increasingly popular. This technology has shown success in image recognition, object detection, and object segmentation. A report by Usui et al. (2019) also observed that 91% of logs were detected by CNN. Alternatively, previous studies using CNNs have been limited to detecting logs and not to estimate the properties of logs. The appropriate grabbing positions of logs vary as well, depending on the shape of the logs. Thus, the properties of the logs should be collected for autonomous loading. This study therefore focused on the precise detection of logs by image segmentation using CNNs, including the acquisition of log properties for the autonomous log loading of forest machinery.

2. Materials and Methods

2.1 Data Collection

The experiments were conducted at Gunma and Ibaraki prefectures, located in central Japan. The species of the logs were sugi (*Cryptomeria japonica*), hinoki (*Chamaecyparis obtusa*), and momi (*Abies firma*) from Gunma Prefecture and sugi from Ibaraki Prefecture. Videos of log stacks were then taken with a stereo camera (ZED, Stereolabs) with a resolution of 1270 × 720 pixels per single image.

2.2 Instance Segmentation

In this study, we applied the instance segmentation method to detect objects. Although deep CNN, such as Yolo (Redmon et al., 2016) have already been proposed for general object detection, these methods only detected the target object as a rectangle. Therefore, for a more accurate detection of the properties of the logs, it was adequate to extract detailed shapes of the logs from the images rather than extracting the logs as a rectangle. Furthermore, we used Mask R-CNN (He et al., 2020) as an instance segmentation method that can detect individual objects discretely in pixels. Additionally, data augmentation was important for robust detection. Subsequently, although various data augmentation methods based on image processing had already been proposed, in this study, we use RandAugment (Cubuk et al., 2020), which performed these image processing methods randomly. Then, to train the segmentation model, images were cut from the captured videos, resulting in 351 extracted images. All images were supervised manually. Afterward, test data from 3 locations (Ibaraki-1, Ibaraki-2, and Gunma-1) were extracted from the whole dataset, after which this process divided the dataset into 295 images for the training data and 56 images for the test data, respectively. For evaluating the detection; accuracy, precision, mean average precision (mAP), and the intersection of union (IoU) were used.

2.3 Log Properties Processing

This section shows the processing after log detection by CNN to estimate the properties of the logs and to set an appropriate grabbing position of the logs. First, 3-dimensional point clouds were obtained using stereo images. ZED SDK was used in this process. Then, Mask images were used to filter these point clouds obtained from the instance segmentation in Mask R-CNN to extract the points for individual logs. For the extracted point cloud, eigen value decomposition was conducted to estimate the axial directions of the logs. Subsequently, the point cloud was rotated so that the axial direction and Y-axis matched, after which the cylinder length was finally calculated using the difference between the maximum and minimum values in the Y-axis direction. To classify the logs into 3 m and 4 m, the threshold of the log length was set to 3.5 m. Alternatively, for evaluating log lengths, the other dataset consisting of 100 stereo images in Ibaraki was prepared. F-measure was used as an index for evaluation.

3. Results and Discussion

3.1 Instance Segmentation

The mAP and IoU results obtained from each location are shown in Table 1. Due to the training, the mAP was at least 0.65, whereas, the IoU was 0.74 as observed in multiple places. Detection examples are shown in Figures 1–3.

Table 1. The mAP and IoU results from each place

Place	mAP	IoU
Ibaraki-1	0.882	0.742
Ibaraki-2	0.649	0.842
Gunma-1	0.912	0.790

Figure 1. Example of detection (Tsukuba-1)

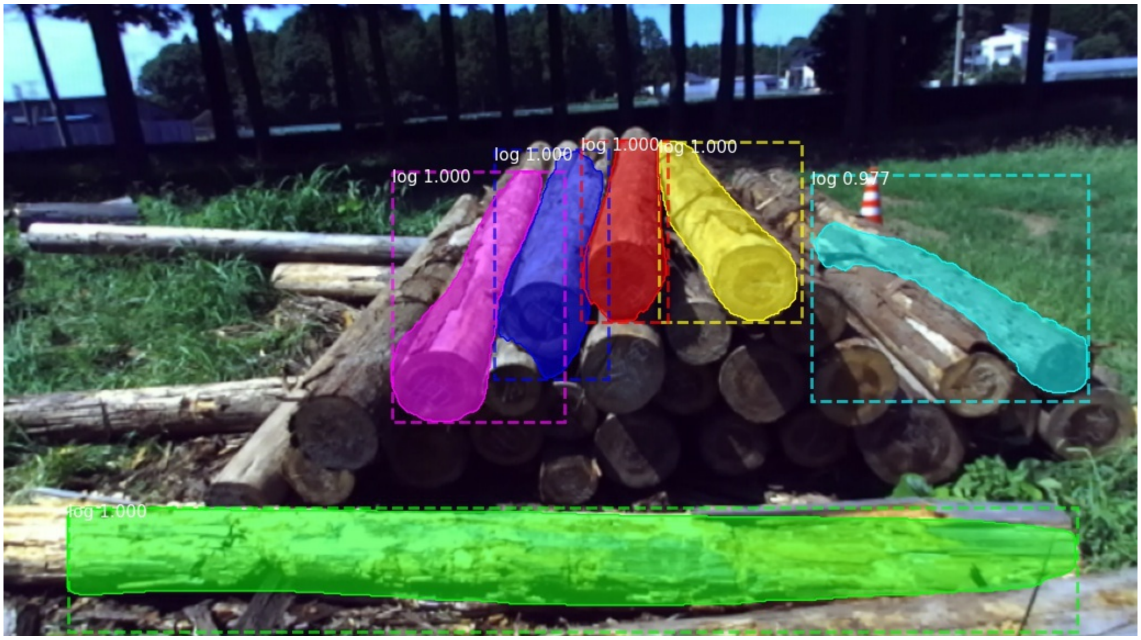

Figure 2. Example of detection (Tsukuba-2)

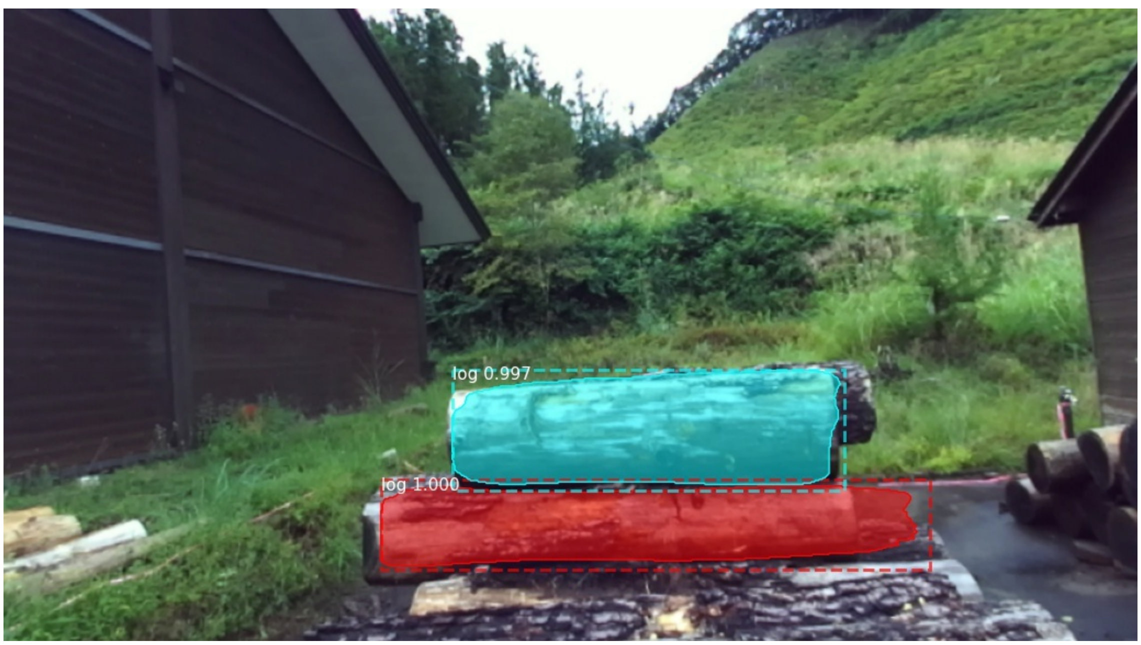

Figure 3. Example of detection (Gunma-1)

Results also showed that the mAP and IoU of the entire dataset were 0.81 and 0.78, respectively. Comparison of data augmentation results is shown in Table 2.

Table 2. Comparing data augmentation results obtained from RandAugment and no augmentation

Data Augmentation	mAP	IoU
RandAugment	0.811	0.775

No Augmentation	0.385	0.747

Compared to the model without RandAugment, mAP experienced a 0.426 point increase. Therefore, it was suggested that log detection by instance segmentation can be applied to multiple places.

3.2 Estimation of Log Properties

Results obtained from the classification between 3 m and 4 m logs are shown in Table 3. The F-measure of classification was 96%. For more precise measurements, the log length was subsequently estimated directly, after which this value was estimated with an RMSE of 0.356 m.

Table 3. The accuracy indices for log length estimations

Accuracy	Precision	Recall	F-measure
0.960	1.000	0.917	0.957

3.3 Trends of Detection and Estimation

From the results, Tsukuba-2 showed the lowest mAP, which means that the detection models did not find the logs at the other locations. In the detection of log stacks, the trained model also failed to detect individual logs due to occlusion in a few cases. However, it was observed that the trends in the models detected if the entire log was visible in the image. Alternatively, the detection of the log failed only if part of the log was visible. Therefore, it was suggested that this cause led to the decreasing mPA values in Tsukuba-2.

From the estimation of log properties, it was observed as well that the algorithm classified the logs between 3 m and 4 m. In contrast, the direct estimation of the log length showed an RMSE of 0.356 m. It could not estimate the position to grasp the logs. Hence, it was suggested that incorrect detection of the logs, which due to low IoU, led to inaccurate point extractions. Additionally, points calculated using stereo images in one shot had more noise than points obtained from the LiDAR. Therefore, it was further considered that both increasing IoU of log detection and noise reduction contributed to the accurate estimation of log properties.

4. Conclusion

This study showed individual log segmentation by CNN and estimation of log length for autonomous log loading. Results showed that the mAP was at least 0.65, whereas, the IoU was 0.74 in multiple locations. Additionally, the mAP and IoU of the entire dataset were 0.81 and 0.78, respectively. Thus, it was suggested that log detection by instance segmentation can be applied to multiple places. Moreover, to estimate the shape of the log, we masked the point clouds obtained from the stereo camera using the detected images of the logs. Due to the classification of the log length, our system then classified the logs into 3 m and 4 m with 96% accuracy.

5. Acknowledgment

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Towards as usable roll-over protection system for quadbikes

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ABSTRACT

In forestry and farming, quadbikes are commonly used to transport people or equipment to the work place. Quadbikes largely contribute to a more efficient work during for example forest inventory, tree planting, machine services, and firefighting. Unfortunately, the numbers of accidents and deaths due to rollovers has increased despite the emphasis that has been put on Quadbike safety during the last decade. A few countries have implemented regulations that demands a roll-over protection system (ROPS) on quadbikes, but in most countries, including Sweden, ROPS is not a legal requirement for the private user. Thus, the use of ROPS in Sweden is currently extremely rare. Therefore, this study aims to improve the understanding of how the introduction of ROPS can support and hinder both safety and usage of Quadbikes in a Swedish context. A total of 50 quadbike riders were equipped with a light ROPS, called Quadbar Flexi, for their professional and private use during a period of 2 years. They will continuously evaluate the effect of the ROPS on efficiency, usability and safety. A combination of both quantitative and qualitative material and methods are used to cope with the complex issues of safety and usability. In an initial pre-test survey, many of the participants reported that they had firsthand experience of Quadbike related incidents or accidents and believed that the ROPS would increase their safety. Nevertheless, more than 80 % believed that the addition of this specific ROPS will affect the usability of the vehicle, e.g. their driving technique, their abilities to transport goods or the storage of the quadbike. First results shows that the ROPS are easily fitted to a majority of quadbikes. However, forestry specific usage with extra equipment like electric winches and openable storage spaces are often hindered by the specific ROPS. The results highlights the challenges in quadbike safety and designing for safety. The problem of fitting a standard ROPS on all quadbike models imply either that future quadbike designs must be standardized or that each quadbike is equipped with purpose built ROPS, preferably directly from the factory. Nevertheless, the ROPS must be designed with the wide variety of use in mind, including the attachment of extra equipment.

A new type of renewable energy source derived from forestry

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ABSTRACT

A dendromass in the form of firewood obtained from forest harvesting or optionally forest harvesting residues that remain in a forest after the harvest such as branches, roots or stumps can be derived from forestry operations and used for energy purposes. Stumps and roots are considered as a material of non-standard size. Their transportation is difficult, and they consist of mineral contents (stones and soil). The grubbing head is one of the tools that could be used in the stump removing process and functions as an adapter to the boom of an excavator.

Therefore, the Faculty of Forestry and Wood Technology at Mendel University in Brno developed a new grubbing head prototype for obtaining a new type of biomass from forest sites. This new prototype enables harvesting stumps in a manner that distorts the layer of the organic soil only to a minimal extent. After a stump or its parts are removed from the subsoil, the grubbing head allows for stump extraction to occur until the point where the soil is separated from the removed stump. The soil falls into the space left by the removed stump. With the help of the bottom part of the grubbing head, the surface is then modified, aligned, compacted and set for subsequent forest regeneration and establishment activities. Stump parts are stored in piles with the assistance of the hydraulic boom of an excavator. Those relatively clean parts of stumps are then exported from the site. When the humidity reaches 30 %, stumps are converted into woodchip with the help of a wood crusher. The woodchip is then transported to an incinerator or a power station with the use of various means of transport. This woodchip has optimal calorific value and represents a source of renewable energy derived from forestry.

After assessing the data of all real values obtained from multiple field measurements, it was concluded that the average time of the processing of one stump, including the modification of the subsoil after the removal and the transition of the excavator to another stump, is three minutes. An experienced operator is therefore capable of processing approximately up to 20 stumps on a site per hour.

The new grubbing head prototype will bring new economic opportunities to extensive mass harvesting in all forests. Furthermore, the regions that will use the new grubbing head prototype might see an increase in employment.

New slinging technique for rope-assisted felling on steep slopes

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ABSTRACT

There are various methods for timber harvesting and felling in steep terrain. One possibility is the so-called transitional terrain with slopes between approx. 35 and 55% is the combined method of motor-manual felling by forest workers with a rope tractor. In this method, the felling process is often supported by the applied rope or the tractive force of the tractor. One reason for the support is that the trees on the slope should often be felled against the natural direction of fall, which can hardly be achieved with conventional wedges. In addition, for work safety reasons, the feller should stand at a safe distance when the tree starts moving. This reduces the risk of being hit by the snapping or falling trunk or by falling deadwood.

In order to be able to use this support from the tractor rope, however, it is mandatory to attach a steel or synthetic fiber rope to the tree at a certain height. To ensure that the rope can be attached to the tree at the required height, many companies still use methods that are not without risk in terms of ergonomics and occupational safety. Often the rope is pushed upwards with the help of cut branches, whereby the height required for the available pulling force is often not reached. In some places, telescopic poles or a ladder carried along are used for this operation. These procedures are time-consuming and not very ergonomic and safe.

The newly developed slinging technique (called: Waldkircher Anschlag-Technik - WAT) consists of a rope sling guided in pulleys, which automatically runs up the (knotless) trunk by the pull of the tractor winch located on the slope above, ideally at least up to the required slinging height or beyond. As part of a bachelor's thesis, the prototype developed was tested using a time study and measurement of the attainable heights. The result of the test in the Waldkirch municipal forest shows that the technology works and meets the safety requirements. The poster presents the new technique, the operating conditions, and the accompanying scientific research.

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Improving Yarder Productivity Through Optimizing Cable Payload in Forestry Steep Terrain Operations

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Abstract: Steep terrain forestry operations are executed with cable logging systems. The maximization of cable yarding log payload is a relevant factor to improve forestry productivity levels and achieve competitive costs since it allows to minimize the overall cable operation including operation and setup times. We introduce a Bayesian-based optimization heuristic designed to minimize the overall operation time achieved with a standard multi-span yarding system, one of the most commonly configurations in use today, based on an efficient algorithm and accurate new forest inventory models just recently made available at industrial level. The first field test informs levels of improvements up to 7% under normal operation conditions including setup plus operational working times.

Keywords: *Forest operation planning, cable logging, forest modeling, optimization*

1. Introduction

For the next decades, about 50% of Chilean forestry operations will be executed in steep terrains with cable yarding systems. In this scenario, the maximization of cable yarding log payload is crucial to improve forestry productivity levels and achieve competitive costs for this economic sector. In order to carry out an accurate steep terrain planning process, it is necessary to define an optimal solution for a complex combination of related activities which includes, among others, the optimal location of cable yarding systems, the maximum operation's payload for the cable yarding system, the construction of access roads to the productive area and the transportation of final products to the clients.

During the last two decades, the Chilean forestry area has been using a computational system named PLANEX [Epstein] to support the steep terrain planning process, including road construction and machinery location planning. The system is based on a graphic interactive interface linked to a geographical information system (GIS) storing information on topography, timber availability and geographical barriers like rivers and ravines. The decision process of PLANEX is based on an optimizations heuristic algorithm. The system has been used successfully, leading to important cost savings as well as better preservation of the environment [Legues]. Although Planex defines the location of cable landings, it does not define the optimal yarding configuration for each line and do not considers the setup times required for the complete operation.

One of the most commonly used yarding configurations today in Chile is the multi-span yarding system wich utilizes intermediate supports to enable "the carriage" to carry a load of logs over a topographic break in slope, condition which otherwise inhibits cable operations since the line would bite into the ground. There is a big opportunity in optimize the "multi-span" yarding configuration, i.e., the number, size and position of supports in order to maximize the cycle payload. It is also relevant to minimize the overall cable operation including setup times, since cable setup times constitute an important proportion of total costs.

It is a common practice in the Chilean forest industry to use the software LOGGER PC [Jarmer] in order to calculate the maximum log payload for each line. Since there is no optimization criteria involved in this calculus, wich leaves in the judgment of the operator the yarding configuration, there is a great oportunity in productivity improve by defining the optimal yarding configuration and setup times. Yarding configuration options depends largely on mechanical analysis of cable systems. As mentioned by [Dupere], there are two different approaches concerning the mechanical analysis of cable yarding systems. The European traditional method consists of linearized analyses of cable structures [Pestal], while North American one lies on closer to reality non-linear analyses [Carson], [Chung 2002]. Although the load path during cable yarding is a dynamic problem, all the existing methods treat it as a static case due to the relatively low speed of the load along the skyline.

According to [Dupere], the predominant cable system in Europe is known as standing skyline. The skyline is fixed to anchors at both ends implying a constant unstretched skyline length for any load weight and location. The static response to a point load by such cable structures is characterized by the skyline shape and tensile forces change with the load location. It is also important to consider that the cable elasticity also increases the total length of the skyline and also the loaded span length increases by gaining some of the available unloaded adjacent spans cable length [Bont 2012]. The simplified European method to assess the geometric layout of a cable road is established from linearized analyses of cable structures known as “Pestal Equations” [Pestal] where only the changes in skyline shape are considered. This method leads to shorter spans and more intermediate supports than necessary as shown in previous work [Bont 2012].

By contrast, under North American non-linear analyses of cable structures approach, there are considered the cable elasticity and changes in shape and tensile forces according to load location. Although these approaches are more realistic they remain computer-time consuming and by the way are concentrated on single-span cases [Dupere]. [Bont 2012] developed a complete computer-aided program based on [Zweifel] “close-to-catenary” approach for multiple spans configuration which included all the cable responses cited previously. Their algorithm also enables optimizing the intermediate supports locations while respecting predefined safety conditions.

The setup of cable yarder lines is an important part of total costs of a cable yarding operation. Unlike ground-based operations, considerable time is required for rigging a cable line before extraction can begin, as well as taking down the rigging after the extraction is complete. Basic rigging steps include laying out the guylines, preparing the guyline anchors, connecting them and tightening them appropriately. The use of intermediate supports is another specific rigging option that can be employed to extend the terrain range that a yarder can effectively operate. This involves a support jack being rigged into a sturdy tree along the lines that will suspend the skyline above the ground. The use of intermediate supports in cable lines have beneficial effects such that it allows the yarder system to harvest on terrain that is not concave, allows the lines to be extended and allows the logs to remain at least partially suspended as they are being extracted from the stump to the landing. Cable operations are most efficient in larger clearcut operations, where the proportion of rigging time is small compared to the time spent extracting timber. Also, once a yarder is set-up, subsequent lines from the same yarder/landing location can be rigged relatively quickly [Stampfer]. A large number of factors influence individual yarder installation times. Line length, terrain factors, extraction direction, and yarder type have been identified as key factors in central Europe. Subsequent lines from the same landing location require shorter installation times [Stamper]. Finally, both the number of intermediate support installations as well as the height of the supports are critical factors influencing setup times.

Since some years, it has been available LIDAR technologies that recently allows to obtain a census of the forest, describing each one of the trees at each geographic position. Arauco developed a pilot proyect oriented to evaluate the accuracy and feasibility of semi-automatic forestry census methods, over operational plantations of Pinus radiata [Bustamante, Sandoval]. The pilot considered a LIDAR cloud points of 16 point/m^2 and was used to identify top height trees, and delineating its crowns width thru a segmentation algorithm. As a result, we were able to extrapolate the pilotage area of study an generate an accurate tree census, obtaining an “individual tree” model in the study area, that includes the position of the tree, the height and the height-diameter relationship, required to evaluate intermedia support feasibility.

We develop a computerized method that integrates accurate mathematical approaches for the structural analysis of cable systems. Our tool contains data from a geographic information system (GIS) to consider all the different possible cable locations and directions, a mechanical model to search the optimal layout of intermedia support and cable tensile forces for each potential cable line to insure workers' safety to select the optimal set of cable lines that minimizes the whole operation at minimal cost including setup times. Within the present work and based on previous research we propose a geographic based software tool oriented to fulfill those objectives. Using results from this software we have tested real cable yarding operations for different conditions of steep terrains and forest conditions and have found productivity improvements up to 7%, based on proper setup times and intermedia support selection as we describe in the present paper.

2. Problem Formulation

In order to examine all possible paths for logging the harvest area we built 10 mt by 10 mt cells where each "individual tree" is referred to the cell where the tree is located. Each line is associated with a "harvest cone" with its apex been the yarder location and a 50 meters base at the bottom of the harvest area. The cone intersects all the feasible logging cells (see Figure 1). Each cell would be harvested thru the nearest "point" of all potential lines, asuming that the log are going to be harvested thru this point (our model does not consider a down hill rolling of the logs). Also, each line has a "Yarding line", which is a 4 meter's width box along the cable which contains all the intemedia support candidate trees (see Figure 1).

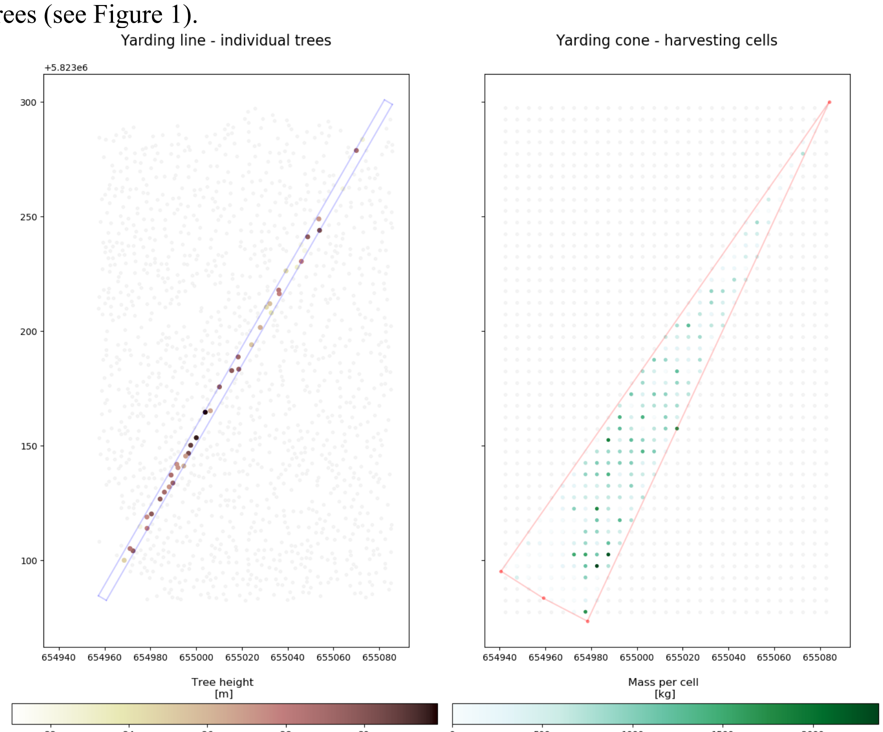

Figure 1 – Yarding line and cone

Our model looks for a design that minimizes the time to complete the whole yarder operation within security conditions. The mathematical formulation is compound by a network location problem looking to minimize the complete setup and cycle time for all the feasible yarder positions. In addition, we maximize the log load which can be carried out from the farthest point on the skyline to the yarding area while not exceeding the maximum allowable skyline tensions and maintaining adequate log clearance [Brown]. To solve the problem, we propose a two phase approach. First, we run the "geometric phase" to optimize the design of each potential line. The second phase consists on choosing a subset of the already optimized potential lines, which are able to harvest the timber associated to the logging yard at the minimum cost.

2.1 Geometric Phase and the Bayesian Optimization Method

For the "geometric phase" we build a GIS-based tool that draws the potential lines for each predefined yarder locations. We use the locations suggested by PLANEX, see [Epstein]). In addition, we evaluate several points around each of these locations to find a better near point when the operational complexity of the cable is analyzed in full detail.

Each yarder locations defines a fan of lines over the harvesting area (see Figure 2). The GIS tool eliminates unfeasible lines based on terrain slopes. We drawn the lines closer to each other so the harvested cones of them got overlapped allowing a bunch of feasible solutions. This geometric phase drawns all the feasible lines considereing full harvesting coverage, area limits and the environmental restrictions. Each potential line has to be feasible, which means that depending on the composition of slopes, the skyline should be able to "run" completely thru it, otherwise it is eliminated as a candidate (see Figure 3).

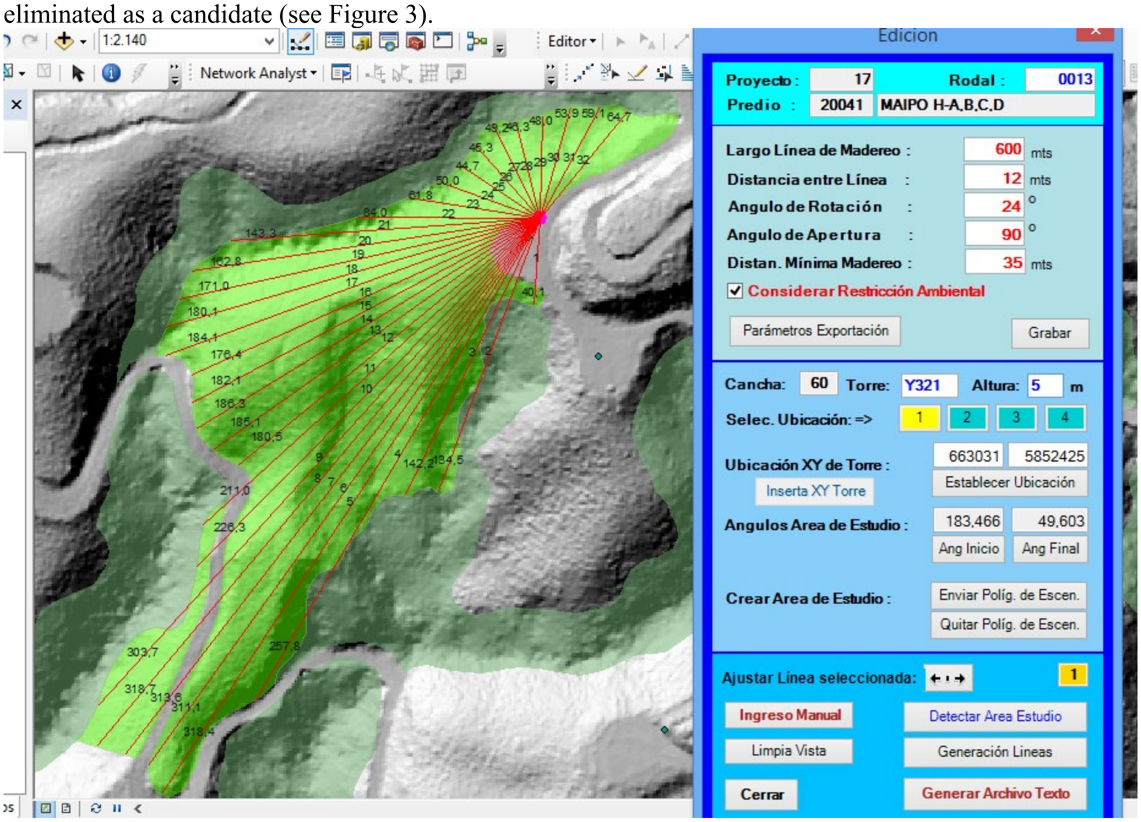

Figure 2: Geometric Phase

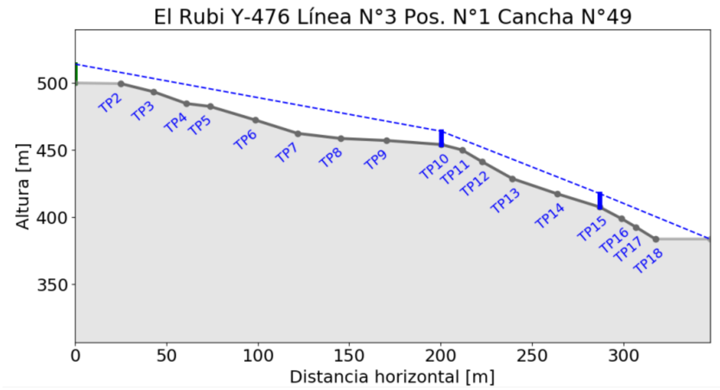

Figure 3: Feasible line

Since the limited number of yarder locations due to road availability, the irregular shape of the harvest area and the heterogeneous distribution of mass in between cells, the geometric phase should offer enough lines to make feasible harvesting the whole area.

The problem of optimizing intermedia support has been mainly solved by intuition or by trial and error, see [Bont], and the rules of thumbs proposed by [Pestal]. [Sessions] proposed an automatic procedure consists on installing intermedia supports on all protruding profile points and then eliminate the second of three consecutive intermedia support. This heuristic procedure iterates until a termination condition is met but without a guarantee of optimality. [Leitner] proposed an optimal intermedia support location algorithm without considering minimal ground clearance. [Bont] developed another optimal intermedia support location algorithm based on close to catenary cable mechanics. However, the model does not consider the absence of trees near the proposed intermedia support location.

Based on these previous works, we develop a maximum "log load algorithm" for each potential line with the following steps:

1. Define a descending list of {max loads} from 3 Tons to 1.5 Tons.
2. Define an ordered list of {support-type configurations}, been the first one, no intermedia support and "tail in stump", the second one, no intermedia support and "tail in support", the third one intermedia support and "tail in stump", and so on, been the last one 3 intermedia support and "tail in support".
3. For each combination of {max load} & {support-type conf.}
    a. For each {intermedia support location} in the line identify all support trees in the "yarding line" and select the feasible ones.
    b. Evaluate all the combination {feasible intermedia support location, quantity of intermedia support, height } using the Skyline XL tension equations and calculate the maximum log load as the objective function.
4. Once evaluated all combinations, select the maximum load achieved

During the "log load algorithm" when evaluating phase (3.b) and given that the selection of the optimal log load must be performed by the extremely computational expensive tension equations, we implemented a Bayesian Optimization method since it has been successfully used to optimize complex black-box functions whose evaluations are expensive [Jenatton][Snoek]. The Bayesian Optimization method allows us to evaluate all the combination of intermedia support positions in order to maximize the log load of each feasible line.

The basic tension equations were developed by [Kendrick] and now are implemented in Skyline XI, a system developed by Oregon State University and Oregon State Forest Service and used worldwide as a tool to get the maximum tension for cable operations calculus. We run Skyline Xl as a subroutine to evaluate maximum cable tensions.

2.2 Optimization of the Overall Operation Phase

The Bayesian stage gives the technical and economic performance of many overlapped feasible lines. Using this data, we built a mixed-integer optimizations model to select the subset of lines that harvest the whole area at minimum cost or maximum efficiency thru minimizing the setup and cycle time. In addition to the logical constrains, we do not allow the crossing of logging lines because of safety constraints. Other environmental constrains were already considered in the Geometric Phase. To find a global optimal solution, we allow a line to harvest some cells that are "over-distance" from the yard, in a practice that we call "non-optimal harvesting" in opposite of "optimal harvesting" when the cell is at the normal reach of the line. This option involves a loss of local efficiency but allows harvesting difficult cells helping to find a global optimum. We restrict this practice to harvest only a reduced number of cells. This mixed integer model is described below.

Overall Optimization Model:

Sets:
I: Cells to be harvested
J: Potential yarder instalation points
L: Potential lines
L_j: Set of lines asociated to instalation point j
I_l : Cells to be harvested optimally using line l
I'_l: Cells to be harvested non optimally using line l
L_i : Lines that harvest optimally cell i
L'_i: Lines that harvest non optimally cell i
R_l: Set of all lines that violates the crossing restriction for line l

Parameters:
$f_j: Instalation\ time\ for\ position\ j$
$n_l^j: Instalation\ time\ for\ line\ l\ for\ position\ j$
$c_l^i: Logging\ time\ for\ cell\ i\ using\ line\ l\ optimally$
$c'^i_l: Logging\ time\ for\ cell\ i\ using\ line\ l\ non\ optimally$
$v_i: Total\ mass\ available\ on\ cell\ i$
$q_l: Total\ quantity\ of\ cell\ feasible\ to\ be\ harvested\ optimally\ by\ line\ l$

Variables:
$Xo_{il}: Indicates\ 1\ if\ cell\ i\ is\ logged\ optimally\ thru\ line\ l$
$Xs_{il}: Indicates\ 1\ if\ cell\ i\ is\ logged\ non\ optimally\ thru\ line\ l$
$Y_i: Indicates\ 1\ if\ cell\ i\ is\ logged\ optimally$
$T_j: Indicates\ 1\ if\ location\ point\ j\ is\ activated$
$Lo_l: Indicates\ 1\ if\ line\ l\ logs\ optimally$

Objetive Function:

$$\boldsymbol{Min}\ z = \sum_{j \in J} f_j \cdot T_j + \sum_{j \in J} \sum_{l \in L_j} n_l^j \cdot Lo_l + \sum_{j \in J} \sum_{l \in L_j} \sum_{i \in I_l} c_l^i \cdot Xo_{il} + \sum_{j \in J} \sum_{l \in L_j} \sum_{i \in I'_l} c'^i_l \cdot Xs_{il}$$

Constraints:

$$Y_i \geq 1 \qquad \forall\ i \qquad (1)$$

$$Y_i - \sum_{l \in L_i} Xo_{il} - \sum_{l \in L'_i} Xs_{il} = 0 \qquad \forall\, i \qquad (2)$$

$$\sum_{i \in I_l} Xo_{il} - q_l \cdot Lo_l = 0 \qquad \forall\, l \qquad (3)$$

$$Lo_l - BigK \cdot \sum_{k \in R_l} Lo_k <= 0 \qquad \forall\, l \qquad (4)$$

$$\sum_{l \in L_j} Lo_l - BIGj \cdot T_j \leq 0 \qquad \forall\, j \qquad (5)$$

$$Y_i, Xo_{ik}, Xs_{ik}, Lo_k, T_j \ binary$$

The objective function minimizes the logging time of cells "optimally logged" plus the logging time of cells "over-distance logged" plus the lines setup and yarder installation times. Restriction (1) obligates to harvest all cells. Restriction (2) obligates to harvest a cell thru an optimal line or thru an "over distance" line incurring in an extra harvesting time. Restriction (3) activates an optimal line only when all its associated cells are activated are reached by an optimal operation. Restriction (4) restricts the activation of optimal lines that violates the "crossing line" condition. Restriction (5) activates the installation of a yarder in a given position when at least one line associated to the position is activated.

3. Implementation and Results

We have implemented this algorithm in a 64 bits Windows System, with an Intel Xeon 2 Server and 156 GB RAM. The Geometric phase was implemented over an ESRI Arcgis graphical environment. The user defined the landing location, all the alternative tower positions, environmental restrictive polygons and parameters to evaluate the potential lines, such as distance in between lines, logging distance and cone width. The Bayesian Optimization's first step of the model was implemented on a Python 3.0 environment and solves a landing in a time ranging from 15 minutes to 17 hours, depending on the complexity of the terrain conditions and the number of lines. The MIP Mathematical overall optimization procedure was implemented in GAMS 24.9 that runs under CPLEX 12.7.1

Once the two steps on the algorithm were finished, a digital report is send back to the geometric phase and a graphical view of the result is presented to the final user. This final report includes the graphical view of the selected lines, the maximum log load of each line at each point and the cells covered by the solution. As traditional planning of lines tends to define an exit support for the line in its first 20 meters, the proposed solution tends to define higher log loads for the lines increasing the overall productivity of the team. Additionally, as the model is very strict in complying with technical, security and environmental restrictions, it generates solutions that are friendlier with the environment and safer.

We test the solutions given by this proposed methodology for 5 landing positions in the study area. For each landing, where the initial position of the tower was defined by operational crew, we calculate and compare the optimal line configuration with the traditional operational solution, that is usually build using the "LoggerPc" tool with a later field validation. We use standard parameters to calculate the total time of each solution as a way to compare both approaches. The results are shown in section 3.2.

3.1. Preparation of Input Data

The software has been tested in one of the operational areas of Forestal Arauco located in Llico, Arauco, Bio Bio Region, Chile. The test included Radiata Pine stands whose characteristics are described below:

Size of the stand (ha)	40
Age of the stands (Years)	21
Density of the stands (Tree/ha)	1300
Average height of the stand (m)	26
Average volume by tree (m3/tree)	0.5
Average volume by stand (m3/ha)	600

The team characteristics are described below:

Harvesting mode	Full tree
Felling mode	Traditional (manual chainsaw)
Logging mode	Cable using multispan skyline
Processing mode	Processor
Yarder Height (m)	14
# Anchor (#)	5

For the sake of the study we got digital land maps including environmental restrictions and plantations, planned area maps included harvesting areas, roads, landing locations, associated harvest areas and DEM (Digital Elevation Model) LIDAR based maps. We also built an "Individual tree" model layer for each landing location based on [Bustamante, Sandoval]. For each tree we had the position, total height, an estimate Diameter at Breast Height (DBH) and Height-Diameter relationship.

From Arauco's productivity systems we recovered the average time of the operational cycle at different extract distances and slope conditions for the specific equipment being tested. We also recovered average setup times including installation of the yarder, change of line and intermedia support installation.
From the planned area maps we got a dot at each landing zone that we represent by a rectangle of 50 x18 square meters, drawn along the road and centered on the original dot and allows the installation of five different locations for the yarder, one position every ten meters along the landing.

On each yarder location it is possible to define subsequent lines that require shorter installation times. Depending on the size of the harvesting area, we define as many consecutive lines as possible to cover the complete harvesting area. Each line is defined by a yarder location point and an azimuth direction which defines the course of the line. Each line defines a 5-meters sequence potential intermedia support points.
From de "individual tree" model and LIDAR information it is possible to estimate, with high accuracy, the height-diameter to any tree in the harvest area [Curtis] [Huang] [Huang 2000] [Dorado][Sharma]. Using the height-diameter relationship we were able to find the "candidate trees for intermedia support" at different locations through the line.
From the "individual tree" model it is possible to estimate the volume of wood available on each point of the harvest area [Curtis] [Huang] [Huang 2000] [Dorado][Sharma]. Using standard density (Kg/M3) functions we estimate available tons to carry out of the harvest area.

3.2. Numerical Results

We test the model for the landing number 36 in the study area. We recovered the lines defined in the field by the experts (landing direction, length, number and positions of intermedia supports) and we compare them with the optimal lines defined by our system. To calculate setup times, for installation and intermediate support, we use the parameters given by the manufacturer of the specific equipment. Also, as the "traditional" solution does not consider any tree model, we associated the most common parameter from the "individual tree model" to calculate operational times, using the maximum load capacity defined by the operators. The optimizations model selected lines 5, 10, 14 21 and 29, as shown in Figure 4. The profile of one the five selected lines by the mathematical model is shown in Figure 5.

In Figure 6 we show the lines selected by the optimization model as well as the lines defined by the traditional approach. The traditional crew selected lines 15 and 19 while the optimization model selected lines 14 and 21. The traditional method selected lower setup-time lines but slower in operation speed. When considering the overall productivity, the inclusion of more complex lines gave a better productivity due to faster overall operation times. Finally, we present a summary of total times for the complete harvesting of landing 36.

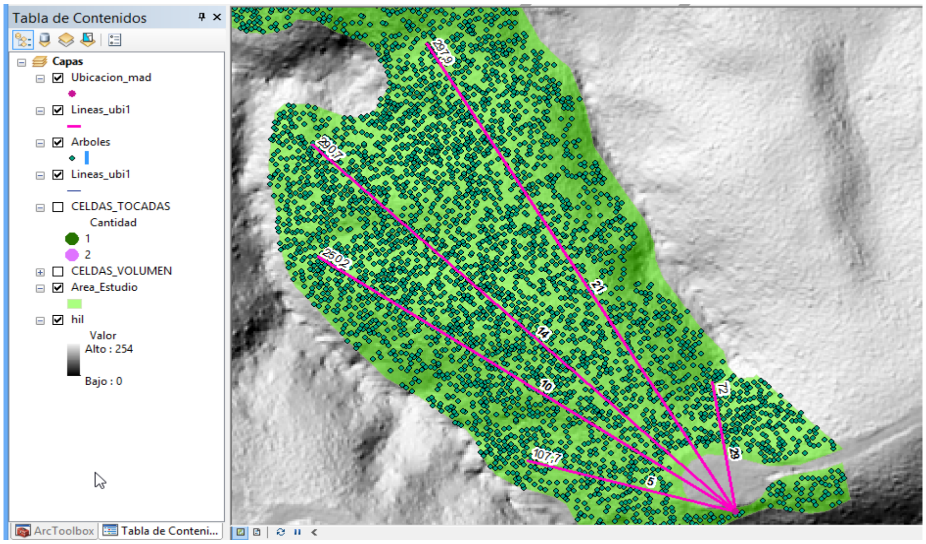

Figure 4: Selected lines

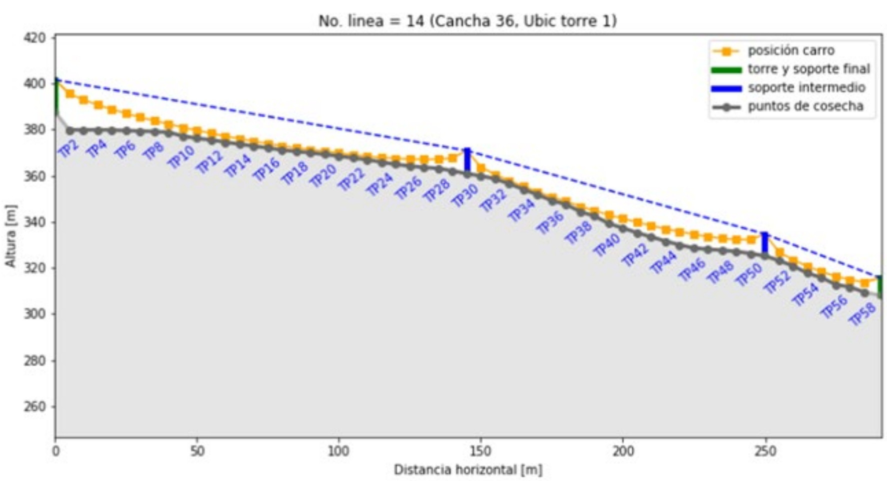

Figure 5: Profile of selected lines

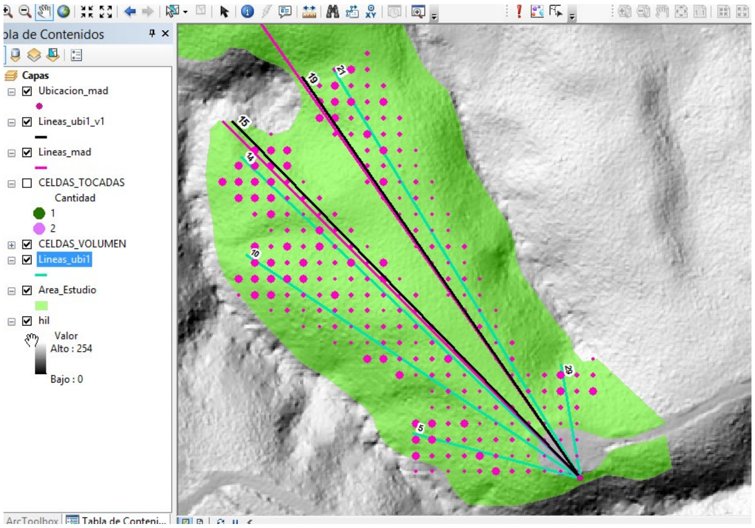

Figure 6: Comparison of traditional versus optimization harvesting lines

SUMMARY TRADITIONAL LINES	Setup Times (Hr)	Operation Times (Hr)
Tower Instalation	1	0.00
Line 5	0	3.78
Line 10	4	12.06
Line 15	2	36.65
Line 19	4	26.56
Line 29	4	2.61
Setup & Operation	15	81.66
	Total	96.66

SUMMARY OPTIMIZED LINES	Setup Times (Hr)	Operation Times (Hr)
Tower Instalation	1	0.00
Line 5	0	3.78
Line 10	4	12.06
Line 14	6	27.55
Line 21	6	23.25
Line 29	4	2.61
Setup & Operation	21	69.25
	Total	90.25

Productivity Improvement	7%

When we compare the total operational and setup times for the landing using the traditionally approach with the solution given by the optimization model, defined lines, we obtain an average of 7% of productivity improvement.

4. Conclusions

We showed that the LIDAR technology has the accuracy to build a tree census of the harvesting pilot area, obtaining an "individual tree" model that allows us to identify optimal intermedia support for the lines. Moreover, it was possible to identify in the field the intermedia support candidates to maximize log load capacity.

Even though the two step model generates accurate solutions to harvest a study area, still the line Bayesian-based optimization step is highly time consuming taking a bunch of time in difficult cases. For example, in a complex landing area, the process may take from 17 to 20 hours. We are working to improve this running time. An option to increase the speed of this stage is to evaluate the model only in some critical points of the line, instead of doing every 5 meters.

Despite the individual tree model showed accurate results to identify intermedia support candidates, in the case of high density forests, i.e., forest with more than 700 trees by hectare, it became difficult to identify individual trees in the forest. For such cases we propose a statistic tree model based methodology instead of an individual tree model, where the existence of a certain quantity of candidate trees in a specific area near the line is guarantee.

In our experience, it is of vital importance to select the log lines that maximizes the log load capacity oriented to increase productivity in steep terrain zones. This paper presents an optimization approach, that we solved using a two steps heuristic procedure that supports the latter decision. The methodology, that combines operation research techniques with geographic information technology, has been successfully tested in a pilot area in Chile with an important real impact in forest operations. The application of the model in real operational conditions gave us a direct improvement of 7% in productivity versus the traditional method.

5. Acknowledgments

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Mechanism and Operation design by 3D Modeling for Cable Yarding

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ABSTRACT

In the mountainous forest area, cable skyline systems are major method to harvest trees. In spite that they have utility, they have not been easy to apply because of the complexity of mechanism and the difficulty to place them on mountainous terrain.

The high-definition digital local terrain information made it easy for them to design, and the simulation method using CG technology makes it possible to examine various location relationship, mechanisms, etc. of real three-dimensional space by Virtual Reality method.

Here I introduced Unity, tool for 3D Game development, to enable 1) modeling the main rigging method in a digital three-dimensional space, 2) easy to design cable rigging together with validating and revising yarding operation, through virtual yarding operation with keyboard control, 4) designing and creation of data system for storing the results of the operation to improve following operations, which may support timber SCM. They can be applied a new cable skyline mechanism and automation for various operation in mountainous area, including silvicultural tasks.

Standardizing and creating Databa on cable skyline system and operation are also be considered from technical inheritance and operation evaluation/improvement closely related to site condition.

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Salvage Logging in the sensitive forest: evaluation of productivity and costs in cable yarding operations

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ABSTRACT

Harvesting of wood in steep terrain can only be implemented by a limited set of operational alternatives; it is therefore important to be efficient in such conditions, to avoid incurring high costs. Harvesting of abiotically disturbed forests (recovery crops caused by wet snow, strong winds), which is becoming common these days, it can significantly affect the operational efficiency of mining operations. Under such circumstances, bending can occur and can cause permanent damage to the internal wood without any external display of such damage. When left in the forests, broken and uprooted trees favor insect epidemics. This research study was carried out to evaluate the performance of truck-mounted uphill cable laying logging operations deployed in conifer stands. A time study was used for the estimated productivity and cost of yarding and predictive models have been developed to relate the time and productivity consumption for relevant operational factors, including wood grade damage. The average operating conditions were characterized by an extraction distance of 101 m and a lateral yarding distance of 18 m, with a productivity rate of 20.1 m3/ h. In response a different types of delays, the productivity rate dropped to 12.8 m3/h. Under the prevailing conditions, the lateral construction site accounted for 32% of the gross work cycle time and 50% of the time free from delays machine work cycle time. A decrease in lateral yarding distance and increase payload volume at maximum machine capacity would ultimately lead to site productivity of almost 30 m3 for SMH (programmed machine hour). The calculation of the gross costs of climbing yarding showed that labor costs (35.7%)

were slightly higher than fixed costs (32.9%), and double compared to variable costs (17.7%). The remote control of the truck, mechanical loosening mechanisms and radio-controlled chokers are just some of the improvements that it would lead to increases in operational efficiency.

Economic viability of the full-tree harvest under conditions of uncertainty: a study in the southeastern region of Brazil

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ABSTRACT

Due to the financial contribution and the operational costs for the acquisition of forest machines, conditioning forest managers to analyzes under conditions of uncertainty, decision models based on the Monte Carlo method can be adopted, which allow describing the behavior of the variables. In view of this, the objective was to assess whether the capital expenditure on the acquisition of forest machines for the harvest of Eucalyptus under conditions of uncertainty, adds value to the forestry company. Historical series were weighted over the six-year period of technical-economic data on timber harvesting from Eucalyptus forests, same age, in the state of Sao Paulo, Brazil. Full-tree harvesting system was evaluated, therefore, the felling of the trees was with a Feller-buncher, the dragging of the bundles carried out by a Skidder, and the processing in logs by two Grapple saws. The cash flow was projected for six years with the useful life of the machines. The opportunity cost rate for the use of capital was estimated using the weighted avarage cost of capital due from third party capital. The uncertain variables considered as inputs were the capital expenditure for the acquisition of forest machines, the tariff for operations, the volume of wood for operations, the cost of machines per hour of use, the depreciation of forest machines and the residual value. As outputs adopted for decision making, the net present value, the modified internal rate of return and the discounted payback period in years were estimated. When considering that the cost of equity was 9.1%, that 45.3% of real assets are financed at a rate of 7.9%, a weighted avarage cost of capital of 7.3% was also estimated, also included as a minimum attractiveness rate. The average net present value was USD 2,371,983, standard deviation USD 386,788, indicating 5th percentile USD 555,992 and the 95th percentile USD 1,831,464. The average value of the modified internal rate of return was 18.5% with a standard deviation of 4.5%, therefore, 11.2% higher than the minimum attractiveness rate. The average value of the discounted payback period was 1.4 and the standard deviation was 0.22, less than the useful life of self-propelled forest machines. The results demonstrate that the capital expenditure in the acquisition of machinery promotes an increase in the net wealth of the forestry company.

Artificial intelligence for the recognition of roads from photointerpretation

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ABSTRACT

Forest roads are a important part of the forest harvesting process. Knowing where they are located and whether they were executed as the project involves a great deal of monitoring and editing by geoprocessing tools. In order to automate this activity of photointerpretation and generation of road shapes, Klabin S/A, in partnership with national startups, created a tool capable of interpreting data obtained through UAV images, identifying roads and comparing with the original road location design. The tool is able, through machine learning, to read pixel by pixel (3x3m in size) what is represented in the image and to interpret it as being a road or not. Images were filtered and processed in the SIG Quantum GIS, being submitted to the random forest machine learning method (algorithm, which creates several decision trees, in a random way, where each tree is used in the choice of the final result). After this submission, the images were classified and filtered, beginning step two of the process, where an algorithm for cleaning the image noise through the OpenCV library was used. This process generated two classes of shapefiles, the line vectors and the polygon vectors. Once this processing is done, the identification response is confronted with the project, generating KPIs. These generated indicators include: unplanned and executed road; planned and executed road, and; planned and not executed road. With the inclusion of this new tool in the planning process, it

was possible to reduce the analysis time required for photointerpretation and generate indicators more quickly and effectively.

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Forest Road Route Design by Point Sequence Approximation Approach

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ABSTRACT

The development of forest road network in Russian forests, which is necessary for intensive forest management, requires modern methods of forest roads designing. In the eighties of the last century the tangent method used for road profile designing was replaced by the more progressive quadratic parabolas approach. In Russia, it is nowadays known as the Antonov's method. As for the forest roads' layout, the traditional method is used for its designing so far. According it, the route is depicted as a broken line and then circular and, at radiuses less than the recommended value, clothoid arcs fit into the angles of the turns. These clothoid arcs are named easement curves. The radius of the clothoid varies from infinity to the radius of the circular curve with which the conjugation occurs. The total number of clothoid segments in the road layout is always even, two in each curve. This method does not always provide the required smoothness of the path, and the length of the road is not the shortest. Therefore, the traditional methods of forest roads designing are being replaced now by more advanced technologies. One them is the point sequence approximation (PSA) method. Its essence is as follows.

Using the terrain map, the designer draws a sketched line of the future route guided by the terrain, the location of the contour obstacles and controlling the grades using the horizontal equivalent value. Then the sketch line is approximated by a set of straight lines, circular curves and clothoid lines. The accuracy of the approximation is controlled by the least-squares method, it means that the roadway is selected that corresponds to the minimum of the sum of squares of deviations of points of the sketch line from their corresponding points located on the alignment.

When approximating points on a sketched road alignment line, we consider a number of constraints imposed on the road alignment path. Main is the requirement of route continuity. It assumes that the start point of its each subsequent element coincides with the end of the previous element. Additional constraints are the requirement to pass an alignment through some fixed points on a sketch line, such as a matched intersection or junction with an existing road or a previously constructed infrastructure elements (bridges, culverts etc).

Road Network Planning for Tourism Development in Arasbaran Forest

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Abstract: It is very important for managers to plan a road network that meets all the requirements for tourism development and management. The aim of this study was to design and plan the road network for tourism management in the Arasbaran protected area. For this purpose, 14 different scenarios of road network were designed to access the recreational area using PEGGER extension in ArcView regarding the suitability map. Then, they were evaluated in terms of technical, environmental, and socio-economic criteria to achieve the optimal-designed road network. Regarding the results, the 7th scenario, with a road density of 3.34 mha^{-1}, an accessibility of 64.68%, and in terms of minimum costs and environmental impacts on the basis of the highest suitability value (72.26) was chosen as the optimal option. Therefore, taking into account the cost and environmental impacts and using GIS capabilities, it is possible principle design of the road network, and as a result the development of existing access roads in order to develop tourism in the area.

Keywords: Arasbaran protected area, planning, road network, tourism

1. Introduction

According to the International Nature Conservation Union (IUCN), the definition of ecotourism includes having fun while supporting the protection of the natural and cultural resources. Tourism management business provides opportunities to local residents in favor of development (Cetin and Sevik, 2016). Nevertheless, ecotourism planning can be considered for creating job opportunities, improving the economic status, and reducing consequently the environmental impacts (Bhuiyan, Siwar, Ismail and Islam, 2011). Forest areas with natural and human attractions have more potential for recreation, thus attracting the attention of forest-based recreation and tourism planners. Forest-based ecotourism is a non-consumable service, included among the alternative market-based approaches, developed upon the recreation service provided by the forests. Ecotourism is in harmony and may enhance the principles of sustainable forest management (Wickramasinghe, 2012). Therefore, tourism provides the potential for economic development, nature conservation, and provision of budget for conservation in the national parks and forest areas (Bhuiyan, Siwar, Ismail and Islam, 2011). Hence, forest recreational can be considered for forests management to reduce degradation factors and their sustainable conservation (Borzoei, Maleknia and Zeinivand, 2014).

Arasbaran protected area with its natural and human attractions is considered as a tourist region. In a modern and functional recreational area, a well-developed road network is necessary to guarantee the best fruition as possible for tourists. Indeed, a sustainable management and utilization of a forest area, especially developing recreational activities, can be only achieved through a suitable road network (Gumus, Acar and Toksoy, 2008; Khalili, Hosseini, Pourmajidian and Fallah, 2010; Enache, Stampfer, Ciobanu, Branzea and Duta, 2011). Moreover, an efficient forest road network guarantees the best outcomes in terms of forest operations, surveillance, recreational activities and forest management in general, including fire prevention and fire fighting in fire-prone environments (Laschi, Foderi, Fabiano, Neri, Cambi, Mariotti and Marchi, 2019). It is fundamental to guarantee the best accessibility to the area, avoiding environmental impacts or interventions which could negatively affect the environmental protection (Cetin, 2015). In order to reduce the negative consequences related with the enhancement of forest infrastructures (e.g. road construction) in the protected areas, a set of particular access policies should be applied in terms of social, economic and environmental impacts (Clius, Teleuca, Davi and Morosanu, 2011). Designing road network in accordance with the technical principles can also lead to an increase in the road network efficiency and a decrease in the construction costs and subsequent environmental impacts (Majnounian, Abdi and Darvishsefat, 2007; Alizadeh, Majnounian and Darvishsefat, 2011).

Nowadays, geographic information system (GIS) has become one of the most popular tools in spatial planning and management. In fact, these technologies are useful to manage a context where many factors should be considered for an efficient management. Due to its numerous capabilities (e.g. data processing with lower costs and higher speed and accuracy than traditional methods), GIS has been increasingly applied in forest road network planning (Alizadeh, Majnounian and Darvishsefat, 2011; Shahsavand Baghdadi, Pir Bavaghar and Sobhani, 2011; Naghdi, Mohammadi Limaei, Babapour and Ariamanesh, 2012; Meignan, Frayret and Pesant, 2013). Multi-criteria decision making (MCDM) and analytical hierarchy process (AHP) can be properly used along with GIS and the combination already employed in forest road network planning in forest areas and national parks (Shahsavand Baghdadi, Pir Bavaghar and Sobhani, 2011; Hayati, Majnounian, Abdi, Sessions and Makhdoum, 2013; Salehi, Rahbari Sisakht and Jahangirian, 2015; Laschi, Neri, Brachetti Montorselli and Marchi, 2016) proved the high capabilities of these techniques. Sepahvand (2003) in a study in a part of the Hyrcanian forest, surveyed the openness ratio of different road variants to complete an existing road network to access the recreational areas in a multi-functional forest. Also, Shahsavand Baghdadi, Pir Bavaghar and Sobhani (2011) designed 6 road network variants considering the environmental, technical and economic criteria using a multi-criteria evaluation (MCE)-GIS procedure, then technically compared the variants and the existing road network. This procedure was then applied to assess the existing road network of a forest park in Yasouj in terms of landscape and technical criteria (Salehi, Rahbari Sisakht and Jahangirian, 2015). A combination of weighted linear combination (WLC) and analytical network process (ANP) was also used to prepare the potential map for road planning and assess the road network alternatives (Moghadasi, Hosseini and Fallah, 2015). Moreover, other studies (Gumus, Acar and Toksoy, 2008; Nasiri, Hosseini, Sorkhi and Tafazoli, 2012) considered environmental impacts when proposing a new forest road network or modifying an existing road network. While others mainly focused on the technical and economic factors when proposing the optimal road network in a multi-functional forest (Hribernik and Potocnik, 2013). Hayati, Majnounian, Abdi, Sessions and Makhdoum (2013), Bugday (2018), and Javanmard, Abdi, Ghatee and Majnounian (2018) in their studies regarding forest road planning have provided the suitability map to reduce cost and environmental impacts of the road network. Dragan and Cocean (2015) in a study in Apuseni National Park, by assessing the constraints of effective road network on tourism development proposed major routes for improving road infrastructures that provide the access to the most famous park area and connect the sites.

The Arasbaran protected forest is an area with a great potential for tourism. To enhance this potential, a well-developed forest road network is necessary. Considering the capabilities of GIS and multi-criteria evaluation techniques, as mentioned above, in forest road network planning, the purpose of this study was to apply a combined MCDM-GIS approach to modify and develop the existing road network of the area in accordance with criteria affecting tourism planning and management.

2. Materials and Methods

Arasbaran forest is located in the north-west of Iran and sparely in the northern slopes of the Garadagh mountains of East Azarbaijan province in the region of Arasbaran (Alijanpour, Eshaghi Rad and Banej Shafiei, 2009). This region has been registered as one of the ninth biosphere reserves of Iran in UNESCO (Mohammad-Dustar-Sharaf, Mirfakhraie, Zargaran and Azimi, 2016).
The first step to implement a correct forest road planning, is to define the main parameters. In this study, this information has been obtained by a Multi-Criteria Decision Making (MCDM) and an Analytical Hierarchy Process (AHP), applied in a previous study developed for the same area that created a suitability map for forest road network planning (Talebi, Majnounian, Makhdoum, Abdi and Omid, 2018). The suitability map resulted is a fundamental layer for road planning (Figure 1).

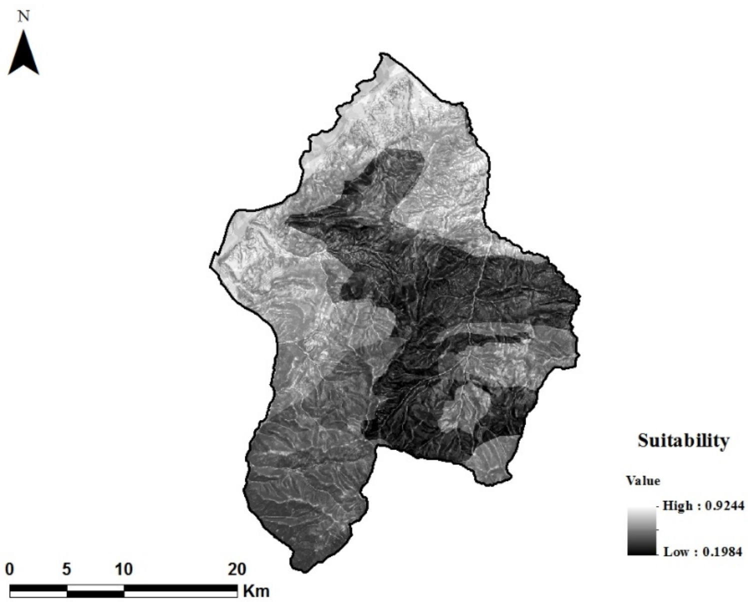

Figure 1. Road suitability map

2.1 Planning the Road Network Scenarios in GIS Environment

The road networks were planned considering both suitability map for road planning and capability map for tourism planning, which was already prepared for the same region thanks to the results obtained in a previous study (Figure 2) (Talebi, Majnounian, Makhdoum, Abdi and Omid, 2018). The tourism capability map gives information about the areas that have capability for intensive and extensive recreation considering the different ecological criteria. All of the 14 scenarios of road networks were automatically designed regarding the topographic lines on the digital topography map to access the different recreational areas with a minimum density using PEGGER in ArcView environment (Rogers, 2005).

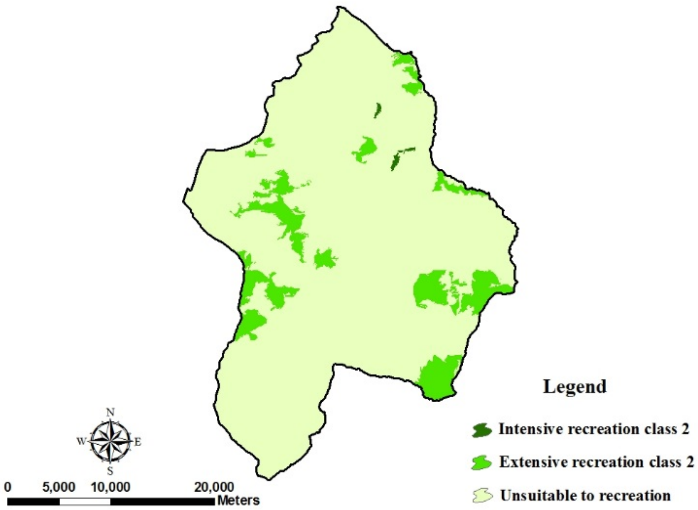

Figure 2. Ecotourism capability map of the area

Also, in order to reduce the road construction costs and environmental impacts, road planning was carried out regarding the different classes of the suitability map. It is noteworthy to mention that, a total length of 149.6 km of the existing road network was used when designing the new road network scenarios. Finally, the road networks designed in ArcView were transferred to ArcGIS environment for further evaluations. Our evaluation includes the technical, socio-economic, and environmental criteria which will be addressed in detail in the following sub-sections.

2.2 Technical Evaluation

In this evaluation, the Backmund criteria were used. This is a traditional theoretical technique to evaluate the forest road network. Backmund criteria such as road density (RD, m/ha), maximum access distance (RS/2, RS is road spacing), opening-up (OP%) percent (accessibility), and Backmund index (RD/OP%) (DSPS, 2012; Caliskan, 2013) were computed for each road scenario.

2.3 Socio-Economic and Environmental Evaluation

To provide the economic and environmental evaluation, each road network scenario was overlaid with the suitability map to calculate the total pixel value in correspondence with roads. The highest value, the best suitability of the road. Given that, higher values in suitability map represent more desirable pixels, therefore a road network with higher value per unit length would be preferred. Moreover, to provide an economic evaluation of each road variant, the cost of earthwork volume was calculated according to cut and fill volume. In this regard, the road networks were integrated with the classified slope map and the number of pixels of road scenario intersecting each slope class was extracted. After that, the average area of cut and fill operation for each slope class was calculated regarding the hillside normal profile. Then, cut and fill operation volume per slope class was estimated considering the average area of cut and fill operation and number and size of the pixels (10 meters). Finally, by multiplying cut and fill operation volume of each slope class per cubic meter of earthwork volume, the cost per unit length was calculated for each road scenario, according to the different prices for various lands (such as soft, hard, and rocky), (CPBO, 2017).

Furthermore, to develop a social evaluation, the designed road networks were overlaid with the map of ecotourism capability (Figure 2) to check if the road network provides access to the recreational areas. In this regard, the passage percentage of road network scenarios intersected with different classes of ecotourism capability was calculated. Moreover, the number of villages surrounding the forest accessed by the designed road network scenarios were also considered for the evaluation. With regard to the number of villages covered by a given road network, the village

coverage percentage was calculated per unit length of each road scenario. Villages within the maximum distance of 500 meters of roads were considered as villages covered by road network.
Taking into account all the information and the evaluation made, the final step of the analysis was carried out. Scenarios were ranked on the basis of the results obtained in all the described evaluations (under a technical, economic, environmental, social and recreational points of view), so that scenarios with top ranks were selected in terms of economic and environmental evaluations (such as multi-criteria evaluation and cut and fill operation cost), then the selected scenarios based on technical and social evaluations were ranked. Finally, the best scenario selected (with higher rating) was proposed as the optimal road network.

3. Results

3.1 Road Network Planning

The suitability map was classified into four different classes of suitability regarding road construction (see Figure 3). As it can be seen from Figure 3 the area mostly located in the "*medium*" (49.83%) and "*high*" (30.11%) suitability classes, while "*low*" and "*very high*" classes cover 15.14% and 4.92% respectively.

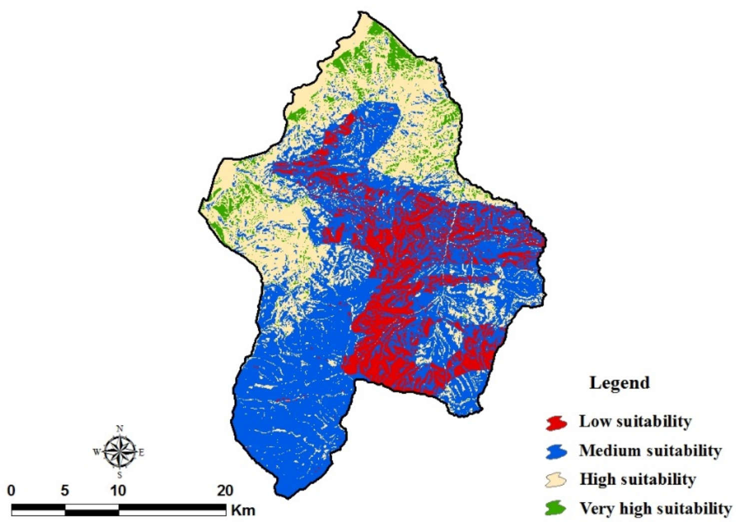

Figure 3. Classified suitability map for road network design

Figure 4 shows the 14 road network scenarios that were designed for tourism planning and management in the study area.

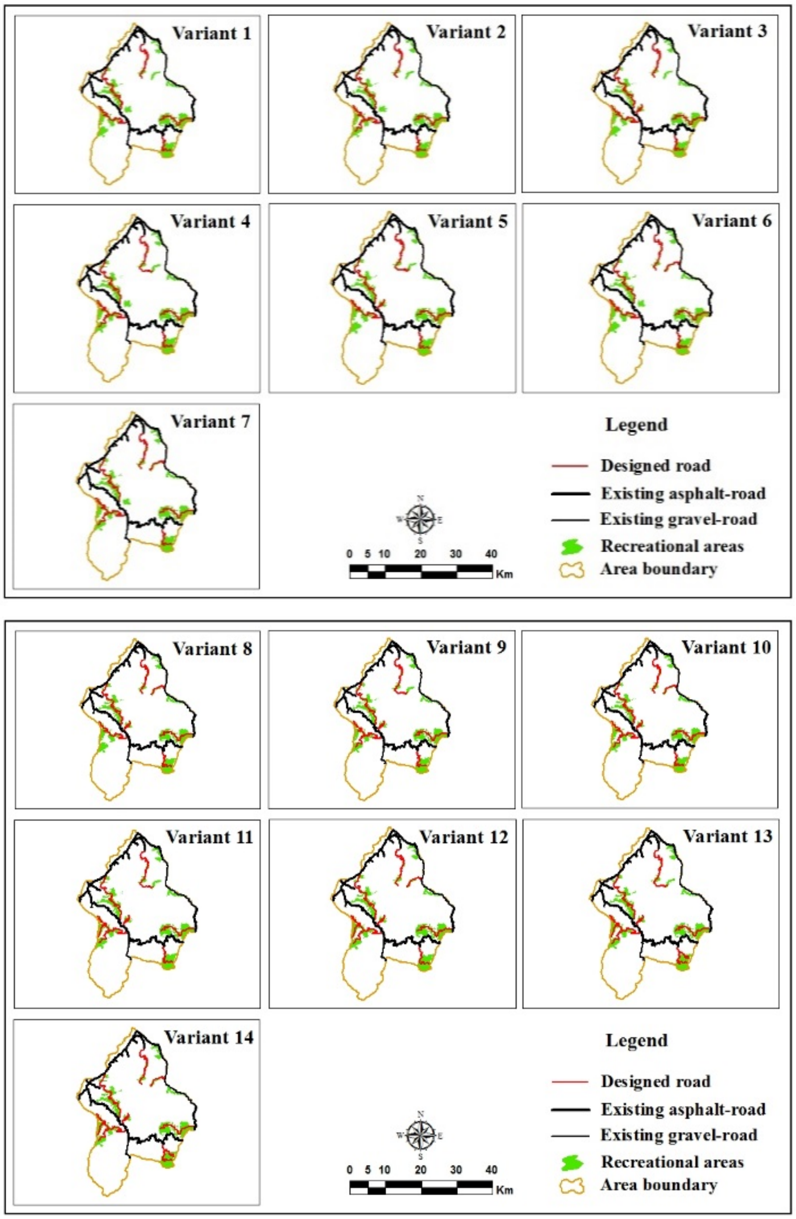

Figure 4. Designed road networks

3.2 Technical Evaluation of the Road Scenarios

The results of this evaluation indicated that scenarios 1 and 14 in Figure 4 had the minimum and maximum length and road density, respectively. The scenarios 1 and 10 showed the minimum and maximum accessibility in difficult access (Backmund model), respectively. Generally, scenario 1 had the least value of Backmund index. Technically, smaller values of this indicator are more desirable, therefore scenario 1 was selected as the best road variant in terms of technical evaluation. The results of technical evaluation are summarized in Table 1.

Table 1. Technical criteria for evaluation of designed road networks

Scenarios	Total road length (km)	Road density (m/ha)	Road spacing (RS-m)	Maximum access distance (RS/2-m)	Accessibility (%)	Backmund index (RD/OP%)
1	251.93	3.14	4,459	2,230	63.16	0.0497
2	260.25	3.24	4,321	2,161	64.03	0.0506
3	261.02	3.25	4,308	2,154	63.17	0.0514
4	265.04	3.3	4,242	2,121	64.75	0.0509
5	265.81	3.31	4,230	2,115	63.91	0.0517
6	259.65	3.24	4,321	2,161	63.75	0.0508
7	267.97	3.34	4,192	2,096	64.68	0.0516
8	268.74	3.35	4,179	2,090	63.85	0.0524
9	274.14	3.42	4,094	2,047	64.74	0.0528
10	277.07	3.45	4,058	2,029	64.78	0.0532
11	277.41	3.46	4,046	2,023	64.38	0.0537
12	280.34	3.49	4,011	2,006	64.44	0.0541
13	283.89	3.54	3,955	1,978	63.98	0.0553
14	286.82	3.58	3,911	1,956	63.99	0.0559

3.3 Socio-Economic and Environmental Evaluation

Based on the multi-criteria evaluation, higher values in the road suitability map regarding the maps standardization represent more desirable pixels. Therefore, with the highest unit value (72.26), scenario 7 was selected as the optimal-designed road network in terms of cost and environmental impacts. The results of this evaluation are presented in Table 2.

Table 2. Evaluation of the designed road networks on the suitability map (economic and environmental evaluation)

Variants	Total value	Total road length (Km)	Suitability Value per Km
Variant 1	18095.84	251.93	71.83
Variant 2	18723.18	260.25	71.94
Variant 3	18729.55	261.02	71.76
Variant 4	19115.53	265.04	72.12
Variant 5	19121.89	265.81	71.94
Variant 6	18736.11	259.65	72.16
Variant 7	19363.45	267.97	72.26
Variant 8	19369.81	268.74	72.08
Variant 9	19749.23	274.14	72.04
Variant 10	19997.16	277.07	72.17
Variant 11	19966.59	277.41	71.98
Variant 12	20215.86	280.34	72.11
Variant 13	20363.59	283.89	71.73
Variant 14	20612.85	286.82	71.87

Based on the estimation of cut and fill operation, scenario 10 with the estimated cost of \$ 983 per kilometer, and scenario 13 with the cost of \$ 1,100 per kilometer had the minimum and maximum construction cost, respectively (Table 3).

Table 3. Estimated cut and fill operation cost for the designed road networks (economic evaluation)

Variants	Road length (Km)	Total cost (\$)	\$/Km
Variant 1	102.32	107,135	1,047
Variant 2	110.64	114,950	1,034
Variant 3	111.41	115,325	1,035
Variant 4	115.43	117,083	1,014
Variant 5	116.2	117,458	1,011
Variant 6	110.04	109,925	999
Variant 7	118.36	118,115	998
Variant 8	119.13	118,115	991
Variant 9	124.53	125,273	1,006
Variant 10	127.46	125,339	983
Variant 11	127.8	134,161	1,050
Variant 12	130.73	134,836	1,031
Variant 13	134.28	147,746	1,100
Variant 14	137.21	148,421	1,082

Analysis of the accessibility of each road scenario to the recreational areas showed that, scenario 14 and scenario 1 with providing access to 27.85%, and 23.98% of the recreational areas were the highest and lowest, respectively, in this regard (Table 4).

Table 4. Access percentage of the designed road networks to recreational areas

Variants	Recreational classes			Total access
	Intensive recreational (IR)	Extensive recreational (ER)	Unsuitable for recreation	
Variant 1	0.8	23.18	76.02	23.98
Variant 2	0.78	24	75.22	24.78
Variant 3	0.78	24.56	74.66	25.34
Variant 4	0.95	23.56	75.49	24.51
Variant 5	0.94	24.11	74.95	25.05
Variant 6	2.11	22.49	75.4	24.6
Variant 7	2.04	23.31	74.65	25.35
Variant 8	2.04	23.85	74.11	25.89
Variant 9	0.92	24.86	74.22	25.78
Variant 10	1.97	24.61	73.42	26.58
Variant 11	0.9	25.65	73.45	26.55
Variant 12	1.95	25.39	72.66	27.34
Variant 13	0.88	26.21	72.91	27.09
Variant 14	1.91	25.94	72.15	27.85

Also, in terms of providing access to the villages, it was found that all the road network scenarios mostly showed the same range of coverage, with the scenario 4 providing a little higher coverage (13.58%). The results are presented in Table 5.

Table 5. Villages coverage by designed road networks

Variants	Village number	Total road length (Km)	Village coverage per unit length (%)
Variant 1	34	251.93	13.5
Variant 2	35	260.25	13.45
Variant 3	35	261.02	13.41
Variant 4	36	265.04	13.58
Variant 5	36	265.81	13.54
Variant 6	34	259.65	13.09
Variant 7	35	267.97	13.06
Variant 8	35	268.74	13.02
Variant 9	37	274.14	13.5
Variant 10	36	277.07	12.99
Variant 11	37	277.41	13.34
Variant 12	36	280.34	12.84
Variant 13	37	283.89	13.03
Variant 14	36	286.82	12.55

3.4 Final Evaluation of Scenarios

Considering the suitability map obtained by multi-criteria evaluation and the cost estimate based on cut and fill operation, scenarios 6, 7, 8, and 10 were selected as top ranked scenarios. According to the results of technical evaluation, Backmund index in scenarios 6, 7, 8, and 10 was 0.0508, 0.0516, 0.0524, and 0.0532, respectively. Therefore, scenario 6 was selected as the optimal scenario in terms of technical evaluation, being the one with the least Backmund index. Moreover, considering the percentages of access that each road scenario provided to recreational areas, scenarios 10, 8, 7, and 6 were selected as the top four scenarios, with 26.58%, 25.89%, 25.35%, and 24.6%, respectively, while taking into account the evaluation of villages coverage, scenarios 6, 7, 8, and 10 resulted the best road networks with coverage percentage of 13.09%, 13.06%, 13.02%, and 12.99%, respectively. Finally, according to all evaluation processes, scenarios 7, 10, and 6 obtained the first, second, and third ranks, respectively. Table 6 summarizes the results of final evaluation and the scenario 7 has been identified as the optimal designed road network because of the minimum value of the total ranks. Figure 5 shows the optimal-designed road network.

Table 6. Ranking of the best scenarios

Scenarios	Multi-criteria evaluation	Cut and fill operation cost	Backmund model	Access to the recreational areas	Village coverage	Total ranks	Scenarios priority
Scenario 6	3	4	1	4	1	13	III
Scenario 7	1	3	2	3	2	11	I
Scenario 8	4	2	3	2	3	14	IV
Scenario 10	2	1	4	1	4	12	II

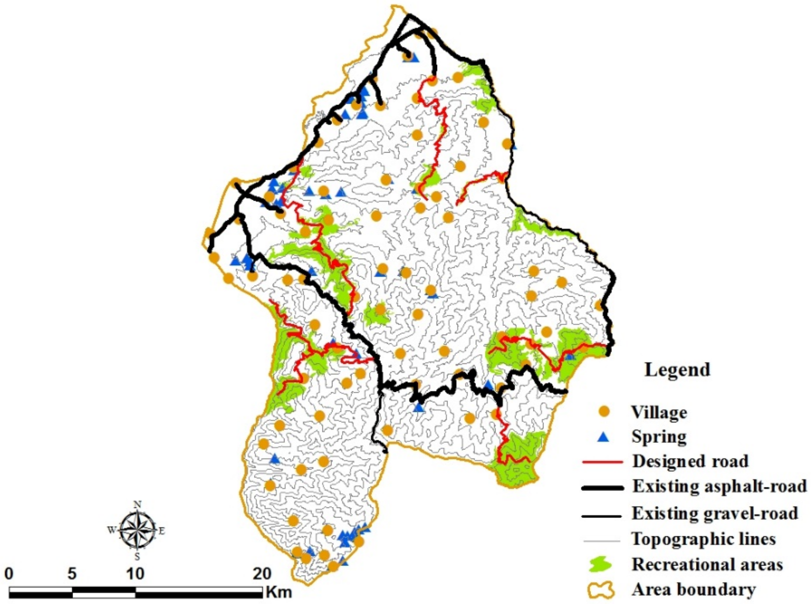

Figure 5. The optimal-designed road network

Regarding the analysis of road networks, the designed road network with the least Backmund index, more value, and more access to the recreational areas was better than the existing road network (Table 7).

Table 7. Comparison of the existing and designed road network

Road type	Technical				Suitability map	Access to the recreational areas (%)	Village coverage per Km (%)
	Road length (Km)	Density (m/ha)	Accessibility (%)	Backmund index	Value per Km		
Existing road	520.11	6.48	74.18	0.087	68.91	6.71	14.04
Optimal-designed road (scenario 7)	267.97	3.34	64.68	0.052	72.26	25.35	13.06

4. Discussion

A detailed road network planning has been carried out assessing technical, environmental, and socio-economic aspects, to provide a road network which well contributes to tourism development and management in the study area. In this study evaluation processes were performed in accordance with studies carried out in relation to road network planning and evaluation, such as Abdi, Majnounian, Darvishsefat, Mashayekhi and Sessions (2009) that used economic and technical criteria, Shahsavand Baghdadi, Pir Bavaghar and Sobhani (2011) who applied environmental and technical criteria to evaluate the road network scenarios, and Hayati, Majnounian, Abdi, Sessions and Makhdoum (2013) used multi-criteria evaluation technique to consider technical, economic, and environmental criteria. Also, Hribernik and Potocnik (2013) applied technical (accessibility coefficient), economic (reducing skidding cost) criteria and multipurpose role of the forest to evaluate the designed road, and Caliskan (2013) evaluated the planned road network based on Backmund criteria. In a forest park area, landscape and technical criteria using multi-criteria evaluation were applied by Salehi, Rahbari Sisakht and Jahangirian (2015) to assess the existing road network. Regarding the evaluation of the designed road networks and according to the results of technical evaluation

(Backmund model) clearly showed that, in higher road densities, the accessibility amount reduces. In fact, although increasing road density would decrease the distance between the roads, it would not necessarily lead to a substantial increase in opening-up percent (%). This is mostly as a result of dead (double) zones by different branches of a road network. This would, in turn, lead to an increase in Backmund index. The results obtained from the technical evaluation support the results of Abdi, Majnounian, Darvishsefat, Mashayekhi and Sessions (2009) and Shahsavand Baghdadi, Pir Bavaghar and Sobhani (2011) studies. In fact, the Backmund index is considered as a fundamental principle in the evaluation of road network, being this index important to define the quality of road network: lower the Backmund index, higher the quality of the road network. Accessibility evaluation was developed using the maximum access distance regarding the Backmund model in three classes, easy, medium and difficult accessibility for tourism. In other studies, accessibility analysis has been developed considering different distances in relation to the logging type. In this regard, Laschi, Neri, Brachetti Montorselli and Marchi (2016) considering altitude gaps of 100 and 200 m, proposed accessibility classes, accessible (served), hardly accessible (barely served) and inaccessible (not served) for logging.

Developing the suitability map, scenarios were assessed focusing on economic and environmental impacts. Regarding this evaluation, the best scenario was the one with the highest suitability value (the lowest cost and environmental impact), characterized by the highest value resulted by MCDE. This is the confirmation that the economic and environmental issues are considered as the most important in developing an efficient road network. On the other hand, technical issues and principles also play an important role, which must be taken into account. Therefore, at first, scenarios were evaluated and selected based on suitability map (multi-criteria evaluation) and estimated costs (cut and fill operation costs). Then, scenarios were investigated and evaluated in terms of technical and social issues. Finally, regarding the total ranks obtained from the evaluations, 7th scenario was selected as the optimal option with a density of 3.34 m ha^{-1}, accessibility of 64.68%, cut and fill operation cost of $ 998 per km, considering the highest value obtained from the multi-criteria evaluation and the lowest cost and environmental impacts. In most studies, road network design and evaluation have been carried out aiming at timber production (Gumus, Acar and Toksoy (2008), Abdi, Majnounian, Darvishsefat, Mashayekhi and Sessions (2009), Enache, Stampfer, Ciobanu, Branzea and Duta (2011), Naghdi, Mohammadi Limaei, Babapour and Ariamanesh (2012), Caliskan (2013), and Hayati, Majnounian, Abdi, Sessions and Makhdoum (2013)).

The optimal-designed road network which showed lower value of Backmund index, higher value of suitability and providing more access to the recreational areas was better than the existing road network. The designed road with the length of 268 km, provided access to about 65% of the area, while the existing road network with a total length of 520 km, provided access to about 74% of the area. Although, the existing road network provides more access to the area, its total length is about twice the length of the designed road network, and thus they are not comparable. For developing a region, there is a need for infrastructures, especially access infrastructures. Onyeocha, Nnaji, Anyanwu, Ajoku, Opoola, Faith and Maduakolam (2015) assessing the impact of road transport infrastructure on tourism development and concluded that the road infrastructure has leads to tourism growth increase, transport, and revenue increase in the region.

5. Conclusions

In summary, tourism planning is one of the important functions in forest ecosystems which can be considered for forest management, reducing the degradation factors and enhancing sustainable forest conservation. Developing tourism function in the natural landscape is dependent on the development of economic infrastructures, especially road infrastructures. Providing the appropriate access to the suitable tourism areas is required for tourism development and management in the study area. Therefore, regarding the increasing growth of tourism and multi-purpose use from forest areas, this study has paid particular attention to this topic and took into account the forest tourism activities in a forest protected area. In fact, the studied protected area of Arasbaran has a great potential for tourism. For this reason, tourism planning can be considered to improve the economic and social conditions, as well as for achieving the conservation purposes of this region. This study developed, through the use of GIS and MCDM-based approach, an innovative assessment of forest road network taking into account all the described factors aiming at a better functionality for tourism and recreational purposes. The optimal road network was proposed for providing access and connecting to suitable tourism areas and consequently tourism development in the region. Overall, the results of this study can be applied for tourism development and management in other forest protected areas.

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Evaluation of soil compaction caused by different wood extraction methods

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ABSTRACT

In recent decades, the technological evolution in the forestry sector and in particular in the field of mechanization and forestry uses has led to an almost exponential growth in the use of more powerful but above all heavier machines. The use of these machines during logging operations can affect the physical properties of the soil, especially by excessive soil compaction. Soil compaction causes reduced tree growth as a result of the reduced water permeability, restricted root space, poor aeration, and high soil mechanical resistance that can limit root elongation and penetration. This study evaluated the effects of the passage of forest machinery on the ground, in particular on the soil bulk density and on the total porosity in a forest of southern Italy. The survey included a combination of three levels of traffic intensity (1, 5, and 15 passes) of a John Deere 548H skidder, a John Deere 1110D forwarder, and a Landini 135 TDI farm tractor equipped with a winch. The soil bulk density and the total porosity were assessed at different points of the wood extraction track. Soil samples were taken using special steel cylinders, both on the undisturbed ground and during the logging operation after 1, 5, and 15 passes with the various machines. From the study of the effects on the ground of the different machines, the results showed that soil bulk density increased with the number of passes while the total soil porosity decreased, for all three machines used in this study. Most of the compaction, expressed as an increase in soil bulk density, occurred during the initial passes. Furthermore, it was evident that during skidding operations particular attention should be paid to minimize the negative effects of wood skidding on the ground in the cases of skidder and farm tractor with winch. In particular, for the farm tractor, the different dimensions of the wheels have also facilitated the phenomenon of cutting and mixing of the surface layers of the soil. Concerning the forwarder, the weight distribution over more axes compared to the skidder and farm tractor, and the lowering of the center of gravity, on the other hand, tended to have less impact on changes in the physical properties of the soil.

Forest road damages caused by heavy rains in Nikko and Kanuma areas of Tochigi prefecture, Japan

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ABSTRACT

In this study, we compared and analyzed the forest road damages that occurred in Tochigi prefecture during the Kanto Tohoku heavy rain in September 2015 and the East Japan typhoon in October 2019. The first and second stages of the tank model related to the landslides on the Yokone forest road (Kanuma Meteorological Observatory) are close to 100-year return period in both 2015 and 2019, and the forest road damages occurred because the sediment by the landslides overflowed the Sabo dam and filled the drainage facilities. The Akaihara forest road (Imaichi Meteorological Observatory) had a large value of 75 years for the 1st and 2nd stages of the tank model in 2015, but it was lower than the 50-year return period in 2019. However, a disaster occurred because the culvert was blocked due to an increase in the outflow rate of the sediment and logging residues by clear-cutting on the catchment area in 2019. On the Nishizawa forest road (Igarashi Meteorological Observatory), the road collapse occurred in 2015 because the probability of the first and second stages exceeded 300 years. Since the probability was about 10 years in 2019, no disaster occurred. As a summary, at the survey sites this time, it was confirmed that the drainage facility was blocked or damaged due to the outflow of forest residue due to clear cutting, which have also increased the runoff rate. In order to show these relationships statistically, it is necessary to expand the survey in the entire Tochigi prefecture and obtain field data. In addition, future research will review the 10-year probability rainfall intensity, which is the standard for forest road drainage facility design in Japan, considering the increases on the runoff rate of the sediment and logging residues during clear-cutting.

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Profitability of Hardwood Harvesting Operations in Tochigi Prefecture, Japan

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Abstract: In this study, profitability of hardwood harvesting operations by three forestry entities in Tochigi prefecture, Japan was examined. Three forestry entities were Utsunomiya City Forest Owners' Co-operative (FOC), Takahara Forestry Co-operative (FC), and Haga Area FOC. Utsunomiya city is the capital and is located in the central area of Tochigi prefecture. Utsunomiya City FOC provided operators' daily reports and product sales reports of three operation sites harvested in 2016, 2017, and 2019. These sites were located near houses and had almost flat terrains. The sites were broad-leaved dominated forests mixed with conifer. Takahara FC provided data of a site harvested in 2017. Takahara is located in 30 km north of Utsunomiya. Thinning operation was conducted to improve forest health and to make the residual stand a high value. Haga Area FOC provided data of four sites harvested in 2011 before March 11 of the Great East Japan Earthquake and 2018. Haga area is famous for Siitake mushroom cultivated on bed logs of Konara oak. Economic balances of Utsunomiya City FOC and Takahara FC which mainly produced pulp logs were deficient. Especially, Utsunomiya City FOC had the largest deficient because Utsunomiya City FOC used mini and small-sized machines and took care of neighboring houses. On the other hand, Takahara FC obtained subsidy for thinning operations from Government of Japan. Therefore, the operations had the profits with subsidy. Bed log productions of Haga Area FOC were almost profitability. However, immediate criteria (maximum values of radioactive cesium) were established after the Great East Japan Earthquake. Then, a survey should be conducted before harvesting bed logs. Therefore, it was more and more difficult to find appropriate forests for bed log production year by year according to the survey. Moreover, stand and terrain conditions of appropriate forests would be more and more severe than before.

Keyword: Bed log for Siitake mushroom, Charcoal, Firewood, Chip log, Great East Japan Earthquake

1. Introduction

Government of Japan projected to increase timber supply and demand from 24 and 76 million m^3 in 2014 to 40 and 79 million m^3 in 2025 based on the forest and forestry basic plan of Japan established in May 2016 (Forestry Agency of Japan, 2016). Timber supply from coniferous and broad-leaved forests occupied 89% and 11%, respectively, whereas stocks of those forests occupied 71% and 29%. Broad-leaved forests were used for firewood and charcoal production until the 1960s. However, those forests have been lagging in terms of tending operations since then. Therefore, harvesting and regeneration operations of broad-leaved forests are expected to maintain the relevant ecological, economic, and social functions of broad-leaved forests, as well as to increase timber supply. In this study, profitability of hardwood harvesting operations by three forestry entities in Tochigi prefecture, Japan was examined.

2. Materials and Methods

Three forestry entities were Utsunomiya City Forest Owners' Co-operative (FOC), Takahara Forestry Co-operative (FC), and Haga Area FOC. Utsunomiya city is the capital and is located in the central area of Tochigi prefecture. Utsunomiya City FOC provided operators' daily reports and product sales reports of three operation sites harvested in 2016, 2017, and 2019 (Table 1). These sites were located near houses and had almost flat terrains (Figure 1). The sites were broad-leaved dominated forests mixed with conifer. Softwood produced from conifer was almost sold for lumber and hardwood produced from broad-leaved was sold for pulp (Table 2). The sites were clear felled and conifer seedlings were planted. Operations were conducted with chainsaws for manual felling and processing, a mini-sized grapple-loader (5.0-ton weight), a small-sized grapple-loader (7.6-ton weight), and two 10-ton payload short- and long-body trucks. Furthermore, bush cutters were used for clearing before harvesting in 2017 and 2019. Moreover, a small-sized grapple-loader (7.1-ton weight) and a medium-sized grapple-loader (13.2-ton weight) were rented and 2.8-ton payload forwarder was used in 2019.

Table 1. Study sites

	Utsunomiya			Takahara	Haga			
	2016	2017	2019	2017	2011A	2011B	2018A	2018B
Year	2016	2017	2019	2017	2011	2011	2018	2018
Age	59	58	62	53-57	17	22	41	27
Slope (degree)	0.5	4.7	0.5	17.0	29.1	12.8	35.9	24.0
Area (ha)	0.33	0.79	0.89	8.62	1.97	2.00	1.00	0.40
Production (m^3)	70.42	261.92	297.40	621.96	132.73	171.54	48.95	43.20
Production (m^3/ha)	213.40	331.54	334.15	72.15	67.37	85.77	48.95	108.00
Labor input (man-day)	14.0	65.6	56.0	147.0	54.0	70.5	66.5	21.0
Productivity (m^3/man-day)	5.03	3.99	5.31	4.23	2.46	2.43	0.74	2.06
Revenue (JPY)	377,625	1,473,406	1,546,343	4,057,024	2,840,010	3,488,424	1,512,450	1,342,170
Revenue (JPY/m^3)	5,362	5,625	5,200	6,523	21,397	20,336	30,895	31,069
Revenue (JPY/ha)	1,144,318	1,865,071	1,737,464	470,652	1,441,629	1,744,212	1,512,450	3,355,425
Cost (JPY)	911,924	3,310,907	3,421,857	7,684,776	2,130,464	2,568,066	1,813,190	767,087
Cost (JPY/m^3)	12,949	12,641	11,506	12,356	16,051	14,971	37,038	17,757
Cost (JPY/ha)	2,763,405	4,191,021	3,844,783	891,505	1,081,454	1,284,033	1,813,190	1,917,716
Balance (JPY)	-534,299	-1,837,501	-1,875,514	-3,627,752	709,546	920,358	-300,740	575,083
Balance (JPY/m^3)	-7,587	-7,016	-6,306	-5,833	5,346	5,365	-6,143	13,312
Balance (JPY/ha)	-1,619,087	-2,325,951	-2,107,319	-420,853	360,176	460,179	-300,740	1,437,709

Figure 1. Study sites (Left: Utsunomiya, Middle: Takahara, Right: Haga)

Takahara FC provided data of a site harvested in 2017 (Table 1). Takahara is located in 30 km north of Utsunomiya. Thinning operation was conducted to improve forest health and to make the residual stand a high value (Figure 1). Therefore, production and revenue per ha of Takahara FC were less than those of Utsunomiya City FOC. However, productivity of Takahara FC ranged among productivities of Utsunomiya City FOC even with thinning operation because Utsunomiya City FOC used mini and small-sized machines and took care of neighboring houses. Operations were conducted with chainsaws for manual felling, a medium-sized processor (15.7-ton weight), a mini-sized grapple-loader (5.2-ton weight), a medium-sized grapple-loader (16.0-ton weight) and two 3.5 and 5.5-ton payload forwarders, and a 10-ton payload long-body truck.

Haga Area FOC provided data of four sites harvested in 2011 before March 11 of Fukushima Nuclear Accident and 2018 (Table 1). Haga area is famous for Siitake mushroom (*Lentinula edodes*) cultivated on bed logs of Konara oak (*Quercus serrata*) (Figure 2). However, Siitake mushroom cultivation has been declined in Japan (Figure 3) because consumption of Siitake mushroom has been declined and imported Siitake mushroom from China has been increased. In Tochigi prefecture including Haga area, 100 km southwest of Fukushima nuclear plant, Siitake mushroom cultivation has been drastically declined since 2012 and bed logs from other prefectures have been increased (Figure 4) because immediate criteria (maximum values of radioactive cesium) were established. Then, a survey should be conducted before harvesting bed logs. Haga Area FOC investigated forty bed logs for Radioactive cesium with criteria of 40 Bq/kg before harvesting. It is more and more difficult to find appropriate sites for bed log production below criteria year by year. Therefore, productions per ha in 2018A were less than those in 2011. However, revenues were almost same between 2011 and 2018A because prices have been increased (Table 1). Price of bed logs from other prefectures was 88,000 JPY/m^3 (110 logs were converted to 1 m^3) and species was Sawtooth oak (*Quercus acutissima*). Therefore, some farmers of Siitake mushroom in Tochigi prefecture have willingness to use domestic bed logs that are a cheaper and familiar species with cultivation even with risks of radioactive cesium. Operations were conducted with chainsaws for manual felling and processing, 0.8-ton payload forwarder (Figure 1). Grapple-loaders could not be used due to avoiding log injuries. Bush cutters were also used for clearing before harvesting. The exchange rate was USD 1 = JPY 110 on February 28, 2019.

Table 2. Production, Price, and Revenue of Utsunomiya

	2016			2017			2019		
	Production (m^3)	Price (JPY/m^3)	Revenue (JPY)	Production (m^3)	Price (JPY/m^3)	Revenue (JPY)	Production (m^3)	Price (JPY/m^3)	Revenue (JPY)
Softwood									
lumber	5.47	11,328	61,944	53.11	10,967	582,432	49.49	9,885	488,205
pulp	-	-	-	19.85	3,000	59,550	11.81	3,197	1,020,384
Hardwood									
pulp	64,97	4,860	315,681	188.96		831,424	236.20	4,320	37,754
Total	70.42	5,362	377,625	261.92	5,625	1,473,406	297.40	5,200	1,546,343

The direct operational cost, DC (JPY), was estimated using productivities and hourly operational costs for labor and machinery. Labor hourly costs, LC (JPY/h), were set to JPY 2,550/h for Utsunomiya City FOC, JPY 2,212/h for Takahara FC, and JPY 1,714/h for Haga Area FOC according to the interview with entities. Machinery fixed and variable hourly costs, FC and VC (JPY/h, Table 3), were based on depreciation, management, maintenance and repair costs as well as fuel and oil expenses (Sawaguchi, 1996; Forestry Mechanization Society, 1999; Zenkoku Ringyo Kairyo Fukyu Kyokai, 2001; Japan Forest Technology Association, 2010, Forest management planner association, 2016).

$$DC = LC \times LN \times ST + (FC \times ST + VC \times PT) \times MN + OE \qquad (1)$$

where LN is the number of workers, ST is the scheduled time, PT is the productive time, MN is the number of machines, and OE is the other expenses. The scheduled time and the productive time were shown in Table 4. OE is the rented expenses of Utsunomiya City FOC in 2019, JPY93,000 for mini-sized grapple-loader and JPY293,000 for medium-sized grapple-loader, and stumpage price and bed log transportation expenses of Haga Area FOC, JPY736,120 for 2011A, JPY815,800 for 2011B, JPY334,400 for 2018A, and JPY239,500 for 2018B. In addition to the direct operational costs, indirect operational costs were estimated as 40% of the direct operational cost (Forest management planner association 2016).

Figure 2. Shiitake mushroom

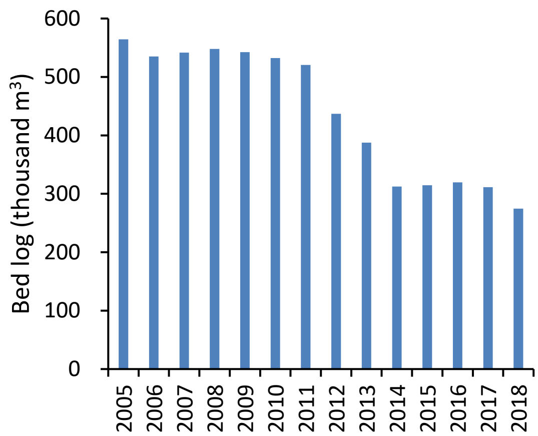

Figure 3. Bed log in Japan

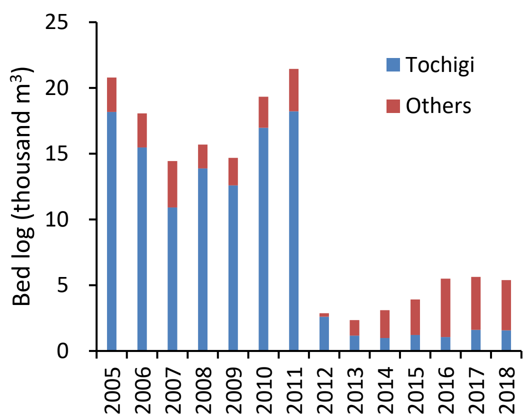

Figure 4. Bed log in Tochigi prefecture

Table 3. Machine fixed and variable hourly costs (JPY/h)

	Chain	Grapple-loader			Processor	Forwarder				Truck		Bush
	saw	Mini	Small	Medium	Medium	0.8	2.8	3.5	5.5	Short	Long	cutter
Fixed	82	1,575	1,764	5,152	2,722	348	2,262	3,046	3,351	1,903	2,501	10
Variable	388	785	1,182	2,847	1,602	179	1,431	2,028	2,333	1,641	1,698	47

Table 4. Schedule and productive times (h)

			Chain	Grapple-loader			Processor	Forwarder				Truck		Bush
			saw	Mini	Small	Medium	Medium	0.8	2.8	3.5	5.5	Short	Long	cutter
Utsunomiya	2016	Schedule	112.0	24.5	31.5							17.5	21.0	
		Productive	48.0	17.5	22.5							15.0	18.0	
	2017	Schedule	448.0	91.0	122.5							35.0	56.0	28.0
		Productive	192.0	65.0	87.5							30.0	48.0	20.0
	2019	Schedule	329.0	24.5	98.0				28.0			70.0	28.0	42.0
		Productive	141.0	17.5	70.0				8.0			60.0	24.0	30.0
Takahara	2017	Schedule	280.0	98.0		161.0	245.0			126.0	126.0		14.0	
		Productive	200.0	42.0		103.5	70.0			36.0	36.0		14.0	
Haga	2011A	Schedule	241.5					115.5						21.0
		Productive	181.1					38.1						15.8
	2011B	Schedule	304.5					14.0						49.0
		Productive	228.4					46.2						36.8
	2018A	Schedule	332.5					91.0						42.0
		Productive	249.4					30.0						31.5
	2018B	Schedule	98.0					49.0						
		Productive	73.5					16.2						

3. Results

Costs and economic balances were estimated in Table 1. Economic balances of Utsunomiya City FOC and Takahara FC which mainly produced pulp logs were deficient. Especially, Utsunomiya City FOC had the largest deficient because Utsunomiya City FOC used mini and small-sized machines and took care of neighboring houses. Operations in these sites of Utsunomiya City FOC were conducted for main purpose of thickets clearing rather than hardwood productions. Takahara FC conducted thinning operations. Subsidy of JPY490,000/ha was obtained for thinning operations with production more than 70 m^3/ha in Japan. Therefore, the operation had the profits of JPY30,000/ha with subsidy.

Bed log productions of Haga Area FOC were almost profitability and the profit of 2018B was the largest because the harvested volume was the largest and the bed log price was increased from 2011 to 2018. On the other hand, the balance of 2018A was the lowest and deficient because the cost per m^3 was the highest. This is because the slope was the steepest and the production per ha was the smallest. Therefore, it would be more and more difficult to find the profitable sites for bed log productions considering the criteria of radioactive cesium. Moreover, stand and terrain conditions of appropriate forests would be more and more severe than before.

4. Acknowledgement

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Can the terrestrial laser scanner become a widely used tool for estimating biomass production from hybrid poplar crops?

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ABSTRACT

Hybrid poplar crops have become alternative sources of biomass, especially in the temperate zone. The expansion of the short rotation crops (SRC) is supported by economic and ecological considerations. The literature provides many methods of biomass estimations, where a precise estimation is necessary for the sustainable planning of wood resources. The terrestrial laser scanner (TLS) can be used for estimating the production of above ground wood biomass (AGWB) brings an important technological leap among indirect methods. TLS technology is justified when destructive methods become difficult to carry out and allometric equations do not give accurate information. The aim is to estimate the biomass productivity on tree parts (stem and branches) with TLS technology, comparing the results with the gravimetric method. The study is carried out in NE Romania, on two clones of hybrid poplar (Pannonia and AF8) in the same vegetative conditions and crop technology (1667 trees per hectare) after five, six and seven growing seasons.

In Romania, TLS technology has never been used in short rotation wood crops, only the few cases in forest inventories. In this regard, getting fast data at minimal cost became a necessity for stakeholders, especially when this is performed with great accuracy.