PROCEEDINGS

Proceedings of the Joint 44th Annual Meeting of Council on Forest Engineering (COFE), the 54th International Symposium on Forest Mechanization (FORMEC), and 2022 IUFRO All-Division 3 Meeting

One Big Family - Shaping Our Future Together

October 4-7, 2022
Corvallis, Oregon, USA

Editors
Woodam Chung
Christian Kanzian
Peter McNeary

COUNCIL ON FOREST ENGINEERING

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Message from the Chairs

We welcome you to the 44th annual meeting of the Council on Forest Engineering (COFE) and the 54th annual meeting of the International Symposium on Forest Mechanization (FORMEC). This year's event is the last of the three consecutive annual meetings jointly planned by COFE and FORMEC. We are pleased to end this series with a hybrid event, allowing many of us to reconnect face-to-face in Corvallis after a hiatus in international travel. We view this year's in-person attendance as a testament to the resilience of this research community in the face of challenges shared by all of us across the globe, and we thank those of you who have travelled great distances to be here.

As the international ties that exist within this community continue to endure and strengthen, we wish you all the best for a productive conference filled with learning, connecting, and the making of fond memories. Ours is a unique field of scientific inquiry that we believe sets an example for the world to follow.

Best regards,

Woodam Chung Karl Stampfer

COFE-FORMEC-IUFRO 2022 Chairs

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Cognitive Workload – Does this Emerging Issue Matter for Forestry?

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ABSTRACT

Increasing mechanization and automation resulted in work systems that decreased biomechanical workload considerably and reduced forestry work – besides motor manual work – from "very heavy" to "moderate." This triggered a shift from biomechanical work to monitoring and control tasks enabled by cognitive processes. Following this trend, a new scientific field, "neuroergonomics," emerged, aiming to study the interaction of brain activity and cognitive work performance in real-world settings. The concept of cognitive workload emerged in the late 1950s and since then has been an essential issue in safety-critical areas, such as air traffic control, aviation, or the control of nuclear power plants. Up to now, very few explorative studies on cognitive workload in forest work systems are not robust and are lacking in reproducibility. The purpose of the presentation is twofold: (1) to provide a framework for cognitive workload, and (2) to review current approaches to assess and quantify cognitive work roads and their real-world settings. The presentation addresses three significant issues. First, it looks at four categories of tools to assess cognitive workload, in particular (1) self-assessment procedures, (2) task fulfillment/performance, (3) psychophysiological parameters, and (4) analysis of brain activity measurements based on the brain-computer-interface concept and machine learning. Second, it introduces the systematic approach of capturing real-time brain activity, extracting features, and training a prediction model with tools from machine learning. Third, it screens selected findings from forest-related studies. Whereas self-assessment procedures, particularly the NASA TLX questionnaire, have been prevalent, brain-computer-interface approaches have not been used in forestry. However, they will become the gold standard, and there is a need to perform a concerted action based on a factorial layout to better understand the problem of cognitive workload in forestry.

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Coaching Forest Engineering: Soccer and Forest Harvesting Simulators

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ABSTRACT

Modern coaching for team sports such as soccer emphasizes the use of small sided conditioned games (SSCG). SSCG are particularly useful for coaching emergent actions that are dependent on context. The SSCG can be manipulated to encourage behaviors through interpersonal interactions and interactions with other elements in the field of play. Coaching through the use of SSCG considers soccer as a system with emergent properties (i.e. properties that cannot be predicted simply by the presence of the elements in the system). Some authors in forest engineering are adopting a systems approach to forest engineering and in particular they are suggesting the environment must be added to the human, technology, and organization elements. Considering a forestry operation as a system is difficult for students who lack extensive experience in forestry activities. With the development of forest harvesting simulators combined with terrain building software, students are able to place many of the important elements of a forest operation in a virtual system and then conduct the operation to see what properties emerge. This paper applies the concept SSCG to the development of forest harvesting simulator activities for education in forest engineering. Tradeoffs were found between encouraging creativity, emphasizing coaching points (learning objectives), and the time available for the activity. Increasing rules in the SSCG helped to constrain the activity so that it fit into the time available for a typical undergraduate weekly assignment; however, this reduced the emphasis on creativity and the opportunity to gain greater understanding of the system. A common feature of the SSCG that emphasized creativity was the use of an iterative solution, where the students were adjusting the simulation to improve the solution.

Keywords: education, systems theory, experiential learning, computer simulation

Smart Forest Operations - Concept for Future Forestry or Buzzword?

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Industry 5.0 in Forest Management - Digitalisation and Automation

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ABSTRACT

Forestry and the export-oriented forest industry play a vital role in the Swedish economy. National management services are dominated by large-scale organisations whose core business model focuses on timber production and trading. The predominant forest management method focuses on efficiently harvesting raw material for the well-integrated sawmill industry adapted to the cut-to-length process. Business ecosystems, generally defined as a web of networks connecting suppliers, distributors, and product markets, have been discussed and evaluated over the past 20 years. Digital ecosystems, a more recent phenomenon, attempt to illustrate the digital interconnection between actors and objects to create added value in a business transaction and follow the digital transformation. There is a push towards industry 5.0 solutions enabling emerging digital ecosystems within the Swedish forest value chain, i.e. an integrated, adapted, optimised, service-oriented, and interoperable manufacturing process correlated with algorithms, big data and high technologies, emphasising sustainable, human-centric and resilient technologies. This study aimed to evaluate how the Industry 5.0 framework contributes to forest management processes in developing digital ecosystems and automation and clarify perceived barriers. The current state of digitalisation, potential and obstacles of further digitalisation and autonomous operations were derived from users and stakeholders within the Swedish forest sector on three separate occasions in 2019 and 2020. Digital processes were studied based on qualitative data from interviews. After that, forest companies, forest owners' associations, contractors, manufacturers, and researchers were approached with a web-based survey followed by a subsequent workshop about future expectations, needs and obstacles of future autonomous forestry work. To conclude, the results showed that the individual processes might be highly digitalised, but links between processes are underdeveloped or not digitalised, which means that digitalisation's full potential and added value cannot be utilised. The Swedish forest sector is pushing towards further automation and system developments, i.e. Industry 5.0 solutions, while stressing the systems' cost-effectiveness and ability to increase sustainable forest management. Thus, the challenge is to connect those automated and digital processes into digital ecosystems to make the forest management process even more efficient. Due to the many barriers and the significant push towards industry 5.0 solutions in forestry, this study identified a need for a forestry automation community, i.e., a grouping of researchers, users, machine manufacturers, etc., that drives the automation issue and the forest sector's priorities through collaboration.

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The Future of Timber Harvesting in Steep Terrain

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ABSTRACT

More and more machines are being tethered on steel wire ropes (ropes) and being sent down steep slopes. The goal is to make timber harvesting on steep terrain safer and more productive. This, however, gives rise to new problems. Many rope-tethered machines have not been designed to work on steep terrain. They do not have appropriate and tested attachment points for the tether rope and the diesel engines and hydraulic components are not always properly engineered for working on steep slopes. Many operators are not trained in the proper use of traction winches. It is common to see connected machines driving against the pulling direction of the rope to avoid obstacles requiring a lot of force. Sometimes the connected machine is not able to move and is forced in the rope pulling direction. This can damage the surface of the soil and is inefficient. It becomes particularly clear with machines that are used to transport wood, as much more power is required on the rope of these machines than machines for felling and cutting logs. To overcome these problems, Ecoforst and their partners have been working for several years on an unmanned semi-automatic skidder that can theoretically even operate horizontally on steep slopes. The unmanned skidder, which is controlled with two radio systems, finds its own way to the predefined wood storage area. For picking up wood, it is sent back down to the operator of the shovel loader. Once a path has been defined, the machine follows it by itself. To be able to steer on steep slopes, the attachment point for the rope has been specially designed so that the driving unit can operate independently of the rope and the load. The first attempts have been very successful. A few small steps are now required for the machine to be ready for series production.

Remote Sensing and Precision Technology

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Testing the Efficiency of Low-cost Dual-frequency GNSS Receivers for Real-time Positioning Vehicles in Mechanized Forestry

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ABSTRACT

In the age where forest operations are getting more accurate, the vehicles are at the epicentre. Harvesters and forwarders are equipped with sensors, computers, and most importantly GNSS receivers that record big data on processed trees, machine information, and locations. However, frequent reported errors in the positions have reduced the performance of these data for future applications, such as modelling forest productivity. Hence, enhancing the positioning accuracy of the vehicles' data is a key factor in the pathway of precision forestry.

We designed this research to test the efficiency of newly low-cost dual-frequency GNSS receivers for positioning of vehicles in real-time kinematic (RTK) mode in the mechanized forests of Finland. For this purpose, we selected some logging trails in forest stands that pass through trees with various characteristics. Our system was included a low-cost GNSS receiver (i.e. ublox-ZED-F9P module), an antenna, and a computer system mounted on a vehicle that receives the standard corrected data using the Internet server from the established local base stations based on an NTRIP-protocol. We controlled the positioning accuracy of the low-cost receiver via a geodetic-grade GNSS receiver with an error less than one centimetre.

Our results indicated that the absolute errors between the positions recorded by the low-cost receiver and control points were ranged between 1.5 cm and 1.8 m with an average of 43 cm. The top factors that affected the positioning accuracy of the low-cost receiver were tree height, ground elevation, ground slope directions, and canopy elevation and density. Moreover, we observed a high integrity and continuity of positions within the area of logging trails and without a significant deviation in positioning accuracy (test value = 0.5 m, p-value < 0.05).

We tested the efficiency of the low-cost receiver with only its standard patched antenna. There is a possibility to increase the positioning accuracy of the system using multiple antennas or geodetic-grade ones. The low-cost GNSS receiver showed high performance in acquiring reliable and consistent positions and the system has a strong potential for navigating harvesters and forwarders in the pathway of precision forestry in commercial forests.

Keywords: real-time kinematic positioning, low-cost GNSS receiver, positioning accuracy, mechanized forestry

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Use Of Lidar-Based Single Tree Inventory To Characterize Effects Of Roadside Fuel Break Treatments On Growing Stock Volume And Removal Revenue

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ABSTRACT

Low volume forest roads are critical for forest management activities, providing access for mechanized harvesting operations, recreational use, and providing for wildland fire protection. In fire-prone regions, well maintained forest roads also support fire preparedness by serving as firelines, particularly when adjacent vegetation is reduced. Because roads border or pass through many stands on managed forest landscapes, it may be difficult to quantify the value of land that may be removed from productivity when permanent roadside fuel breaks are installed. It can be also be challenging quantifying the value of growing stock removed. This study aimed to assess the effects of road use on the occurrence of tree health and species composition within different potential roadside fuelbreak widths. The study was carried out on the Big Meadow Creek Unit of the University of Idaho Experimental Forest (UIEF). The relationship between tree parametric data obtained from a complete lidar-derived single tree inventory of the UIEF and five road types (e.g. main haul gravel, secondary, native surface, etc.) was studied. Tree species composition and health (mortality) within 50 and 100 foot fuel break zones were examined. Results indicated that there is a significant relationship between forest road types and tree mortality in the research area. Among other things, this study demonstrates the value of single tree inventory data obtained from lidar for quantifying forest road right of way and fuelbreak treatment operations in detail.

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Measurement of Individual Tree Parameters with Carriage-based Laserscanning in Cable Yarding Operations

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ABSTRACT

Cable yarding is the technology that enables efficient and sustainable use of timber resources in mountainous areas. Carriages as an integral component of cable yarding systems pull a payload along a skyline and undergo a significant development. In addition to mechanical and functional development steps, carriages are increasingly used as carrier platforms for various sensors. Sensor technologies based on mobile laser scanning, machine vision, global navigation satellite systems (GNSS), and camera technology, or a combination of these, enable the development of intelligent user guidance and provide a higher level of automation and digitalization.

The goal of the present study was to assess the accuracy of individual standing tree and stand variable estimates obtained by a mobile laser scanning system mounted on a cable yarder carriage, under various stand and terrain conditions. A sample of eight cable corridors (in total 3,187 standing trees) was scanned in July 2020 using a GeoSLAM ZEB Horizon (GeoSLAM Ltd. Nottingham, UK) mobile laser scanner mounted on a Koller SKA 1 (Koller Ltd. Schwoich, Austria) carriage. The cable corridors were selected in such a way that a broad variation in forest type (broadleaved, coniferous, and mixed) and forest structure (one- or two layered) was represented. Four different scan variants were performed for each cable corridor: (i) slow downhill and uphill (average carriage speed: 0.7 m s-1), (ii) fast downhill and uphill (average carriage speed: 1.3 m s-1), (iii) only slow uphill and (iv) only fast uphill. The results of the carriage laser scanner data were compared with personal laserscanning (PLS) results using the same scanner and the same algorithms for automatic tree detection and dbh modelling. Manual measurements served as reference data. The analysis of the 3D scans showed that the tree detection rate dr (%) and the RMSE (cm) of dbh estimation strongly depended on the scan variant and the distance of each individual tree to the skyline. The average detection rates in 5 m and 15 m distance to the skyline were: 95.5% and 87.4% for variant (i), 95.0% and 84.1% for variant (ii), 94.0% and 80.5% for variant (iii), 88.4% and 64.0% for variant (iv), respectively. The corresponding average RMSEs of the dbh estimation were: 1.93 cm and 2.59 cm for variant (i), 1.94 cm and 2.98 cm for variant (ii), 2.38 cm and 2.97 cm for variant (iii), 2.33 cm and 3.79 cm for variant (iv), respectively. This study shows that individual tree and stand information can be collected automatically, efficiently and accurately using laser scanners mounted on carriages. With further development of hardware and software, such systems can provide important information for the planning, operation and supervision of timber extraction with cable yarders.

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Sensing Technology and Machine Learning Algorithms for Detecting Tree Quality Features and Optimizing Bucking during Harvesting Operations

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ABSTRACT

Achieving the highest value from a plantation resource is reliant on quality, timely and accurate measurement of key-value influencing tree quality features (e.g. sweep, branchiness) to support optimized stem bucking decisions. Due to the difficulties associated with the measurement of tree quality features in the field during forest inventory work, these attributes are usually excluded from optimal bucking procedures. At harvest time, in addition to diameter and length measurements, current onboard machine optimization systems rely on operator assessment of other key features like stem sweep, limb diameter, limb angle, and internal characteristics like stiffness and strength. These repeated observations, judgments and operations performed by the operators may result in reduced productivity and value losses. Emerging and new sensing technology like LiDAR, photogrammetric point clouds, and high-definition stereo imaging, represents an opportunity to leverage more accessible and affordable data collection to capture some of the factors that are currently estimated by operators with accurate measurements and improve the value recovery.

In our study, we present a non-destructive, automated methodology to optimize stem bucking based on point cloud data acquired with a mobile laser scanner (Hovermap LiDAR system), which maximizes tree value. The raw point cloud was processed with machine learning algorithms, which enabled the automatic detection of the trees in the plot as well as the estimation of diameters at different tree heights and stem sweep. This information was then used as an input to a dynamic programming bucking algorithm which optimized the value of each tree based on market and tree data. The methodology was tested on two Radiata pine plots located in South Australia, consisting of about 50 trees each. The bucking results were compared for three sets of input data: two generated from point cloud data collected with the LiDAR scanner (including and excluding sweep) and one generated from a taper equation based on manual DBH measurements. The metrics used for the comparison included total value, value per product, total volume, volume per product, and the number of logs per product.

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Comparison of Wood Stack Volume Determination Between Different Manual, Photo-Optical, iPad-LiDAR and Handheld-LiDAR Based Measurement Methods

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ABSTRACT

The measurement of roadside wood stacks in the forest still plays a decisive role in many forestry operations. Traditional manual measuring methods can be laborious, inaccurate and error-prone. Therefore, the issue is whether 2.5D or 3D optical remote sensing measuring methods can provide more precise or detailed results and advantages in further data processing. This current study examined and partly developed nine different manual, photo-optical, iPad-LiDAR and handheld-LiDAR-based wood stack measurement methods. Forty-seven wood stacks, ranging from 8.9 m^3 to 209.3 m^3 o.b. (totalling approximately 2700 m^3 o.b.) were measured and compared using these nine methods. However, all the methods are volume estimations and, thus, none of these can be seen as the real or true wood stack gross volume. Surprisingly, the results varied significantly within and between the individual methods, with up to 9.15% mean relative deviation. The relative deviation is strongly dependent on the size of the wood stack. The 3D measurement methods using iPad RGB and LiDAR recorded lower timber volumes than the other methods, in contrast to the method applied based on samples taken with handheld-LiDAR, which overestimates the volume. Generally, optical- and laser-based surveying techniques could become more widely applied in measuring wood stacks in the future. However, such automatic wood stack gross volume determination still faces some challenges, and needs to be improved.

Detailed information on the measuring procedures, methods and results will be presented at the conference.

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Measuring Large Harvest Residue Piles on Complex Terrain with Georeferenced UAV Imagery

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ABSTRACT

Measuring the piles of woody residues that accumulate at Whole Tree Harvesting landings is a difficult task to complete with accuracy. With more value potentially ascribed to the accumulated material and piles also presenting post-harvest environmental risk, measurement and active management are increasingly important. By capturing georeferenced photogrammetric models of piles of woody harvest residues in rolling-to-steep terrain pre- and post-harvest, this presentation describes workflows to remotely measure volume and depth. Initially 37 piles were measured post-harvest using a terrain estimation methodology. Model accuracy is dependent on the model of the underlying terrain. In a further case study, the method was refined through georeferenced modelling of the pre-harvest terrain. Using the refined method, the case study pile which draped over a fill slope was found to contain 2000 +- 110 m3 bulk volume of harvest residues, an average depth of 1.3 m and maximum depth of 3.8 m. These workflows enable efficient and safe data collection, also leading to high resolution results that can be used for reconciliations or post-harvest risk management of piles.

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Fusing Harvester Head and Remote Sensing Data to Predict Harvest Yields

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ABSTRACT

Context: Planning of forest harvest operations requires a reliable prediction of the harvested volume per log sorts, ideally based on the knowledge about the characteristics of the forest stands, the harvest and bucking prescriptions, and the harvesting system. However, the accuracy of current forest inventories is often insufficient or relying on simplistic assumptions on the processing of tree logs, thus requiring time-consuming pre-harvest cruising to provide the required information. Objective: The goal of this project is to develop and evaluate a methodology to predict and map the production and productivity from single-grip harvester head data, using remote sensing data on stand and site conditions as predictors.

Methods: Total productivity (in m3/machine-day) and the production by log assortments (in m3/ha) are compiled from a group of single-grip harvesters data collected by a large industrial forest company in Eastern Canada (New Brunswick). Stand and site attributes for each machine-day are used as predictors, obtained from area-based lidar inventory (400m2 resolution), photo-interpreted species composition, climatic soil and drainage maps, and lidar-derived digital elevation models for slope and aspect. Both predicted variables and predictors are compiled on a 400m2 grid (20m x 20m pixels). Machine learning algorithms are trained and validated with distinct datasets from a random division of the original dataset The precision and accuracy of the learners are compared using R2, relative root square error (RRSE) and bias. Once the model is successfully trained, predicted value of production for each 400m2 can be mapped for stand and site conditions that are comparable to those included in the training dataset. Our initial dataset contains 34 500 pixels, representing the collection of 6.4 million logs cut from 274 000 stems. First results First training iterations of the prediction model using k-NN and the random forest algorithms were performed using data from 1800 machine-days (40 harvesters), from clear-cuttings in spruce-fir dominated stands. For the total harvested volume (in m3/ha) at the 20m x 20m pixel scale, the best model provided a reasonable fit with a R2 of 0.64, with no significant bias, and a RRSE of 61%. However, when the values where aggregated at the machine-day scale (~1 ha), the R2 increased at 0.93 and the RRSE lowered at 28%, suggesting that pixel-level errors tend to cancel out when aggregated. The precision of the volumes per assortment varied by product type from an R2 of 0.34 to an R2 of 0.88). It is worth mentioning that this iteration lacked information about the bucking prescription and that better results can be obtained once this information will be considered in the model.

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Automated Sweep Measurement of Logs by Harvesting Machines

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ABSTRACT

Over 95% of plantation forest volume harvested in New Zealand is cut into logs using mechanised processing machines. Compared with manual processing of stems into logs using chainsaws, these man-machine systems provide a safe work environment for log processor operators, are highly productive, and involve detailed measurements of log diameter for every decimetre of length along a stem. Assessment of quality features (e.g., sweep, knot size, spike knots, scarring, etc.) that determine a log's grade, however, relies on input from the machine operator - input based on visual cues that have to be made at high speed from some distance away from the log. Some forest companies set a maximum reject rate of 4% of total logs produced by their harvesting crews; the maximum reject rate relates to both machine measurements (length and diameter) and assessment of quality features.

Excessive sweep (curvature) has a negative impact on lumber volume recovery, lumber grade recovery, mill sawing productivity, lumber drying and mill profitability. A 2013 survey of New Zealand sawmill log customers and log suppliers found that sweep was at the top of the list of the most frequently named log quality problems by customers but ranked towards the bottom of the list, however, by suppliers. Almost a decade later a second survey found that sawmillers still ranked sweep at the top of the list of their log quality problems - indicating that log suppliers had not been able to effectively address this issue. A 2020 study carried out at New Zealand's largest sawmill found that 56% of rejected Douglas fir logs and 50% of rejected radiata pine logs were due to excessive sweep. In 2020 work was begun that is expected to lead to the development of an automated and objective system for assessing sweep during log processing. The initial work was based on video-footage of harvesting operations found on the web. It successfully demonstrated proof-of-concept of the potential viability of using machine vision and deep learning to automatically assess sweep in logs being processed in the forest. The initial work also identified implementation issues that need to be addressed. An alpha prototype system, that includes both hardware for image capture and software for image processing, is currently under development. This presentation will describe the sweep measurement challenge, proof-of-concept trial, and progress with the alpha prototype development in more detail.

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Automated Volumetric Measurements of Truckloads Using Photogrammetry, 3d Reconstruction, And Convolutional Neural Networks (CNN)

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ABSTRACT

Given that wood represents on average up to 50% of the delivered costs, it is critical to adopt correct measurement procedures and technologies that provide better estimates of the wood delivered by trucks. Poor measurements will not only impact the revenue obtained by haulage contractors and forest companies but also might affect their contractual business relationship. Also, manual measurements of stacked logs or on trucks are time-consuming and labour 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 intelligence algorithms have been developed and implemented as alternatives to laser scanning-based solutions.

In this research, we have developed and validated an automated volumetric measurement system of truckloads (Eucalyptus nitens pulplogs) from images collected with an unmanned aerial vehicle (UAV, drone) and processed with Structure from Motion (SfM) and 3D reconstruction techniques. Also, we have applied a Convolutional Neural Network (CNN) model, called KPConv, on the point cloud generated through photogrammetry and SfM, for the detection and segmentation of logs on trucks, an estimated log volume from a Poisson surface reconstruction algorithm. The original data set included images from 19 truckloads (B-doubles). Before training the DL models, the images were pre-processed and augmented, and about 80% and 20% of this data set were used to train and validate the CNN model, respectively.

As a way to validate the results and test the accuracy of our approach, we compared the volumetric estimates with those from manual measurements as well as with measurements obtained with a commercial truck laser scanning system. 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. Our research also proposes pipelines and guidelines for the implementation of this technology in operational conditions.

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Detection of Old Logging Trails - The Initial Step to Solve the Logging Trail Network Design Problem

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ABSTRACT

Optimization framework of the CTL forest machinery traffic can be divided into two sub-problems. The initial positioning of the harvester movement creates the first sub-problem and the latter optimization of forwarder traffic forms the other sub-problem referred to as the trail network design problem (TNDP) and the forwarder routing problem (FRP), respectively. The first attempts to solve either the TNDP or the FRP problem have not achieved wider acceptance because they were based on rather inaccurate descriptions of trees and terrain, had insufficient understanding of operators' working techniques, and suffered from a lack of information regarding previous operations. The TNDP problem has lesser importance in the areas where logging trails are regarded as permanent.

In modern forestry, based on the rotation forest management (RFM), forest stands are thinned two-three times before the final cutting. Logging trails are designed in the first commercial thinning. However, a part of or the entire logging-trail network might disappear under the forest canopy before the next thinning due to regeneration or development of the forest crowns. Hence, we have developed a novel system based on deep learning, in the Forest Technology group of the University of Helsinki, that uses high-density laser scanning data to detect old logging trails that were established in the previous commercial thinning. The model was trained based on the U-net Convolutional Neural Network (CNN) architecture via a large training and labelling datasets that were obtained from the high-density laser scanning-derived metrics, such as the canopy height model (CHM) and digital surface model (DSM). Our results indicate that the detection of logging trails after the thinning operations is very strong. Although some obstacles, such as canopy occlusions, have hampered the detection of an entire logging-trail network in mature stands, the model showed a reliable performance (up 60%) in these stands before the second or third commercial thinning as well. This provides an excellent platform to optimize logging-trail networks before starting the new forest operations.

We see that interpretation of previous logging operations should be the crucial starting point of any forest operation, since it may have a significant influence on soil properties and tree composition. Depending on the frequency of the harvesting operations, soil disturbances induced by machine traffic or the type of silvicultural system, the new logging-trail network may be beneficial to locate either completely previously occupied locations, completely non-occupied locations or somewhere in between these two options.

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Lessons Learned from Using Single Tree Inventory (STI) in Operational Forestry: Methods to Evaluate Pre-Commercial Thinning (PCT) Treatments

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ABSTRACT

For approximately 2 years we have been working with multiple iterations of lidar-derived single tree inventory (STI) for the 8200-acre / 3300-ha University of Idaho Experimental Forest (UIEF) along with our conventional, stand-based inventory (SBI) program. Single-tree inventory data offers a variety of opportunities for overhauling how we think about and plan virtually all aspects of operational forestry. Rather than using mean, stand-level estimates of merchantable volume, stem diameter, and other stand attributes as the basis for planning and analysis, operations foresters need to quickly become accustomed to working with point pattern analysis for large geospatial data sets that may contain location-aware single tree and product information for millions of single tree records. In the mixed-species conifer forests of the inland northwest where as many as 20 or more product sorts are commonly removed from stands during harvesting, working with tree- and product-level data provides a variety of opportunities for thinking very differently about operational logistics. For example, development of precision stand prescriptions to implement silvicultural objectives and planning of skid trails and landing locations that minimize product handling are two of many tasks that can be implemented through filtering and analysis of census-level single tree point data. As a demonstration of the new 'smart forestry' methods foresters in the region need to be accustomed to, we demonstrate use of STI data to retroactively evaluate precommercial thinning (PCT) and mastication treatments implemented on the UIEF over the prior 9-year period using the actual distributions of inter-tree distances in treated stands, as opposed to plot-based averages used commonly for thinning inspection. Some advantages and recommendations for adapting to the STI approach to operational treatment planning and assessment are discussed.

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Quantification of Harvest Residues from Clear-fell Harvests of Pinus radiata in New Zealand's Steepland Plantations

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ABSTRACT

Clear-fell harvesting the steepland Pinus radiata plantations in New Zealand generates significant volumes of woody residues. In current operations, neither the total volume of residues nor a measure of their distribution, in terms of piece size or geospatial, is quantified at the time of harvest. That quantification is increasingly important in aiding the development of bioenergy markets and measuring progress in value recovery rates. Investigating 17 steepland Pinus radiata plantation sites across New Zealand, with a total of 185 sample plots, it was found that the median distributed volume of large woody residues was 88 m3/ha on cutovers. With the trees processed on larger scale landings, residues also accumulate in piles as a processing byproduct. Measuring these piles on 16 sites showed an average 0.23 m3 (bulk volume) of residues in landing piles per cubic meter of timber harvested. On the cutover, on average 30 m3/ha was assessed to be of sufficient dimensions and quality to be a saleable biomass product (being greater than 10cm in diameter and 0.8m in length). This study benchmarks the current availability of large woody residues from steepland Pinus radiata plantations as forest owners, managers and loggers work to improve value recovery during harvesting and seek new market opportunities for forest produce.

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Evaluating the Use of a Photo-Optical Mobile App in the Measurement of Stand Parameters in the Burnt Forest Stands

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ABSTRACT

Field measurements are the primary source for reliable estimates of stand characteristics in forest inventory. Recently, remote sensing technology has been increasingly used to collect stand parameters data in forest inventory. Although the accuracy and efficiency of remote sensing technology are comparable with conventional techniques, it still needs field measurements as a reference for calibration and accuracy assessments. With advanced technology, many sophisticated instruments and tools have been developed for measuring stand characteristics in field inventory. In particular, photogrammetry techniques based on optical and mathematical methods to calculate stand parameters in field measurements have been investigated. In the last twenty years, when smartphones have become the most popular and rapidly developing computing devices, their improved digital cameras have been integrated into the mobile applications that have been used in various natural resource disciplines. This study aims to examine and test the smartphone-based forest inventory application "Trestima." It is a forest inventory system based on the interpretation of images taken with a smartphone. Its accuracy and efficiency in estimating stand parameters have been evaluated in various countries for sample plot measurements and stand-level inventories. In this study, the app was used to measure stand parameters (i.e., volume, basal area, diameter, and height) after the forest fire, which will help accurate and fast post-fire harvest planning. The data collected with the Trestima app in a recently burnt forest stand was compared to the data obtained from traditional forest field measurement (used as reference data). The results indicated that the use of a photo-optical mobile app saved time and provided accurate solutions in the measurement of stand parameters.

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Skidder Production: An Integrated Solution Based on FPDat On-board Computer Systems and Lidar-based Enhanced Forest Inventories

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ABSTRACT

The productivity and utilization of individual forest harvesting machines such as skidders within varying conditions can be compared through time studies and volume allocation. Utilization and productivity information allow adjusting decision-making processes and support logging cost analysis. To obtain this information on a detailed level, costly and time-consuming field observations are required. On-board computer systems for whole-tree harvesting monitoring, such as the FPDatII, collect several machine data in an automated manner. However, they are mostly limited to time observations and lack a direct volume input. Therefore, at operational level, productivity estimations based on on-board computer systems have been typically limited to block-level analyses. Among other machines, this is particularly true for grapple skidders, which are one of the most common machines for ground-based primary transport in whole-tree harvesting.

This study tries to improve the automated productivity data collection of grapple skidders by merging engine status and machine travel information collected with FPDatII units with LIDAR-based volume distribution information. It further tries to test and validate the use of hydraulic pressure switch sensors to record grapple open and closing events with a timestamp and GPS data point. With this approach of automated data collection, the number of machine cycles and the yarding distance will be captured at cycle-level. This will enable the analysis of the effect of skidding distance on skidding operations on a cycle-based long-term data collection and provide productivity information at shift-level. This methodology could allow the industry to benchmark operations in varying conditions, determine factors affecting productivity and enhance the supply chain visibility by allowing to analyze skidder productivity on a daily basis.

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Using LiDAR to Identify Road-stream Aquatic Barriers

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ABSTRACT

The ability of aquatic species to move without barrier amongst habitats is important for their long-term persistence. Identification of these barriers which can impede flow, move sediment, and prevent free movement has become a critical area of stream restoration efforts. Much of the U.S. River and stream network have been fragmented through aquatic barriers (dams and road-stream crossings), however the extent, location, and assessment of these barriers is not fully known (Januchowski-Hartly et al., 2013). Some road-stream crossings have little impact (bridges), however poorly designed, neglected, or incorrectly sized culverts may have large impact on upstream movement of aquatic species (Fritschie & Wolfe, 2020). The volume of work needed to correctly identify and assess possible impact far exceeds the workforce and money allocations, and therefore compounds the lack of knowledge as infrastructure outpaces inventory. There have been attempts at using GIS and/or imagery to remotely sense road-stream crossings. These studies often suffer from low predictability, and often cannot distinguish between bridges and road-stream culverts. While these advances still may aid in identification, when light detection and ranging (LiDAR) is utilized to identify potential barriers due to drop across the road-stream crossing, a large increase in predictability is gained. Between 2016 and 2020, multiple flights were taken over the western North Carolina, northeast Tennessee, upstate South Carolina region using sub-meter Geiger-mode and Linear-mode LiDAR as a part of the USGS 3D Elevation Program (3DEP). These data are publicly available via the USGS National Map as point cloud LiDAR and/or digital elevation models (DEM). Using this data, we (1) tested the accuracy of LiDAR-based road-stream culvert identification, (2) applied this approach to selected culverts that have been ground-truthed for stream crossing characteristics, and (3) tested the approach on larger sections of similar geography to identify road-stream culverts which could pose a barrier to aquatic species movement (specifically upstream). In this presentation we will provide an overview of the developed methodology and the effects this could have on forest management.

Evaluation of Forest Road Reconstruction Project via BIM Approach with SLAM LiDAR Data

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Keywords: object classification, BIM, LiDAR, SLAM, forest road reconstruction

EXTENDED ABSTRACT

1. Introduction

The process of planning and designing forest roads is a complex process. This process requires the technical, economic, and environmental factors to be taken into account simultaneously. Forest roads carry different service functions (firebreak line etc.) apart from their main purpose. In addition, forest roads provide safe and continuous transportation for different vehicles and products with different size (Akgul et al., 2017). One of them is the transportation of wind turbine parts. However, the transportation of wind turbines and towers is very problematic. No matter how new technologies are used in these transports, the standards of the existing roads are generally not enough to transport the turbines and towers to the place where they will be installed. At this stage, three different solutions can be proposed. These solutions are; It is implemented by revising the existing roads according to the standard that the vehicle will pass, constructing new roads suitable for the transportation of wind turbine elements and passing the obstacles by lifting the blade with blade lifter technology. During the road widening process, which is required at these stages, the trees that coincide with the road platform have an environmental impact, provided that they are cut. In accordance with these solutions, during the planning and design phase of road reconstruction activity; it is important to use sensitive data to accurately determine road standards that affect vehicle maneuverability. In the planning and design phase, various data and CAD/GIS software or algorithms are widely used in the creation of the digital terrain model, which is used to determine the terrain structure of the road route for forest roads. However, the technique of obtaining spatial data or the technology used in the production of the digital terrain model directly affects the precision.

Recently, in line with the technological developments, LiDAR (Light Detection and Ranging) systems, which refer to the point cloud-based spatial data collection technology, have been used intensively in the field of forestry as well as in other fields of science fields where spatial data is needed. With the development of technology, different types of LiDAR systems are used. While the first produced LiDAR systems used the time-of-flight (ToF) distance measurement method, phase-based systems are becoming widespread today. In a ToF system, it measures the distance between two points by recording the signal emitted from a laser rangefinder placed at point A and the return signal after this signal is reflected from an object surface such as point B (Petrie and Toth, 2018). Phase-based systems uses the phase comparison method, which is an indirect ToF distance determination method, the laser device sends a continuous laser beam instead of a signal. In this case, the gap value is obtained by comparing the transmitted and received beam according to the type of sinusoidal wave pattern, and the phase difference between them is measured (Boehler and Marbs, 2003). As it is known, as technology develops, obsolete technology is almost always accessible with less cost. The situation is similar for laser-based measurement technologies. Phase-shift-based laser measurement technology is costly as it has subcomponents that require newer technology and therefore higher cost. Although both measurement technologies have their own advantages and disadvantages, systems that perform scanning with the ToF technique stand out as lower cost systems.

In this study, a hand-held LiDAR system that performs spatial data acquisition based on SLAM (Simultaneous Localization and Mapping) algorithm was used. SLAM-based LiDAR systems, which can be carried on the back or in the hand, provide ease of spatial data acquisition as they can be used under the forest canopy. These systems have become widespread in recent years due to the advantages they offer in terms of both cost and ease of use. SLAM-based LiDAR systems are integrated laser scanner and inertial Measurement Unit data on the basis of algorithm-based technology (Laguela et al., 2018). New approaches are required for mapping where the relevant measurement area is small and the field of view very limited. With these approaches, lightweight wearable or hand-held devices have begun to be used for mapping purposes. (Zeybek, 2019). The scanner determines all the details around it with the SLAM algorithm. The SLAM algorithm identifies the objects around the scanner as static and according to this assumption, the points are connected and the whole point cloud is acquired (Sammartano and Spanò, 2018).

On the other hand, Building Information Modeling (BIM) approach is used frequently in different engineering fields. The BIM approach emphasizes the integration of processes, particularly the creation and distribution of digital information by all stakeholders throughout the lifecycle of the infrastructure asset. BIM is one of the most promising recent developments in the architecture, engineering, and construction (AEC) industry. With BIM technology, an accurate virtual model of a building is digitally constructed. This model, known as a building information model, can be used for planning, design, construction, and operation of the facility (Azhar, 2011) The architecture, engineering, and construction (AEC) industry has long sought techniques to decrease project cost, increase productivity and quality, and reduce project delivery time. Building information modeling (BIM) offers the potential to achieve these objectives (Sompolgrunk et al., 2021). BIM is widely seen as a catalyst for innovation and productivity in the construction industry. According to the recent comparative reviews, BIM uses in the building industry have been focusing on the development and detailed analysis of 3D models, and gradually using 4D schedule application, and 5D cost planning. Whereas the BIM uses in infrastructure projects are only at an average level of implementation in the sector (Shou et al., 2015).

Integration of BIM and laser scanning was successfully tested and implemented in the various studies for deviation detection. In this context, there are recent studies on obtaining road lines, traffic signs, guardrails and various road accessories from point cloud data and converting them to the global BIM format, IFC (Industrial Foundation Class) (Zhu, 2020). While the integration between BIM and laser scanning is still developing as highlighted in recent studies, it needs to be further developments. (Wang et al., 2015; Chong, 2016).

In this scenario-based study, the evaluation of road reconstruction activities for the transportation of wind tribune parts was evaluated using the BIM approach and SLAM-based LiDAR data. The aim of this study is to creation of the BIM model of the project with the help of objects created by using the point cloud data obtained in a practical way, taking into account the sensitive forestry criteria. In this way, the road was built in a virtual environment before the field works and the amount of excavation fill and the number of trees to be cut were determined.

2. Material and Method

In this study, the SLAM-based LiDAR dataset which was acquired in the Eagle Rock Reservation region in New Jersey, USA was used. The SLAM-based LiDAR dataset was acquired with PX80 handheld LiDAR system. The PX80 handheld LiDAR system uses a ToF -based laser scanner technology. In line with the constraints imposed by the SLAM algorithm and the PX80 LiDAR system, each data acquisition session was carried out with maximum 20-minute cycles. At this stage, attention was paid to ensure that the starting point and the end point of the data were at the same location in each session in order for the SLAM algorithm to derive correct data and make data matching precisely. Data acquisitions in the selected study area were completed in 7 sessions. After the data acquisition was completed, the raw data were registered with the Leica Cyclone 9.0 software. Necessary noise filtering processes were applied and data was archived in .las format. After this stage, point cloud data was imported into Autodesk ReCap software and converted to .rcp data for use in Autodesk Infraworks software (Figure 1.a). At this stage, LiDAR point cloud density is approximately 14,500 points/m². In Infraworks environment with using the "generate point cloud terrain" command, the point cloud data were classified into terrain models, linear features (road lanes) and vertical features (tree models). In the classification phase, it was aimed to create a sensitive digital terrain model by keeping the level of detail in the software high. The spatial size of the digital terrain model has 31,700 m² 3D surface area (Figure 1.b).

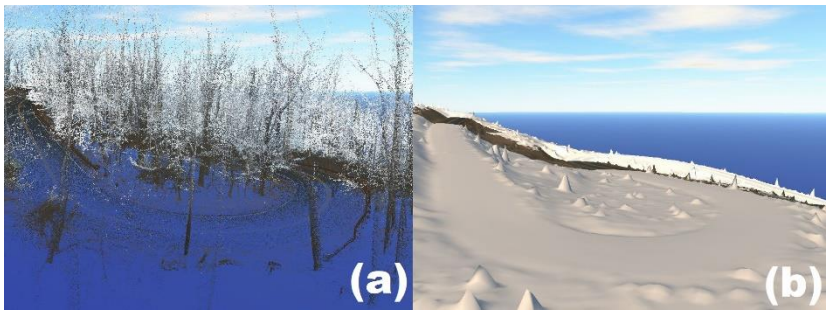

Figure 1. a) Registered raw point cloud data, b) Registered clean road surface point cloud data

As mentioned in the aim of the study, the driving analysis process was carried out in order to accurately determine the road standards that affect the maneuverability of the vehicles in the reconstruction activity. A specially designed 45.34 m long vehicle, which is in the Vehicle Tracking software's library, was used to transport the wind tower parts. By using SLAM-based LiDAR data and BIM approach, the suitability of the geometry of the existing forest road in terms of turns for the relevant vehicle was evaluated. In regions where the geometry was evaluated as insufficient, a new design will be carried out on the point cloud-based digital terrain model data with Infraworks, considering the criteria suitable for the forest road type (Alternative scenario 1). In addition, a BIM-based alternative road route was created (Alternative scenario 2) and compared to both two routes in terms of the amount of excavation-fill, the amount of road material and the number of trees that need to be cut (Figure 2).

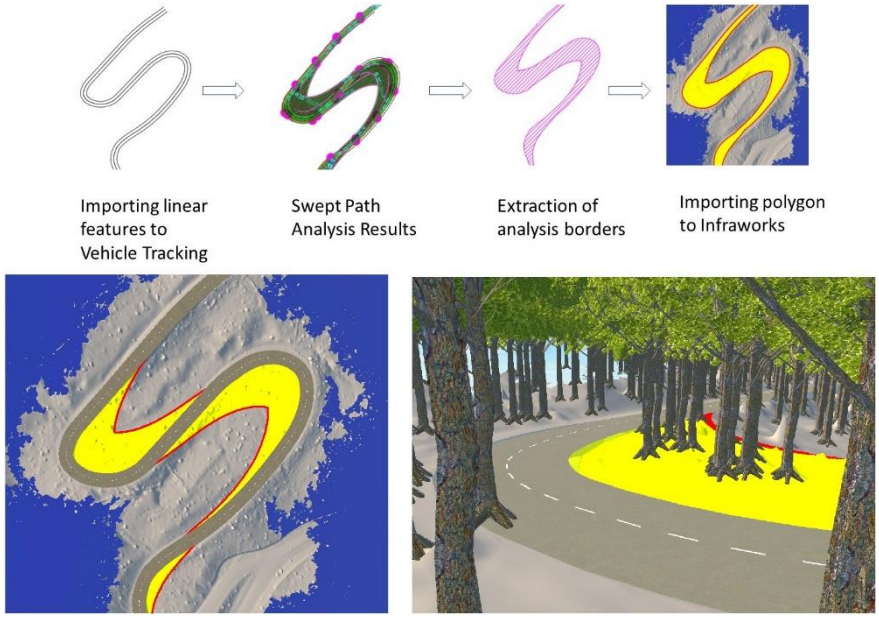

Figure 2. Locations of trees that need to be removed from the field as a result of road widening with vehicle tracking analysis

3. Results

In the study, the results in terms of different criteria regarding the two road routes obtained with the BIM approach using the point cloud-based digital terrain model are given in Table 1.

Table 1. Scenario based results for road reconstruction parameters

Parameter	Scenario-1	Scenario-2
Length (m)	410.12	195.057
Grade range (%)	5.8-8.88	12.58-13.90
K value range	13.011-14.640	19.105
Cut volume (m^3)	1791.577	1185.785
Fill volume (m^3)	1019.614	2198.036
Net volume (m^3)	771.963	1012.251
Asphalt material volume (m^3)	1157.647	273.08
The number of trees which need to be removed	920	290

When the findings obtained as a result of the alternative scenarios are evaluated in terms of earthwork, it has been determined that scenario no. 2 (1012.251 m^3) requires 1.3 times more earthwork than scenario no. 1 (771.963 m^3). However, when the required road material volume and the number of trees to be cut are examined, it has been determined that alternative number 1 is 4.2 times as much as the other alternative in terms of road material and 3.1 times in terms of the number of trees to be cut.

When the obtained findings were evaluated, the following inferences were made as a result of the study.

- It has been determined that high-precision spatial data acquisition can be made using SLAM-based LiDAR systems, especially under the high degree of forest canopy cover. It has been seen that point cloud data has an important role in BIM projects, giving data that will affect the design and cost in the BIM phenomenon for infrastructure, rather than a tool used only for overlap in the as-built model.
- Thanks to the use of BIM in the reconstruction of the existing road and in the design of the bypass road, it has been determined that the data exchange is at high level. BIM can serve a dynamic projecting process in the phase of alternative derivation and comparison of the derived alternatives.

- When the findings obtained from 2 different scenarios were examined, it has been determined that the difference between the number of trees in the excavation areas has consequences that will affect the decision maker in terms of impact on nature. In this respect, the benefit of quickly converting point cloud data into a BIM model has been clearly demonstrated.
- It was observed that the road lines contribute to the correct representation of the model. However, where the road paints have been partially erased, the automatic creation method may have problems.
- Classification results were evaluated in a selected region within the study area. It has been determined that the tree models obtained as a result of the classification have an overall accuracy rate of 90%. It was determined that 86% of the objects classified as signboards and street lamps were trees. It was determined that 36% of the objects classified as undefined were trees or bushes.
- It was determined that some tree groups are classified as single trees due to the dense forest structure. Such objects were modeled by dividing with the "Divide" command in the software. It is thought that more accurate classification results can be achieved in regions with less sparse forest structure.

4. Discussion and Conclusion

On the current road project, linear feature data was created from the road lines and swept path analysis made in the "Vehicle Tracking" software for the special trucks that serve for wind tribune parts transportation. Thus, it was examined whether the existing forest road has sufficient geometry for turns. In regions where the geometry was evaluated as insufficient, a new design will be carried out on the point cloud-based digital terrain model data with Infraworks, considering the criteria suitable for the forest road type. Also, a BIM-based alternative road route was created and compared to both routes in terms of different criteria. As a result, the approximate excavation cost, road material quantities, and the number of trees directly and/or indirectly affected by the construction site were calculated automatically and compared with the BIM approach for each alternative. According to the results, BIM is an effective and practical evaluation approach with high precision data such as SLAM-based LiDAR data for reconstruction and design projects in terms of technical, economic, and environmental perspectives.

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Business, Workforce and Education

The Virtual Wood Supply Arena - Next Generation On-line Training Tool

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The Virtual Wood Supply Arena – Next Generation On-line Training Tool for Forest Logistics

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Keywords: wood supply chain, coordinating operations, weather, trafficability

EXTENDED ABSTRACT

The Virtual Wood Supply Arena (VWSA) is an on-line training tool for managing roundwood purchase, production and transport in CTL supply systems. The training environment simulates 12-week periods with monthly mill delivery goals while handling weekly weather and site trafficability for harvesting and hauling.

Earlier logistics training tools developed by the same group include the Wood Supply Game (D'Amours et al. 2017) and Transport Game (Abasian et al. 2019). The VWSA is designed to come as close to reality as possible in an on-line environment. It includes three roles per company (purchase-, production- and transport managers) managing 10 harvesting teams and 10 trucks over 4 supply regions and 2 climate zones (highlands, lowlands). Deliveries of 5 assortments are managed to 5 mills (2 pulp mills and 3 saw mills). Team KPIs include monthly delivery precision per mill assortment, capacity utilization, relocation- and hauling distances. The user interfaces are presented below.

Each 12-week training scenario may be selected from 4 annual weather cycles (52 weeks). The annual cycles include 1) 10-year average, 2) cold winter, 3) dry summer and 4) warm-wet summer. The training includes both development of monthly goals as well as weekly decisions for each of the three functions.

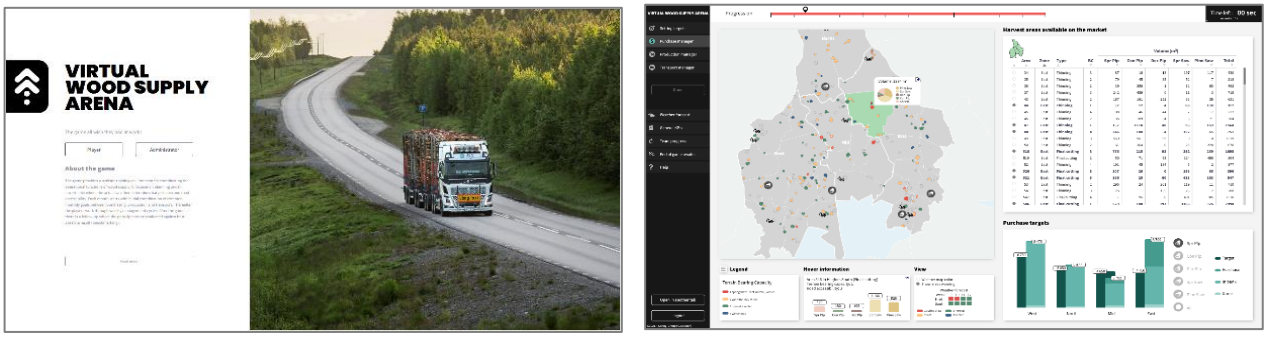

Figure 1. User log-in (left) and purchase manager interface (right)

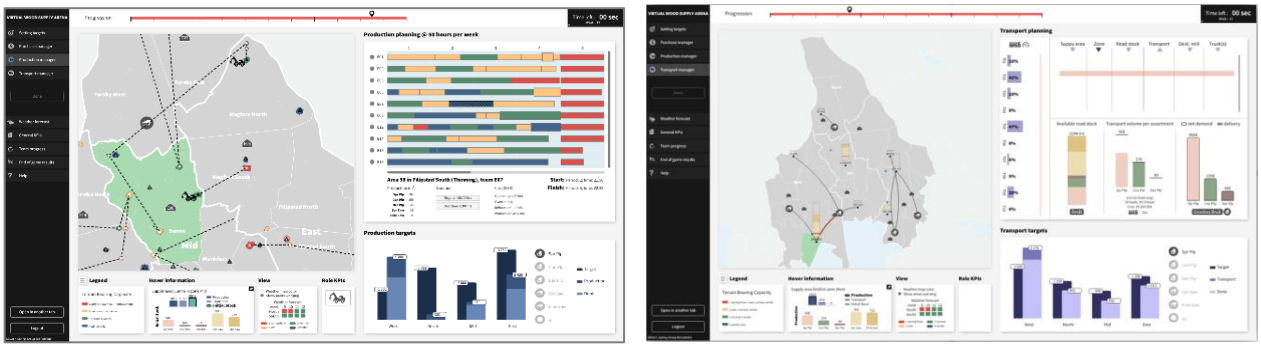

Figure 2. Production manager interface (left) and transport manager interface (right).

In the context of university training, the VWSA provides a high level of realism and accelerated experience-based learning. Participants respond to both typical and atypical weekly variation in the operating environment and learn effective geographical allocation of resources, as well as the adaptive management of road-side stocks to ensure secure deliveries, regardless of trafficability challenges.

The exercise is suitable for participants who have a basic understanding of production and transport management in CTL supply systems. A single training run requires 4-6 hours and is followed by a post-session analysis of team performance. The first prototypes were implemented in forestry training at SLU and Université Laval in 2022. A benchmarking function is under development so that competing teams can compare their performance to an optimal solution. The development of the VWSA was financed the Ljungbergs Foundation of Sweden. The development team includes SLU, FORAC/Université Laval, Skogforsk and Creative Optimization Sweden.

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Incorporating Harvesting Machine Simulators in Training Forest Engineers, Foresters, and Allied Scientists

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ABSTRACT

Forestry harvesting is a system of profound knowledge of the natural environment, machines, loggers, foresters, landowners, public, regulations, and log markets, whose education is essential in understanding how these elements interact to achieve harvesting objectives. Courses for teaching forestry harvesting should be considered at systems level to enable learners understand interactions at systems level and be able to perform future forestry harvesting work. There is need to consider distance forestry harvesting education with experiential activity using simulated environment for example, due to the decline in the number of forest engineering institutions and reduced student enrollment in this program. This study focuses on providing quality forestry mechanized forestry harvesting education using simulated environment. It presents a method for system description for classifying common methods of forestry harvesting and assessing courses for teaching forestry harvesting at systems level that lays the foundation for performing a systems activity e.g., unit layout.

Simulations provide feedback, and in this study, subjects are performing working on a unit layout problem by watching expert operator working with simulated machines. A method for determining and contrasting the performance limits for the simulated machines in the John Deere harvester simulator system with expert opinion that are useful in providing instructions to solving trail layout problem that are not in conflict with education intervention material is provided. Finally, the study developed an educational intervention for subjects enrolled in forest harvesting distance education to evaluate the impact of educational value of the interaction with the simulated environment. In this context, the educational value is defined as would a particular level of interaction with the simulated environment provide the subject with insight that improve the understanding of the harvesting system, as

measured by the changes in the metrics used to assess the quality of the logging plan, for example non-treated area. Subjects completed three online modules in sequence and prepared logging plans for each level of involvement and provided explanation for non-treated patches in the plans. The descriptions of interaction levels are as follows. Level 1, guidelines for unit layout and logging plan instructions, Level 2, videos of guided tour of the simulated environment, and Level 3, videos of simulated logging. Study covariates were obtained from subject demographics. Continuous responses were calculated from the submitted logging plans and analyzed using multiple linear regression looking for correlation with response variables. Results of this study are an important contribution to education in forest harvesting.

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Effectiveness of Simulator Training Compared to Machine Training for Equipment Operators in the Logging Industry

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ABSTRACT

Since the mechanization of forestry operations in the 1960s, forestry equipment operators have learned the skills required for their job mainly through hands-on training using a real machine in real time in the forest. While access to logging equipment is essential to properly train equipment operators, new developments in simulator technology enable inexperienced operators to learn in a virtual setting and practice operating forestry equipment. Forestry equipment simulators offer a cost-effective and safe method for students to learn about the basics of operating forestry machines. They promise to alleviate some of the problems associated with traditional machine training by reducing wear and tear on real equipment and lowering opportunity costs associated with removing equipment from production for training purposes.

Few studies have quantified the extent to which skills transfer between simulated and real heavy forestry equipment. Only one study has directly compared the effectiveness of simulator-based training to machine training, but this study focused on construction-specific equipment. A cost analysis of simulator vs. machine training for new forestry operators was not found in the literature. In this study, a total of 16 participants were trained on simulated or real machinery for 25 hours each. We compared the performance of participants who were trained on simulated, entry-level forestry equipment to those who were trained on machines by testing participants on real equipment in the forest. We also conducted a cost analysis of training new forestry operators on machines vs. on simulators. Preliminary results show no significant differences in performance over time between participants who were trained on simulators and those trained on machines; however, machine-trained students did reach higher performance levels than simulator-trained students after training for the same amount of time. Preliminary results from our cost analysis revealed that simulator-based training for forestry equipment operators is almost eight times more cost-effective than machine training for inexperienced operators. This estimate does not account for differences in performance outcomes between the two training types.

Incorporating the Measurement of Sustainability in Undergraduate Natural Resources Curriculum

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ABSTRACT

Students in forestry and other natural resource fields are taught the importance of sustainable practices throughout their undergraduate coursework. Increasing emphasis has been placed on providing students with the skills and knowledge they will need to meet the challenges of the present and the future. Often lacking in their curriculum, however, are tools that students can use to measure progress or the impacts of their efforts toward sustainability. Common methods to measure sustainability, including risk assessment and life cycle assessment, are frequently taught in engineering curriculum. As such, students are required to have background knowledge in advanced mathematics and experience with computer languages and coding, prerequisites that traditional natural resources students do not always possess. At The Ohio State University, an undergraduate level course was developed to teach students enrolled in varied natural resources majors including forestry, wildlife, and natural resource management introductory principles of sustainability metrics. Students are introduced to concepts that underlie life cycle thinking and risk assessment and are scaffolded through assignments that build to student development of simplified assessment products. In this presentation, I report initial outcomes from 15 in-person and online semester offerings and describe novel aspects of the course.

Young, Beginning, and Minority Logging Business Owners: Characteristics, Barriers, and Proposed Solutions

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ABSTRACT

The overwhelming majority of logging businesses in the US South are owned by white males from the baby boomer generation. One-third of logging business owners in Georgia are 60 years old or older, and in 2017 it was estimated that nearly one quarter of Georgia logging businesses would cease to exist by 2022. Therefore, it is important to consider businesses owned by young, beginning, or minority owners who may succeed them. Family members of logging business owners have historically been the main source of new owners, but this source is being threatened as it becomes less likely for owners to pass their business on to a relative. Twelve young, beginning, and/or minority logging business owners in Georgia and Florida were interviewed to determine their business characteristics and to provide them an opportunity to share their perceived industry barriers and proposed solutions to overcome these barriers. Approximately 25 business owners were identified and 12 agreed to participate. Two participants were young (35 years or younger), three were beginning (owned their business for 10 years or less), five were young and beginning, and two were minorities (non-white or non-male). The average business size was 15 employees, with the smallest being three employees and the largest being 62. The businesses regularly supplied timber to an average of seven mills. Fifty-eight percent of the participants had acquired their business from a family member, while 42% had no family history in the logging industry at all. The median capital investment of these businesses was $1,500,000- $1,999,999, which is consistent with Georgia statewide averages. Owners identified excessive debt from startup costs, difficulty hiring and retaining truck drivers, rising insurance premiums, and finding good employees as barriers to success. Beginning and young logging business owners had particular difficulties finding quality employees because they do not yet have reputations to compete with established logging businesses. Proposed solutions to some of these barriers included: tax breaks from the government, grants from the government to help with financing, legislation to lower insurance costs for logging trucks, and increased mill rates. It was also proposed that state departments of transportation offer trainings to help logging businesses navigate laws and regulations related to trucking. Addressing the concerns of young and beginning logging business owners may help increase business formation and retention in the future.

Assessing Changes in Quebec's Forest Contractor Population: What Insights Can We Gain from a Follow-up Survey?

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ABSTRACT

In 2007, a large sample of Quebec's forest contractor population was surveyed to learn more about the business characteristics and their owners' motivations. A total of 336 contractors provided answers to a survey comprising 57 questions. Among the main results were the participants' strong appreciation for their work environments, co-workers, and opportunities to apply their skills. Nevertheless, 61% of the participants responded that they would not encourage their children to become forest contractors. It was expected that slightly more than 50% of the contractors would close, transfer or sell their operations within five years. A tendency towards larger businesses was also expected based on the responses provided in 2007. In 2021, funding was obtained to conduct a follow-up survey to assess contractor population changes. The new survey was conducted in the summer and fall of 2021. The survey had 63 questions with the objective of allowing time comparisons. Two hundred and six (206) contractors participated in this second survey. The average age of the respondents is slightly younger than what was recorded in 2007 (46 vs. 51). Contrary to what was predicted, average business size has not significantly increased. However, a larger proportion of contractors would see it as positive to double the size of their business (42% vs. 32%). They also express a greater interest for training that relates to new technologies and business. Questions related to Indigenous people were a novelty of the 2021 survey. We also found that the number of Indigenous contractors is still low and that the vast majority of respondents do not hire Indigenous workers (95%). Overall, the 2021 survey provide useful insights to find the way forward to better support forest contractors, notably in terms of training and workforce preparation activities.

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Overview of Logging Businesses in Georgia and Florida and Their Challenges in 2022

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ABSTRACT

Logging businesses in Georgia and Florida combine to harvest more than 50 million tonnes of timber annually, more than 10% of US harvest volume. The University of Georgia has conducted a survey of Georgia logging business owners every five years since 1987. In 2022 Florida was added to this survey. In the first quarter of 2022, questionnaires were mailed to 503 and 132 logging businesses in Georgia and Florida, respectively. Adjusted response rates were 22% in Georgia and 25% in Florida. The average logging business was larger in Florida than in Georgia. The average Georgia logging business produced 1,737 tonnes per week and employed 12 people, whereas Florida logging businesses produced 2,356 tonnes per week with 14 employees. Median owner age was approximately 55 years, and nearly 40% owners were over 60 years old. More than 30% of loggers in both states predicted they would no longer be in business in 5 years. Of those companies expecting to leave the industry, 53% of Florida logging business owners expected to transfer the business to a family member compared to just 25% of Georgia business owners. Most logging business owners from both states had attended college, with 33% of Georgia loggers and 15% of Florida loggers holding a college degree. More than 80% of logging business owners reported that the Covid-19 pandemic had repercussions on their business in the form of reduced production, employees contacting Covid-19, or difficulty finding employees during the pandemic. Most owners of logging businesses in Georgia and Florida cited high trucking, fuel prices, and insurance as significant challenges. They also mentioned long-term challenges, such as a shortage of qualified employees, lack of truck drivers, and low logging rates.

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Composition, Challenges and Needs of South Carolina and North Carolina Logging Businesses

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ABSTRACT

Logging businesses across the nation face a series of challenges from weather and road restrictions, to increased fuel prices. In the past, logging businesses have changed their size, merged into larger companies, or retired altogether. Any changes to the structure and number of logging businesses within a state has an impact on the forest products within that industry. To document and track these changes, logging businesses surveys have been conducted in South Carolina every 5 years since 2012. In 2022, we conducted the latest iteration of the logging business surveys, following the survey template used by the Georgia logging business survey. For this iteration of the survey, we sent mail surveys to approximately 350 and 530 logging businesses in South Carolina and North Carolina, respectively. Response rates for the surveys were approximately 30% and 20% for South Carolina and North Carolina. Results indicate an increase of young and new logging businesses responding to the surveys, but also show a shift in logging business sizes to medium-sized businesses, with a reduction in low-production logging businesses. Additional results presented will address the composition and age of logging business equipment, owner demographics and education, and changes in insurance rates. We will further present South Carolina trends across the last three iterations of the survey, and present results from the first North Carolina logging business survey.

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Decision-making Processes for Strategic Technology Investments in Swedish Large-scale Forestry

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ABSTRACT

Technological development gives forest companies opportunities to maintain competitiveness in the highly cost-sensitive market for forest products. However, no previous studies have examined the technological development decisions made by forest companies or the support tools used when making them. We therefore aimed to describe and analyze 1) the processes used when making such decisions, 2) the associated decision situations, and 3) the use of and need for decision support tools in these processes. Semi-structured interviews were conducted with respondents from six forest companies and a forest owners' association. Two theoretical frameworks were used to analyze the interviews, one for unstructured decision processes and one for decision situations. The respondents' descriptions of their decision processes were consistent with those observed in other industries, and it was shown that decision-making could potentially be improved by investing more resources into diagnosing the problem at hand. The main objective in decision-making was to maximize economic criteria while satisfying threshold requirements relating to criteria such as operator well-being, soil rutting, and wood value. When facing large uncertainties, interviewees preferred to gather data through operational trials and/or scientific studies. If confronted with large uncertainties that could not be reduced, they proceeded with development only if the potential gains exceeded the estimated uncertainties, and implemented innovations in a stepwise manner. These results indicate a need for greater use of existing decision-support tools such as problem-structuring methods to enable more precise diagnoses, simulations to better understand new innovations, and optimization to better evaluate their theoretical large-scale potential.

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How Were Swedish Logging Contractors Affected by the COVID-19 Pandemic?

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ABSTRACT

In Sweden, the volume of harvested wood was record high in 2021 and several of the largest forest industry companies have reported good profits in the past year. Consequently, forestry contractors, who carry out more than 50% of all forestry work including most of the logging both on company-owned forestland and on non-industrial private forest owners' forestland, should have experienced a high demand for their services. This while the COVID-19 pandemic, besides all the health aspects, has entailed various societal restrictions, problems with supply chains, and so on. Since contactor firms in general are small-size businesses, often with only a handful of employees, the hypothesis was that they might be sensitive to such events. Especially since contractors' profit margins have historically been low, and many logging contractors therefore had small financial margins already before the COVID-19 pandemic. Therefore, the objective of this study was to identify (1) if the contractors were affected by an increase in staff absence during the COVID-19 pandemic, (2) if special measures were taken to ensure a safe working environment, and (3) how their financial situation has developed. In May 2022, a survey was sent out to a random sample of 1,175 limited liability companies registered to perform logging. By mid-June, a total of 256 completed questionnaires had been received. Some 64% of the responding contractors stated that logging services accounted for more than 50% of the company's turnover, and these were selected for further analysis. Results show that 34% of the respondents had experienced a higher staff absence than normal, while 60% had not noticed any difference, and a few stated that it had been lower than before. A majority (73%) of the contractors had implemented some kind of special guidelines or work routines during the pandemic in order to decrease the risk of infection at the workplace. Some 55% of the logging contractors thought that their financial situation was worse today compared to the situation before the pandemic, 37% thought that it was the same, and a minority stated that it has improved. Increasing prices on fuel, machine maintenance and supplies were some main factors behind the weakening situation. A conclusion of this study is that high inflation might impose a bigger challenge to contractors than the pandemic itself. In line with previous studies, the findings of this study indicate that contractors have limited power to negotiate prices with their main customers.

North and South Carolina Logging Business Opinions on Challenges and Needs in the Logging Industry

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ABSTRACT

Logging business surveys have been taking place for several decades in various states across the USA. These surveys have played a vital role in giving a general idea about the logging industry and its state. Within this industry, multiple groups of logging business owners exist (e.g., minority, young, and beginning owners), each with unique challenges and needs.

We are conducting in-person and telephone interviews with MBY (Minority, Beginning, and Young) and older logging business owners in North and South Carolina to better understand where they stand in this industry today and the challenges they face. We are aware that established businesses will phase out over time and that MBY logging business owners are important for the future of the logging industry. Our survey collected information on the general business characteristics, owner's background, perception of challenges and future outcomes, access to capital, and future plans of MBY logging businesses owners. With a focus on more established logging businesses, we ask similar questions but also included questions about their retirement/succession planning, profitability, and challenges. All data from the surveys will be pooled and aggregated to form industry-wide summaries and used to detect the emerging trends in the industry. In this presentation, we will be providing an overview of the MBY and older logging business owners and present preliminary results of the 2022 North and South Carolina MBY and succession plan surveys.

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ABSTRACT

Many forest operations researchers spend considerable time in the classroom, yet very few forums for improving and sharing teaching strategies across universities and continents are available. Dodson and Blinn (2021, 2022) demonstrated the utility of creating a community of learning for forest operations instructors in the U.S. This panel presentation will continue and expand this work by presenting examples of best practices from across North America and Europe and provide a moderated forum for discussion of pedagogy in the forest operations classroom.

Panel presentations will include the following:

Charlie Blinn, University of Minnesota: Will share a cross-institution peer learning assignment focused on forestry best management practices (BMPs). Students prepared presentations which provided some context about their state and then reviewed their BMPs; student interaction was encouraged.

Hunter Harrill, Cal Poly Humboldt: Will share his experiences creating video field trips of forest operations for introductory level students during COVID and how he worked with a local forest manager to create student research projects evaluating new tethered logging operations for advanced students.

Luc LeBel, Universite Laval: Coop internships are compulsory in Forest Operations at Laval with students spending 36% of their undergraduate training in forest companies. By graduation, most students are competent first-level supervisors. Serious games are used to prepare students for mid-management duties.

Ola Lindroos, Swedish University of Agricultural Sciences: Will share his experiences on the restructuring of university-level forestry programs in Sweden in order to adapt to a changing world. The challenges are to attract both traditional and new students to a field that includes traditional jobs for foresters and biologists as well as new non-field based jobs. Flexibility for students in choices of courses are contrasted with academic demands and perceptions of rigor.

Dominik Röser, University of British Columbia: Will share experiences with maintaining a forest operations program in a changing world where many different values have to be considered. This is a great opportunity to get the new generation of students excited about forestry whether it is through virtual teaching, experiential learning, or the adoption of new technologies in teaching.

Karl Stampfer, University of Natural Resources and Life Sciences, Vienna will share his experiences with how COVID has changed teaching and learning methods. This is considered in the context of ongoing restructuring of programs with a primary goal of reducing student time to earning their degree.

Forest Operations Planning Issues and Opportunities

Motor-manual Work in European Forests - An Underestimated Challenge in Forest Operations Engineering

Benjamin Engler, Hans-Ulrich Dietz, Thomas Purfürst

Adaptation of Timber Harvesting Methods to Difficult Forest Structures Created by Conservation Requirements

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Cost-efficient Pre-commercial Thinning: The Effect of Felling Season of Early Cleaning

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An Investigation into Infrastructure Density in New Zealand's Small-scale Forests

Jacob Allum, Campbell Harvey, Rien Visser

Evaluating the Suitability of Using a 3D Visualization Tool to Improve Decision Making in Forest Management and Planning in British Columbia

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Creating AI-based Cable Road Layouts by Leveraging LIDAR Data and Multi-objective Optimization

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Comparing Different Equipment Replacement Policies for Logging Machines in Brazil

Carlos Diniz, Romano Timofeiczyk Junior, John Sessions, Renato Robert, João Garzel, Eduardo Lopes, Mathew Smidt

Productivity and Cost of Tornado Salvage Chipping in South Carolina, USA

Joe Conrad

New Ground-Based Skidding Options for the Inland Northwest

Robert F. Keefe, Ebru Bilici

Motor-manual Work in European Forests - An Underestimated Challenge in Forest Operations Engineering

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ABSTRACT

The success of fully mechanized harvesting, such as the Nordic Cut-to-length system, is prevalent and widely visible in European forests and in research of forest engineering. Beside this, motor-manual work is still dominating in European countries, in particular, mountainous areas, Central and South European countries. To better understand the relevance of motor-manual work, a meta-analysis based on literature, expert interviews and a survey was conducted. It identified unexpected high ratio of motor-manual work in Slovenia (80%); Switzerland (80%); Hungary (80%), Austria (79%); Croatia (70%); Czech Republic (65%); Poland (60%); France (48-52%); Germany (40%) and Italy (40%). For most of the motor-manual work accurate and precise data on daily performance are missing, challenging planning and optimization of wood supply chains. Within the presentation needs and consequences for future research will be draw.

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Adaptation of Timber Harvesting Methods to Difficult Forest Structures Created by Conservation Requirements

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ABSTRACT

Forestry in Germany is increasingly considering the demands of biodiversity protection by leaving habitat trees and lying deadwood in the forest. Clear-cutting is avoided by allowing smooth transitions between forest generations. This creates vertically stepped forest structures that do not allow for wide open views. Skid trails are often created at such distances that some of the trees are out of the crane reach of harvesters. These forest structures make management more difficult. A research project investigated how timber harvesting methods can be adapted to these challenges. On the one hand, experts were asked how they adapt their timber harvesting methods to these challenges. On the other hand, timber harvesting measures were investigated in case studies. Prior to timber harvesting, forest structures were recorded. During the operation, the time required by workers and machines was measured. Relationships between time requirements and the characteristics of forest structures were analyzed. Combined timber harvests revealed that trees are often felled by forest workers using hand-held chainsaws not only because they are out of crane reach of the harvester, but also because visibility for the machine operator is obstructed by vegetation. When forest workers and the harvester were working at the same time, the machine often had to wait longer before a tree was felled and could be processed. When the undergrowth was dense, forest workers avoided clearing a path for the escape route and move to a safe distance. They may have felt time pressure from the waiting machine. In some case studies, where only motor-manual work was performed, the time required was significantly greater the more understory there was around the trees to be felled. In two case studies, time requirements were significantly lower when habitat trees were located near the trees to be removed. This was due to accelerated delimbing and bucking of the logs. It is possible that loggers avoid spending extended periods of time under habitat trees for fear of falling branches. They may feel stress, which can increase accident risks and endanger health. We recommend that skid trails are spaced so that all trees can be felled by the harvester, if possible. Assistance systems should be developed for felling so that trees can be felled by the harvester despite visibility obstructions. Where felling by harvesters is not possible, habitat trees should only be arranged in groups in the stand so that hazards from falling branches are kept low.

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Cost-efficient Pre-commercial Thinning: The Effect of Felling Season of Early Cleaning

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ABSTRACT

In Finnish forestry, the first juvenile stand management operation in a planted Norway spruce (Picea abies (L.) Karst.) stand is early cleaning (EC, early pre-commercial thinning), when fast growing broadleaved trees are cut, and crop trees can continue to grow freely. Early cleaning takes place in fertile sites about 4 to 6 years after planting. The next intervention, about five years later, is pre-commercial thinning (PCT), in which the stand's stem number is adjusted to a desired level of about 1800 stems per hectare in spruce-dominated stands.

The worktime spent in juvenile stand management depends mainly on the number and size of the trees to be cut. The emergence, growth, and time the trees have grown are therefore key worktime consumption contributors to juvenile stand management. These are influenced by e.g. site fertility, soil scarification, and the timing of the operation. However, working conditions (e.g. terrain, visibility) and methods can also affect worktime consumption, but we have relatively little knowledge of these effects. In the spring or autumn, when broadleaved trees are leafless, conifer crop trees, as well as terrain obstacles, can be seen easily, and according to a former cross-sectional data, cutting work is also smoother then.

The timing of cutting within the year has also effects on sprouting capacity. Stumps which have been cut during the growing season seem to sprout less than stumps cut in a dormant season. This perception of low sprouting in summer has driven ECs to be done often in summer. The effect of the season on the work time consumption of the operation itself has received less attention. Our study aims to identify how the application season and the method of EC affects the time consumption in EC and in the subsequent PCT. The worktime in EC was recorded in the spring, summer, and autumn in 22 sites, which were either totally cleaned or point cleaned. Later, these sites were measured at the time of the second PCT. Time consumption was estimated in PCT, based on the removal of the sites. EC in spring saved 27-30% in working time compared to summer. The differences were suppressed when also accounting PCT. At the entire management program level, EC applied in the spring or autumn instead of the summer saved 11% or 5% respectively of the total discounted costs (3% interest rate) of juvenile stand management.

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An Investigation into Infrastructure Density in New Zealand's Small-scale Forests

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ABSTRACT

Infrastructure density in plantation forests influences harvesting efficiency, unitized whole-of-life infrastructure cost and environmental risk. Small-scale, first rotation plantation forests currently make up a large proportion of New Zealand's national harvesting output. These forests require new roads and landings to support harvesting. Using publicly accessible aerial imagery, 96 small-scale forests across nine wood supply regions were assessed for internal road infrastructure length, number of landings, size of landings and key forest attributes. Road density averaged 25 m/ha with landings typically occupying 3000 m2 and servicing 13 ha of plantation clear-fell each. A notable result was that 15 of the 96 small-scale forests (16%) had no internal infrastructure, with trees logged to the forest boundary. Multiple Linear Regression showed that road density is positively influenced by forest length/width ratio and average terrain slope, along with a negative correlation with boundary complexity. Landing size had a negative relationship with average terrain slope (%) and forest length/width ratio, along with a positive correlation with forest area (ha). At a high level, these numbers provide benchmarks for infrastructure coverage and costing exercises in New Zealand's small-scale plantation estate.

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Evaluating the Suitability of Using a 3D Visualization Tool to Improve Decision Making in Forest Management and Planning in British Columbia

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ABSTRACT

In the province of British Columbia 95% of the forest is on crown land. Sustainable forestry must meet social expectations, respect the environment integrity and be economically viable. Many organizations be it governmental, environmental, private, or public, have raised the problem that public review and consultation processes in B.C. are not being effective. It is recognized within the province that foresters are lacking relevant tools to share data with other stakeholders. Stakeholders also lack resources and information to provide useful inputs on forestry plans. This research project will help improve forest management and planning by attempting to increase social acceptance of forest management and operations in the forests of British Columbia, by providing a 3D visualization tool, and resources to all stakeholders.

This research project is leaning towards social sciences and used quantitative data to gather rich and detail comments about users and participants' experiences. Individual interviews are performed, recorded, transcribed, and then analyzed and summarized through the software NVivo. The first step is to define how public review and consultation processes are achieved in the current system in British Columbia. Based on our knowledge and the literature, industries must provide forestry plans to public for a reasonable amount of time, most often for 60 days, to gather comments before submitting it for approval to the minister. The tool used for the current processes are most likely technical tools like 2D maps and written reports to support the maps, which stakeholders don't relate to. The second part of this research will evaluate the suitability of using a 3D visualization tool for forestry purposes. The tool will be designed based on answers given in the interviews of the first part. Case studies will be developed with industry partners. Public review and consultation processes will be conducted with the 3D visualization tool, covering the area consulted.

This research project will highlight how public review and consultation processes are achieved in B.C. in the current system. Critical parts and comments of the processes will be identified through interviews with key informants in the forest sector, as well as other stakeholders. The case studies will help define if 3D visualization tools have a place in forestry for consultation purposes. Since qualitative data is more often suggestive and never really conclusive, the results of this research will be composed of stories, experiences, ideas and comments about the use of 3D visualization tool for forestry consultations purposes.

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Creating AI-based cable road layouts by leveraging LIDAR data and multi-objective optimization

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Keywords: multi-objective optimization, cable road layout, personal laser scanning

EXTENDED ABSTRACT

1. Introduction

Cable yarding continues to be an efficient and effective harvesting system for the extraction of timber on steep terrain. Modern European silvicultural strategies, together with environmental pressure, result in smaller harvest areas, lower extraction volumes and a shift from clear-cut to single tree extraction. Yarder installation time has, especially as a proportion to the extraction time, increased significantly, resulting in higher total extraction costs. Digital twins of the forest offer the possibility of optimizing the cable road layout in a way that minimizes installation and operation costs and maximizes the harvesting volume.

Traditional routing methods were first based on manual, then on automated planning using GIS data. Due to the low resolution of the GIS data and subsequent noisy representation of the forest, those approaches are prone to computing mathematically optimal cable road layouts which rely on inexistent support trees and anchors. This study presents an AI supported method for optimizing cable road layouts which utilizes high-resolution terrain and tree maps generated by personal laser scanning (PLS). These maps enable a heuristic optimization process which computes highly realistic cable roads, automatically selecting the most cost-efficient combination of intermediate supports and anchor points, minimizing the environmental impact and maximizing working safety at the same time. The proposed method uses a step-based heuristic, selecting viable individual cable road trajectories and then computing an optimized overall layout. We propose as next step a tool suite which lets users interactively designate, plan and optimize the cable road layouts while encouraging user trust by explaining the algorithms decisions with a human-in-the-loop approach.

2. Related Work

The location-allocation problem is a problem faced in forestry in which the overall goal is to minimize total distribution costs. The problem class was popularized in the 1960s by [1] with the subject of generating an optimal layout for facilities and demand points, and has been researched extensively since then. Various problem formulations exist, including the p-median, simple plant location, and location allocation models [5].
One noteworthy figure in the area of cable-road layouts is Leo Bont. With their 2012 study, they developed an optimisation approach for designing an optimal intermediate support layout for a given ground profile. By using nonlinear cable mechanical assumptions, they were able to speed up computation 30-50x and stipulate lower heights for intermediate supports and a larger span length [2]. In 2018, Bont et al. presents a set-covering model (SCM) and a bounded set-covering model (BSCM)for solving the problem of cable road layouts, and compared these methods

with a previously developed model, CaMLOC. They find that SCM and BSCM are more computationally efficient than CaMLOC and can be used to identify CR layouts for real-world forests areas up to 50 ha within a reasonable period of time and closer to mathematical optimality. Additionally, the BSCM can also be used to estimate the maximum gap in optimality [3].

Following up on this research, Bont et al. presented their next work in 2019, were they present a multi-objective approach for cable road layouts. This allows users to both consider harvesting cost demands as well as reducing environment impacts. Focusing more on the user, they also develop an application concept that aims to further facilitate the use of such an optimization process [4].

While the most recent work of Bont also seems most promising to us, one main problem is that it still relies on very imprecise data. To refer to a widely used colloquialism:

> Garbage in - Garbage out [9]

The generated layouts have to rely on forest stand estimations based on the underlying satellite data, which can lead to infeasible layouts, which can for example mistakenly assume that a given anchor tree is present. Especially when planning practical cable roads for an end-user, trust in the application will quickly decline if it repeatedly computes layouts based on an anchor tree which is not present or otherwise unsuitable.

We therefore propose the integration of high-precision forest stand maps based on personal laser scanning, enabling highly ac-curate and reliable cable road layouts. We furthermore want to employ a multi-objective optimisation, which allows to find an optimal tradeoff between conflicting objectives. Enabling more reliable layouts should also help with user-adoption, a factor which has become the focus of [4] as well.

3. Preliminary Results

The project is based on four sample PLS-generated forest stand maps in the form of one CSV with the exact tree locations (and other relevant information like tree diameter) and a shapefile of the area. The project development was then conducted in Python, utilising libraries like [6], [7] and [8]. Figures 1a, 1b, 1c show the process of data processing leading up to the optimisation problem. In the first step (1a), the location of the individual trees as well as the surrounding areas are parsed. Then, the user can interactively create polygons which describe areas containing important sub-regions, ie. the group of trees below the forest road serving as cable road anchors, the forest stand itself, as well as the target trees supporting the endpoint of the cable road (1b). These polygons are then used to select these groups of trees for further processing. The last sub-figure shows a set of generated possible cable roads, which satisfy a given set of conditions – as of now only the preliminary condition to have a deviation smaller than five degrees to the hill slope (1c).

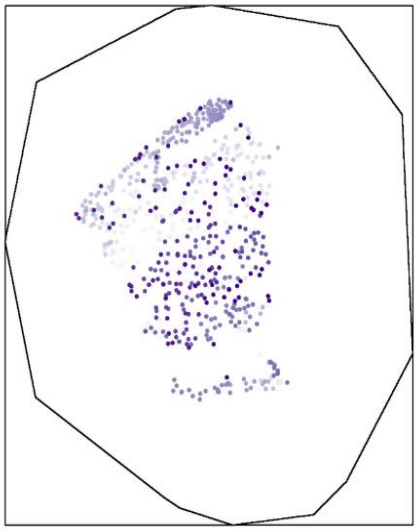

Figure 1a. Forest Stand.

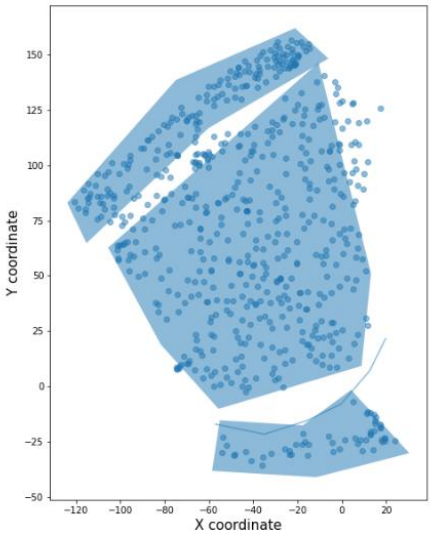

Figure 1b. Delineated Areas.

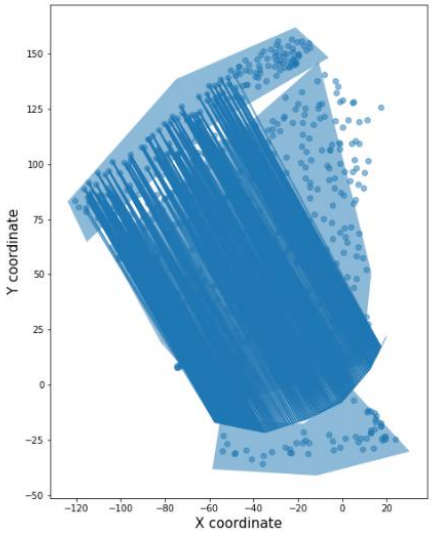

Figure 1c. Possible Cable Roads.

With this set of lines, the optimisation itself takes place. The current formulation is as follows:

$i \in I$ is the index and set of tree locations (demand points).
$j \in J$ is the index and set of possible cable roads (facilities).
$fj \in$ R+ is the cost associated with constructing a cable road $j \in J$.
$di,j \in$ R+ is the distance between facility $j \in J$ and demand point $i \in I$.
$ci,j \in$ R+ is the distance cost between facility site $j \in J$ and demand point $i \in I$.

We furthermore introduce two decision variables:

$selectj \in \{0, 1\}$is equal to 1 if we build a cable road at the proposed location $j \in J$; and 0 otherwise.
$0 \leq assigni,j \leq 1$ is a non-negative continuous decision variable which determines if the demand points $i \in I$ is assigned to facility $j \in J$.

The optimization function looks like the following:

$$\text{Min} \quad Z = \sum_{j \in J} f_j \cdot select_j + \sum_{j \in J} \sum_{i \in I} c_{i,j} \cdot assign_{i,j} \qquad (1)$$

This formulation minimizes the number of activates facilities as well as the absolute distance between each tree (client) and its assigned cable road (facility). This minimization problem is then constrained by the two following two constraints:

$$\sum_{j \in J} assign_{i,j} = 1 \quad \forall i \in I \qquad (2)$$

$$assign_{i,j} \leq select_j \quad \forall i \in I \quad \forall j \in J \qquad (3)$$

The first constraint enforces that each client is only assigned to one factory, the second constraint enforces that every factory that has a client assigned must be opened. This results in a preliminary cable road layout as shown in Figure 2. We can see that the cable roads are evenly spaced and have reasonable trees assigned to them. Computation takes about two minutes on a modern 8-core Intel CPU, but will be optimized further.

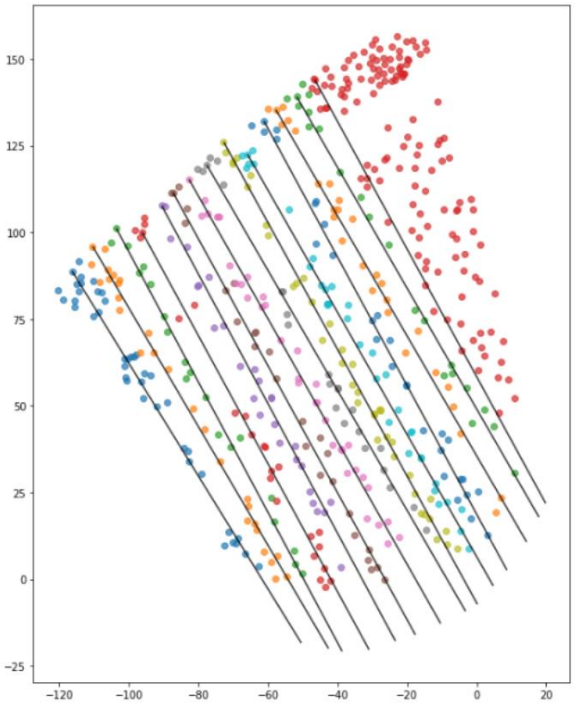

Figure 2. Proposed Layout.

4. Discussion and Outlook

We proposed a more accurate cable road optimization based on forest maps generated by personal laser scanning. We furthermore show-cased a multi-objective optimization to enable attaining a balance between different objectives, such as economical considerations as well as environment impact. In the next steps, we plan to better constrain the computation of possible lines with regard to suitable anchor trees, more accurately compute cable road costs, and finally extend the multi-objective formulation to represent realistic cost factors and environmental considerations. For future work, we plan to investigate how such an application can be designed to enable the user to investigate the tradeoff between different objective factors interactively, building a better understanding of the factors influencing the algorithm and with that building trust. Such a toolsuite will help to improve the adoption of cable road layout tools and can ultimately help with reducing environmental impacts of such operations.

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Forestry Challenges of the XXI century. Exploring the Role of Mass Timber and Forest Plantations in Achieving the Targets of the UN Decade on Ecosystem Restoration and Net Zero Targets

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ABSTRACT

The UN decade on Ecosystem Restoration is looking to change the dynamic of land and forest degradation across the globe. Currently, more than 200 million hectares have been committed by governments to restore degraded landscapes to protect the natural forest, deter deforestation and forest degradation, and increase the sustainability of food production while restoring degraded areas. Ecosystem restoration comprises a wide spectrum of actions that include reforestation, Agroforestry, silvopasture systems, low carbon agriculture, and actions to avoid deforestation, among others. To achieve the ambitious targets at scale, restoration actions need to create and develop new value chains. Forest plantations and managed forests can provide new products such as mass timber to generate new markets that increase carbon capture and reduce the carbon footprint in the construction of new buildings. New mass timber value chains can increase the market incentives for farmers to implement restoration practices that are able to produce quality products to develop a new forest economy; however, those value chains have not come at the expense of degrading natural areas. Forest plantations can also offer a variety of new innovative products that could help countries to achieve targets, but they are often a controversial topic when discussing mitigation measurements, especially when monoculture exotic plantations are part of the discussion. This presentation will provide a holistic perspective of challenges and opportunities for mass timber and timber plantations to support the UN Decade on ecosystem restoration targets. We will also discuss why timber plantations (especially exotics) have become a contingent issue in the climate change discussions and what is the role of forest engineering and operations in implementing restoration actions. Forestry involves the use of a limited asset, the land. An adequate analysis of the implications and life cycle analysis of forest products value chains and their relation to other competitive land uses is needed to understand the potential of mass timber and forest products in mitigating and adapting to climate change while providing transparent data to avoid greenwashing.

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What Evidence Exists on the Motivations for Commercial Thinning of Conifer Forests? A Systematic Map

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ABSTRACT

Among the options available for manipulating forest stands, thinning is traditionally applied to improve the growth of fewer, but they ultimately become larger merchantable trees. The goal is tree removal to decrease competition so that the remaining trees can benefit from more available "growing space", which means growth resources at any given site (sunlight, moisture, nutrients) and other factors, including the physical space. Usually, the poorest quality trees are removed from mature, even-aged stands. In commercial thinning (CT), the intention is to be profitable. Nevertheless, there are implications of the timing and nature of thinning regarding the trajectory of merchantable volume recovery post-operation. Hence, it is crucial to understand the motivations and outcomes of CT better so that silvicultural operations are planned carefully, and profitability is achieved.

We mapped the available literature on CT systematically and produced a comprehensive list of the motivations for this silvicultural operation. This systematic map was not limited to any country but focused on conifer-dominant forests. The search scope focused on hard values, such as economic and silvicultural, and other values associated with CT, such as biodiversity, tree damage, drought, late-successional forest attributes, insect & diseases, soil, wildfire and wind. Using the resulting evidence base, we aimed to answer the following research questions:

Q1. What is the state of the evidence in terms of quantity of studies, tree species type and geographical location?

Q2. What evidence exists on the impacts of commercial thinning on growth and yield?

Q3. What evidence exists on the impacts of commercial thinning on economic return?

Q4. What evidence exists on the impacts of commercial thinning on other soft values (e.g. biodiversity, soil protection, fire risk reduction, etc.)?

Q5. What are the major gaps in the evidence base from primary research studies? We organized the information on CT by study objective, geographic region and species, creating predetermined bins (Q1). We analyzed the reported findings of CT influence on stand growth and yield (Q2) and related them to the economic return (Q3).

We also identified if any other value was associated with CT (Q4). We identified trends, knowledge gaps and clusters by cross-examining the meta-data from the four themes (study characteristic, silvicultural, economic and other values - Q5). Finally, we reported the extracted evidence in a narrative synthesis form and summarized trends with heat maps, describing the volume and critical characteristics of the evidence base.

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Comparing Different Equipment Replacement Policies for Logging Machines in Brazil

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ABSTRACT

We used a dynamic programing algorithm to identify schedules that minimize the total discounted cost TDC of logging machines over a planning horizon including gains from technological progress. The identified schedules were also compared with three alternative replacement policies derived from scientific studies and Brazilian forestry companies. Our case study uses a harvester and a forwarder and a 100-year planning horizon, where the maximum replacement limit was 8 years. To apply the dynamic programing algorithm, it was necessary to generate lists from cash flows, which incorporated the possible replacement combinations of a series of machines according to the length of the planning horizon and the maximum replacement limit. The lists were formed by three descriptors: predecessor node (moment of purchase of the machine), future node (point of sale for the acquisition of a new machine), and arc value (TDC information, the mean production cost and mean production). The results show that the TDC identified for the series of harvester replacements was higher compared to the forwarder. It was also identified that the harvester's economic life is shorter, and with technological progress, there was a reduction in the economic life of both machines. Technological progress was also responsible for reducing the average production cost and increasing the average production of machines. When comparing the replacement schedules, it was found that, although alternative schedules had a higher TDC value and mean production costs, there were very little difference between them. In the harvester's case, schedule 01 had the highest NPC value ($4.36 million). By choosing it, the decision maker would bear an TDC boost of $54,000, while alternative schedules 02 and 03 would

trigger an increase of $42,000 and $31,000, respectively. For the forwarder, the schedule with the highest TDC value was alternative schedule 03 ($3.69 million). The postponement of the replacements made in alternative schedules 01 and 02 resulted in an increase in the TDC of $5400 and $5300, respectively, while the anticipation of the replacements made in the alternative schedule 03 resulted in an increase of $51,000. The aspect that stood out the most in relation to the results presented was the small variation that the alternative schedules presented in relation to the schedules obtained using the dynamic programming algorithm. With a TDC variation of less than 1.4%, the results lead us to conclude that the decision maker will not have much harm in choosing alternative schedules.

Productivity and Cost of Tornado Salvage Chipping in South Carolina, USA

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ABSTRACT

Salvage harvesting is common in the US South because of natural disasters such as wildfires, tornadoes, hurricanes, and insect/disease infestations. The warm and humid climate of the US South means that salvage logging should commence within weeks or months of a natural disaster because of rapid declines in wood quality. Opportunities for individual companies to conduct salvage harvesting are irregular because natural disasters are dispersed geographically and temporally. Consequently, most logging businesses conduct salvage operations with equipment designed to harvest undamaged standing trees. An Enhanced Fujita Scale 3 (EF3) tornado with winds in excess of 250 km per hour struck Aiken County, South Carolina in April of 2020. The tornado uprooted trees and severed other stems above breast height. Salvage timber harvests began in July 2021 and concluded in January 2022, more than one year after the tornado damaged the stands. The goal of this study was to estimate the productivity and cost of salvage harvesting in loblolly pine (Pinus taeda L.) stands following a severe tornado. Salvage harvests were conducted with a rubber-tired drive-to-tree feller-buncher, a grapple skidder, a tracked loader, and a chipper. All stems were chipped and used to produce energy; no roundwood was produced from the harvests. Elemental time-and-motion studies were conducted in three pulpwood-sized stands (<30 cm dbh) and three sawtimber-sized stands (>=30 cm dbh). Hourly harvesting costs were estimated using the machine rate method and per-ton costs were estimated using a modified version of the Auburn Harvesting Analyzer. Skidding was the least-productive in-woods function while trucking constrained overall production in one-third of the stands. Skidding productivity was low in each harvest unit, but especially so in the three pulpwood-sized stands. Stem breakage and low weight per stem reduced skidder payload in pulpwood-sized stands. Harvesting costs averaged $29.65 and $23.79 (USD) per tonne (onboard truck) in the pulpwood- and sawtimber-sized stands, respectively. High salvage harvesting costs mean that landowners should expect significantly reduced stumpage prices from these harvests; nonetheless, landowners do benefit from reduced reforestation costs. Harvesting promptly after a tornado can reduce harvesting costs and allow for greater value recovery.

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New Ground-Based Skidding Options for the Inland Northwest

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ABSTRACT

We are evaluating the first modern, articulated, tracked grapple skidder operating in western North America, a John Deere 648L with G and R quad tracks. Rubber-tired grapple skidders are very common in the inland northwest and have traditionally been paired with a small, straight-tracked machines that are able to work on slightly steeper slopes and in wetter soil conditions than rubber-tired skidders when needed. For example, the CAT 527 or similar sized crawler-dozer with a grapple may be kept on side and used intermittently to access more difficult areas. The 527 model is no longer produced, limiting contractors to reuse and refurbishing of existing machines. Converting articulated, rubber-tired skidders to independent tracks provides an alternative solution that could expand the operational window for skidding in the region, making it possible to skid during wet fall seasons, mild winters and long spring breakup period. The 648L with rubber tires has 13.67 PSI, while the same machine on G and R tracks has 7.61. Quad-track agricultural tractors have been used successfully on neighboring agricultural lands in the region for many years. We provide preliminary modeling and analysis of the ROI for converting rubber-tired skidders to tracks under expanded operability of skidding ranging from 2-8 weeks, paired with a production tradeoff associated with maximum skidding speed, which is reduced from 15.3 to 10.7 mph. Lastly, we consider some broader economic impacts of track systems on utilization of the existing ground-based infrastructure in the Inland Empire.

Supply Chain and Transportation Logistics

Global Overview of Industrial Roundwood Road Transport

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Inclusion of Log Yards in Wood Supply Systems to Minimize Transportation Costs through a Focus on Moisture Management

Imen Chaabouni, Luc LeBel, Shuva Gautam

Digitization Level Assessment of Eastern Canada's Forest Value Chain: A Case Study of CTL Harvester Data Usage

Nicolas Girard, Michel Soucy, Jean-Martin Lussier

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Global overview of industrial roundwood road transport

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Abstract: The aim of the survey was to clarify gross vehicle weights (GVWs) allowed on roads in the domestic timber-trucking logistics of different countries, the share of the road transport of total industrial roundwood long-distance transport volumes, and the average payloads, transport distances and costs of industrial roundwood long-distance transport. The inquiry was sent to a total of 30 European countries with the biggest industrial roundwood removals. Furthermore, the inquiry was sent out to selected major forestry countries in the world (Argentina, Australia, Brazil, Canada, Chile, China, Japan, New Zealand, South Africa, Turkey, United States of America, and Uruguay) in February 2022 and closed in June 2022. A total of 32 countries participated in the survey. GVWs allowed on roads in timber trucking ranged from under 40 tonnes to over 70 tonnes. The results depicted that higher GVWs signify larger payloads in timber trucking. The survey revealed also that road transport is the main long-distance transport method of industrial roundwood in most of the responding countries. The road transport distance of industrial roundwood averaged 112 km. The average road transport cost was approximately €9.7 ($11.0) per tonne of timber. The survey illustrated that relatively low GVWs and long transport distances increase transport costs. Most of the respondents complained about the absence of comprehensive official statistics, and some experts could not answer to all questions or – alternatively – they gave their own best estimates as a replacement. Therefore, up-to-date statistical data on the long-distance transport of industrial roundwood is needed in some countries.

Keywords: gross vehicle weight (GVW), timber logistics, timber truck, transport distance, cost

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An Assessment of the Safety and Efficiency of Log Trucks with Increased Weight Limits on Interstate Highways in Minnesota and Wisconsin

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ABSTRACT

State weight limits for log trucks exceed federal interstate highway weight limits in most timber-producing states within the US. Requiring trucks hauling forest products to use secondary roads instead of the interstate system forces them to travel through communities where they encounter two-way traffic, intersection traffic control structures and pedestrians. More efficient trucking can also provide additional benefits in terms of reducing fuel consumption, carbon dioxide (CO2) emissions, and pavement damage. Safety improvements, efficiency gains and pavement damage costs were estimated if state-legal weight limits for commercial motor vehicles hauling raw forest products were increased on selected interstate corridors in Minnesota and Wisconsin.

Data were collected by GPS trackers installed on log trucks for nearly 450,000 miles (720,000 km). Routes from inwoods locations to a mill were analyzed using Esri ArcGIS Route Analysis software. The Truck Time travel mode was used to estimate the most efficient routes with and without interstate access.

Allowing state-legal, loaded log trucks access to federal interstate highways in Minnesota and Wisconsin would improve the overall safety and efficiency of timber transportation while reducing pavement damage costs and CO2 emissions. Reducing the number of routes that incur two-way traffic and traffic control structures, some of which require sharp turns which increase the potential for a rollover will likely result in fewer accidents, injuries and fatalities.

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Benefits of Implementing Tire Presure Control Systems (TPCS) in Northwestern Ontario

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ABSTRACT

Transporting raw forest products to processing facilities is one of the highest costs of overall timber production. Many forestry contractors and log truck owners are looking for feasible ways to minimize forest road transportation costs. This study proposes a practical solution to reducing forest resource transportation costs by analyzing the costs and benefits of tire pressure control systems (TPCS) in northwestern Ontario, Canada. Data from four log-hauling contractors in the northwestern Ontario region was collected and used to compare the benefits of implementing TPCS compared to trucks without TPCS. Various models provided by TPC International, TIREBOSS Inc., and FPInnovations were used to compare the costs of log hauling with and without TPCS implemented on log trucks. The findings in this study were compared, summarized, and presented in this thesis. When implemented on log trucks, TPCS can substantially benefit the log truck owner and contractor. The main benefits come in the form of cost savings, specifically reduced tire costs, increased traction, reduced fuel consumption, and increased truck utilization. TPCS also increases truck, trailer, and tire life while lowering the income required by the truck owner to meet their costs and profit margin. Furthermore, the results of this study imply that TPCS can reduce the costs of log-hauling and therefore reduce forest transportation costs.

Keywords: central tire inflation, forest road, forest transportation, fuel savings, increased utilization, log truck, reduced costs, tire pressure control system, tire savings, traction savings

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Battery-Electric Log Truck Feasibility in Western Oregon

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ABSTRACT

Just as trees have become a climate-smart commodity, the battery-electric vehicle is seen as a climate-smart method for transportation. The feasibility of the battery-electric log truck depends upon truck cost, battery capacity and weight, topography, haul distance, the cost of electricity, the availability of charging stations, and time to charge. At least two truck manufacturers in the Pacific Northwest, USA now offer truck tractors with battery-electric powertrains capable of negotiating the steep forest roads of the Pacific Northwest. We present a survey of local mills where charging stations might be located to identify possible charging strategies. A sensitivity analysis of delivered cost per ton to truck cost, battery capacity and weight, electricity cost, and charging station location is presented.

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The Biggest Bottlenecks and the Most Potential Development Measures in Long-distance Road Transport of Industrial Roundwood in Finland

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ABSTRACT

The survey detected which matters are regarded as the biggest bottlenecks and challenges in the current operating environment of industrial roundwood long-distance road transport in Finland. Moreover, the aim was to investigate the most potential development measures for the next few years in long-distance road transport. The survey was sent to respondents in February 2022 and closed in March 2022. A total of 86 timber-trucking contractors responded to the survey (response rate 24.6%), 9 representatives of wood-procurement organizations (64.3%) and 9 researchers (60.0%). Respondents considered the rise in fuel prices and generally cost levels, and the profitability of timber-trucking business as the biggest operational challenges. Similarly, the condition and maintenance of the road network was pressed to have a significant need for improvement. Rising costs for other factors (i.e., truck fleet and labor) were also a concern for respondents. In addition, scheduled deliveries for mills, rush at work, seasonal variation in wood procurement, and relatively small storage facilities of mills, were perceived as significant problems. The respondents were also concerned about the wellbeing of timber-trucking contractors. The respondents regarded the improvement of the condition of the road network and the quality of road maintenance as the most significant development targets. All of the respondent groups also called for fuel tax subventions for heavy transport. The contractors particularly underlined a need for pricing transport services to a level of profitable business. Furthermore, respondents pointed out that the timber transport sector needs to be made more attractive and valued. The respondents also emphasized the need to ensure both drivers' and contractors' wellbeing at work. Consequently, the study illustrated that the government is needed to support the timber-trucking industry to cope with the sharp rise in fuel prices. The government is also expected to invest more in the maintenance of public road infrastructure. Poor roads and bridges cause extra driving for timber-truck vehicles and create inefficiencies to the road transport of timber. Besides, taking care of the wellbeing of both drivers and contractors plays a very important role during the next years.

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Supply and Command: Quantitative Methods for Risk Management and Resilience in Wood Supply

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ABSTRACT

Over the last decades, Nordic wood supply logistics have leveraged advances in computing power and technological applicability to focus on optimizing transport routing and streamlining management activities to stay competitive. Insights from these advancements have enabled bio-based industries' business strategies to reduce redundancies and associated costs in their logistic systems. Sawmill and pulp mill production require evenness in their raw material supply regarding volume and characteristics. A supply strategy is embodied by the combinations of sources, resources, and capacities that form a sustainable raw material supply system. Supply management is a continuous business process that adapts to changing assumptions and conditions. Within the framework of a supply strategy, sources are contracted, flows are planned, and resources are scheduled on an ongoing basis to fulfill goals such as delivery security, flexibility, capacity, costs, etc. However, disruptions occur in both supply and demand, which challenges the resilience of the supply chain - its ability to prepare for, react to, and recover from disturbances.

The primary purpose of my doctoral project is to provide novel insight into large integrated forestry companies' opportunities for resilient supply strategies providing cost-efficient responses to disruptions to their raw material supply. In cooperation with one of Sweden's largest integrated forestry companies, we mapped the functional structure of their supply chain (system). We paired the mapping with quantitative insight into the system's dynamics, derived from time-series data on raw material flow. The structure and key characteristics of the supply chain and its components were then statistically modeled to categorize sources/suppliers and sinks/receivers based on their attributes. Correlations between disturbances and their effects on raw material flow will be identified and categorized. We intend to apply this model to different disturbance scenarios, track disturbance impact, and quantify system resilience. Statistical learning methods will then be used to generate mitigation strategies for the disturbance scenarios. Finally, we will propose a framework for augmenting supply strategy resilience to contextual supply chain scenarios.

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Measuring the Performance of a Fleet of Forest Entrepreneurs Using GPS and Public Data Sources

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ABSTRACT

Forest companies often obtain their wood from several independent entrepreneurs operating different types of machines over large areas. In those conditions, data collection for monitoring forest operations requires a significant effort. Such information is needed to provide proper visibility on wood supply activities. A lack of visibility makes it difficult to understand the factors affecting productivity. For wood supply managers, a lack of visibility will translate into a lack of predictability, which is the capacity to forecast deliveries to the mills and their clients. This paper aims to monitor the performance of a fleet of forest entrepreneurs in mechanized cut-to-length (CTL) operations.

Performance indicators were inventoried from the literature to establish what data is required to monitor a fleet of entrepreneurs. Methods to collect and process data were developed. Then, combining information available from forest databases, weather stations, LiDAR-derived maps, and production reports, it was possible to generate key performance indicators. A dashboard was developed in partnership with supply managers. A fleet composed of 45 forest entrepreneurs owning a total of 78 harvesters and 45 forwarders was monitored for a 12-month period. The method has three main accomplishments. First, it offered an expanding database that connects machine production with its environment. Second, it placed in relation individual machines within their production team revealing global system productivity. Third, it provided supply managers with a global view of their entrepreneur fleet and allowed for projections on delivery performance.

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Punch-code Supply Chain Tracking Technology and its Viability in Australian Forestry Conditions

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ABSTRACT

Many industries believe that the distribution and logistics of products are greatly improved through the application of track and trace technologies. Track capabilities allow companies to know where a product is at any given moment within the supply chain. Manufacturers have the ability to know when a product has been delivered to trading partners, and purchasers can better manage inventories and reduce the cost of maintaining stock quantities. Successful tracking and tracing require item coding for necessary identification. Usually, items (or batches of items) or products that differ in form, fit or function are tagged with a unique code.

Some large Australian forestry organisations have recently moved away from paper dockets to electronic docketing systems. The claimed benefits are many and include real-time delivery information, improved data accuracy, improved customer production planning, improved logistics scheduling, reduced labour requirements, improved workforce safety, improved cash-flow, and reduced over-supply, spoilage and shrinkage of log products. On arrival, the load of logs is often mixed with other loads and other logs. The uniqueness of the logs in the load, and some of the information associated with those logs, can be lost particularly for domestic supply chains. It has been argued that a lack of a log tag, track and trace system can lead to a loss of information that could have led to significant improvements in the overall forest to customer supply chain.

In this study, we tested a punch-code system developed by Otmetka Log Marking AB (Otmetka) of Sweden for tagging individual logs. By utilising a matrix of rotating punches in fixed positions a unique code for each individual log can, among other things, be linked to production data from the log processor's computer, location and time of log manufacture. For the log tagging, a manual log hammer, with a grouping of four, non-rotating, arrow-shaped and T-shaped punches, was supplied by Otmetka. The trial was conducted in Queensland and the data set consisted of more than 3,000 images of Hoop pine (Araucaria cunninghamii) logs. Log ends were tagged at random locations; some near the outer-edge of the log, others towards the centre of the log. The images were captured with two camera types (both RGB); a smartphone with a resolution of at least 8 MP and a digital camera with a resolution of about 32 MP with a good quality lens and flash unit (Canon EOS 70D). A deep learning model was trained and implemented

to detect the tagging symbols in a range of conditions including distance to the logs, time after tagging, lightning conditions (day and night), and log surface (wet/dry, rough/smooth).

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An Optimal Ordering Policy for Biomass Supply Chain Optimization Using Integrated Inventory Control and Life Cycle Analysis

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ABSTRACT

The development of biomass energy projects and other bio-based businesses depends on effective and efficient biomass logistics and continuous supply from forestry and agricultural operations. Because the supply chain is not a single vertically-integrated business, but rather a network of multiple business and relationships that facilitate material, capital and information flows, the successful coordination, integration and management of key business processes across members of the supply chain determines the ultimate success of each enterprise. Coordination by a single business in the network can benefit multiple actors. For example, improved inventory management practices can contribute to increased competitive advantage and improved organizational performance of a regional supply chain, increasing investment and profitability over other regions. At the same time, businesses dependent upon raw materials like forest biomass and agricultural crops cannot grow profitability at the expense of environmental sustainability because the competitiveness of bioenergy, biofuel and bioproducts is highly dependent upon their environmental benefits over products derived from fossil fuels. A process-oriented life cycle assessment (LCA), including greenhouse gas (GHG) emissions and other environmental impacts, helps to ensure that the production, delivery and storage of raw materials across the whole biomass supply chain results in better environmental outcomes. In this study, we coupled industrial biomass inventory control methods with LCA to unlock the potential to simultaneously reduce the environmental impacts of the biomass supply chain and increase its economic productivity by improving the efficiency of the total supply chain process with regards to both financial metrics like delivery cost and environmental impacts like GHG emissions. We present a case study of a hypothetical 100-ton per day facility located in Haywood, West Virginia, USA, that produces liquid biofuel and industrial hydrogen using gasification and a Fischer-Tropsch process. A mathematical model of the system is formulated and we proposed an optimal ordering policy for inventory control and sustainable biomass supply chain management to improve biomass logistics to meet demand at the lowest possible cost and also reduce environmental risk.

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Inclusion of Log Yards in Wood Supply Systems to Minimize Transportation Costs through a Focus on Moisture Management

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ABSTRACT

Transportation generally represents the highest component of total logging cost. It is influenced by several factors, one such factor being the moisture content of logs. Hauling of logs with high moisture content over long distances poses a challenge for wood supply systems to remain profitable. The objective of this study is to quantify the benefits of incorporating a log yard in wood supply systems to minimize transportation cost. Log yards can provide numerous services to wood supply systems, such as sorting, storage and node for intermodal transportation. It can also be a location where logs can be stored to allow moisture content reduction to a certain level prior to final delivery. However, incorporating a log yard can add significant cost to the supply chain. Conversely, reduction in moisture content can lead to reduced costs for further transportation. We present a case study from Quebec, Canada of a paper mill with a large wood supply area. The cost-benefit of incorporating a log yard were assessed using LogiLab, a network optimization tool for divergent flows. Moisture content dynamics were embedded within LogiLab to assess different log yard scenarios. Preliminary results show that optimizing transport and allowing moisture management through incorporation of log yards increases profits by almost 2% in certain scenarios. The analysis also showed that more than 2 log yards would not provide additional profit improvements in this specific case. The findings provide useful information for decision-makers; a broader multi-species, multi-mill analysis is envisioned for future work.

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Digitization Level Assessment of Eastern Canada's Forest Value Chain: A Case Study of CTL Harvester Data Usage

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ABSTRACT

The digitization of the various manufacturing processes is taking place at different rates within the forest industry. Capturing the full benefits of this digitization requires data sharing along the value chain, thus requiring that competing firms, suppliers and clients also become an integral part of this industry 4.0 system. The Cut to Length Harvesters collect standardized data that has potential usage along the chain. In Eastern Canada, how this data is shared and put to use is commonly known to be highly variable between organizations, from a single machine owner operator organization that makes no use of the technology, to large vertically integrated firms that put data to use within their own organization. However, this common knowledge has not been clearly characterized leaving unclear how to facilitate the transition to a truly 4.0 forest sector beyond individual firms.

Through semi-constructed surveys and guided interviews of a limited number of harvesting contractors, large landowner and mills in New-Brunswick, harvester data usage was described along with factors that could explain the current situation. Equipment suppliers were also interviewed as they have first hand knowledge of the technologies available in the harvesters and to a certain extent, on how their clients use it. The surveys were constructed in such a way that it would be possible to assess the digitization level of each firm with 8 different dimensions of digital requirements. In this process, it was also possible to identify key factors preventing the use of harvester data at different scales of the forest value chain.

Interestingly, in value chains involving multiple firms, data did not flow out of the harvesters for a number of reasons. Outside from certain obvious challenges such as limited resources, workforce abilities and access to certain data transfer technologies, more fundamental issues became apparent: 1) a misunderstanding of the cost benefit value of this data for firms down the chain prevents them from investing rapidly in this change; 2) there's an important lack of trust between firms, especially in the absence of an overarching system governed by clear rules and regulations. While all firms interviewed had already taken steps for the digitization of their own operations, little has been done to facilitate harvester data usage between organizations.

Harvesting Systems

The Cost of Forest Thinning Operations in the Western United States: A Systematic Literature Review and New Thinning Cost Model

Heesol Chang, Han-Sup Han, Nathaniel Anderson, Yeon-Su Kim, Sang-Kyun Han

Downed Timber Initiative Felling Head: An Attachable Felling Head which Specializes in Harvesting Damaged Timber from Strong Winds of Hurricanes or Tornados for a Rubber-tired Feller-buncher

James Walker, Tom Gallagher, Richard Cristan, Timothy McDonald, Dana Mitchell

Use of Battery-powered Chainsaws in Forestry Practices: A Case Study in a Conifer Stand Thinning

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Economics of Harvesting Hardwood Pulp Stands Using Hybrid Cut-to-length and Whole-tree Harvesting

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Thinning as a Tool to Increase Resistance to Stressors in the Interior of British Columbia

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Characterizing Properties and Bucking Patterns of Eucalyptus Plantation for Optimizing Yield for Smallholders

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Terra-mechanical and Statistical Analyses of Four-Wheel Grapple Skidder Performance Data

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The Cost of Forest Thinning Operations in the Western United States: A Systematic Literature Review and New Thinning Cost Model

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ABSTRACT

Fire suppression and other land management practices have led to dense forests in many parts of the western United States, which has increased hazardous fuels and created favorable environments for landscape-scale wildfires. Mechanical forest thinning treatments have been implemented across the U.S. West to improve forest health and reduce hazardous fuels. However, the main challenge of forest thinning operations is their low financial feasibility. Operational costs are high and revenues are low because these treatments typically focus on harvesting low-value, small-diameter trees, or have no merchantable removals at all. A lack of synthesis and up-to-date tools for costs has hindered landscape-scale planning and treatment prioritization efforts. This study was conducted to synthesize the stump-to-truck cost of forest thinning treatments based on research articles published over the last 40 years (1980-2020) in the western U.S. We systematically selected and reviewed 20 thinning studies to analyze key variables affecting machine productivity and harvesting costs. We divided the thinning operations process into four phases (felling, extraction, processing, and loading) to analyze each machine's cost and productivity. There were various forest machines and tools used for forest thinning operations, and we summarized them into three harvesting method categories: whole-tree (WT; n=18), tree-length (TL; n=4), and cut-to-length (CTL; n=25). The average cost of forest thinning was lowest for a mechanized whole-tree thinning operation at $21.34/metric ton or $2,075/ha. Feller-bunchers and skidders showed the highest harvesting productivity in felling and extraction machines, respectively. We found that extraction cost accounted for the largest proportion of the stump-to-truck cost of forest thinning (33%, 43%, and 34% in WT, TL, and CTL thinning, respectively). Tree diameter and machine travel distance are common variables affecting thinning productivity and thus cost, regardless of different harvesting methods used. With the thinning productivity and cost data from the selected studies, we developed a spreadsheet-based model to estimate thinning costs for various harvesting systems. The model calculates the productivity and cost of the machine used in the stump-to-truck thinning process based on user input information. The results of this literature

synthesis and our new thinning cost model and tool can help foresters develop a cost-effective plan for thinning operations, which helps objectives of forest management more efficiently.

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Downed Timber Initiative Felling Head: An Attachable Felling Head which Specializes in Harvesting Damaged Timber from Strong Winds of Hurricanes or Tornados for a Rubber-tired Feller-buncher

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ABSTRACT

This research project is a part of the Downed Timber Initiative project which is a bold yet obtainable idea which benefits areas affected by hurricanes and tornados in environmental, economic, and social aspects. The Downed Timber Initiative proposes a quick and easy method for harvesting downed timber by implementing new technology on existing equipment that most southeastern logging crews already possess. In this research project, a new kind of felling head will be designed, manufactured, and tested. This felling head can be attached to the front of a standard rubber-tired feller-buncher and feature a boom with the capability of extending a chain and bar grapple saw a maximum of 18 feet from the base of the machine. It can then grab, cut, and stack downed or standing timber for a grapple skidder to collect and bring to the logging deck. The feller-buncher equipped with the Downed Timber Initiative felling head will move through the tract in straight lines, harvesting timber on either side in its 18-foot radius boom operating zone. The mechanical integrity of individual components, hydraulic system requirements, and dynamic (tipping) simulations of the machine system have been tested in engineering software, and the results of each show the machine is suitable for in-woods use. A prototype will be manufactured to confirm the effectiveness of the machine. This prototype will consist of a Barko 80 XLE boom mounted on a modified John Deere FD45 felling head that will be attached to a John Deere 843L feller-buncher. On the end of the boom will be a Waratah FL85 dangle head saw. It is expected that the efficiency of a downed timber harvesting operation for a standard southeastern logging crew to be vastly improved by this machine.

Keywords: hurricanes, tornados, downed timber harvesting, rubber-tired feller-buncher, felling head

Use of Battery-powered Chainsaws in Forestry Practices: A Case Study in a Conifer Stand Thinning

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ABSTRACT

The use of chainsaws in forest operations is still very common in many areas of the world. Despite the high risks related to their use, chainsaws guarantee to operate efficiently with low investment costs. Nowadays, the use of petrol chainsaws in forestry has been considered common, while electric and battery chainsaws have been used only for gardening, hobby, and green maintenance. Despite the high technological level reached by endothermic engine chainsaws, in recent years manufacturers have invested in battery power obtaining rapid improvements in battery life and power. In fact, the power of the most performing battery machines is similar to those of light-type petrol machines suggesting a possible future introduction of battery-powered chainsaws in forestry operations. In this context, the aim of this study was to evaluate the potential use of the battery-powered chainsaw in a conifer thinning, comparing the working times and productivity obtained with two different models of chainsaws, similar in terms of weight and power: the Stihl MS 220 CB battery-powered and the Stihl MS 201 CM with internal combustion. The thinning was carried out by two forestry operators, in two areas of about one hectare within a 70-year-old parcel of Douglas fir. The results obtained showed that within a working day, considering a gross time of about 6 hours for each operator, an average of 15 trees with an average diameter of 25 cm and an average height of 26 m were felled in each area. The two chainsaws resulted actually comparable to each other even if the cutting speed in cross-cutting was lower for the battery model. Cutting times in sectioning were more than 15% of those recorded with the endothermic model and concerning battery life, it was possible to cut and section an average of two plants per charge. Finally, battery chainsaws show high potential but technology will have to solve the problem related to battery autonomy and recharge in forests.

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Preliminary Results of a Prototype Chain-flail Delimber on a Short-rotation Poplar Plantation

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ABSTRACT

Chain flail delimber-debarkers (CFDD) can easily handle more trees per cycle, boosting productivity especially when handling small trees typical of medium rotation industrial plantations.

Chain-flail technology is not at all new - in fact, it was considered an old idea already in the late 1980s- and it is used in many regions to produce high-quality fiber for manufacturing pulpwood. Until now, however, commercial CFDD were too heavy, powerful and expensive for easy use in thinning operations or in European short rotation plantations (SRP). Therefore, an Italian company designed and developed a compact CFDD for the European small-scale SRPs. That machine had to be much lighter and cheaper than any similar products, and the prototype did meet those requirements, weighing 4 t and carrying a tentative price tag ⩽ 100k EURO.

The chainflail prototype was built from a pre-existing root cleaner, consisting of a box-like structure fitted with two rotating flail drums. Each drum carried 20 flails, consisting of 6 hardened chain links each. The original root-cleaner was designed for vertical feeding, so that conversion into a CFDD required turning the unit 90deg, as a first step. Then, an infeed table was installed, for supporting incoming tree bunches. On the other end of the flail unit, a metal chute was added for holding that stem portion that had passed through the flail. The chute ended with a bump plate for indexing trees. That first prototype was installed on a roll-on roll-off platform and mounted on a truck, which also powered the flail drums through its hydraulic PTO.

The equipment was tested in a controlled experiment in Western Slovakia for 5 days. During the test it was fed by a 13-t excavator-based loader fitted with a grapple saw, which also performed crosscutting. The trial was successful, resulting in high productivity and no mechanical downtime. Productivity ranged between 2.5 and 4.7 BDT SMH-1.

Delimbing quality was considered satisfactory by the factory production managers on site and at the receiving facility.

The machine worked best with the smallest trees, which are a challenge for all other options. Further improvements are planned and they may greatly increase the efficiency of the new machine.

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Economics of Harvesting Hardwood Pulp Stands Using Hybrid Cut-to-length and Whole-tree Harvesting

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ABSTRACT

Small-diameter trees (SDT) are one of the major constraints of economic feasibility in regions that lack markets for such non-merchantable products. Northeastern United States is one such region where forest managers make use of a range of approaches to manage those stands. Hybrid Cut-to-length (Hyb CTL) is one of the harvesting methods used in the region for harvesting stands which results in low value products but are composed of both SDT and hardwood pulp. Hence, it is essential to understand and compare the cost and productivity of Hyb CTL with that of Whole tree (WT) harvesting. The primary objective of the field-based study is to estimate the cost and productivity of Hyb CTL and WT harvesting operation. The secondary objective of the study is to evaluate the major factors that affect the delay-free cycle time (DFC) of each of the harvesting phases and the third objective is to conduct a sensitivity analysis on the machine operating cost variables such as fuel, labor, utilization, salvage value, and purchase price of various machines in both the harvesting methods. The current study involves a detailed time-motion study was conducted for all in-wood operational phases in the two different silvicultural prescriptions during January 2022. Machine rates and other related information were gathered from the logging contractors and timberland managing company. Regression models will be developed for determining the influence of dependent variables over the cycle times for each operational phase. The expected results will evaluate in-wood operational cost covering stump to the truck for SDT and pulpwood. Additionally, factors influencing the machine operating cost of the various operational phases will also be determined from the sensitivity model. We anticipate this study will provide working values to timberland managers and operational foresters to take better managerial decisions regarding silvicultural prescription and better manage stands having large proportions of SDT.

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Effect of Main Technical Parameters on Forestry Cranes Productivity in Cut-to-Length Timber Harvesting

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ABSTRACT

Forestry cranes are of paramount importance in forest harvest operations, so designers and manufacturers' considerable efforts have been carried out to improve improving their use and versatility in recent years. However, all these efforts have focused on increasing the power and the reliability of the structure on the basis of the wide range of forestry cranes and increasing their complexity. Thus, the issue of productivity operations analysis taking into the features of the structure of forestry cranes construction, their kinematic parameters and peculiarities of operations were not given due attention, which reduces the efficiency of logging. The purpose of this study is to resolve the next problems: 1) analyze the technical characteristics of cranes for compliance with their use in production conditions; 2) forestry cranes layout features for different forestry operations.

Mechanised forest harvesting operations have a growing trend of using forestry cranes due to their universality, high productivity and level of occupational safety. Whether handling cut-to-length or tree-length timber, the forestry load crane needs to be ergonomic, have speed and high manoeuvrability, optimal main design parameters, and be able to maximize payload for increasing productivity in each work cycle. Today it is expected that the intensity of work of forestry cranes to produce many times the volume needed just a few decades ago - prompting the need for more efficient loading equipment to meet the demands of modern logging. It was found that the productivity of the forestry cranes depends on site and stand-specific characteristics, method of timber harvesting, technical parameters of load cranes, the individual skills of the operator and organizational aspects of works on the felling area. It should be noted that some of these determinants of forestry cranes productivity cannot always be clearly and unambiguously assigned to the influencing factors mentioned above. Therefore, for assessing the performance of the crane and comparing it in our study, usage of productivity values within the duration of one cycle was proposed.

A comparison of forestry cranes` main technical parameters and their construction schemes is carried out on basis of information from leading manufacturers. Furthermore, reference cycles were used to compare the productivity of the crane systems to the current state of the art. Based on these reference cycles, the level of productivity of forestry cranes. Results presented in this study broaden the options to design and test new approaches and technology to improve forestry cranes' performance.

Keywords: forestry crane, forest harvest operations, productivity, technical and kinematic parameters

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Thinning as a Tool to Increase Resistance to Stressors in the Interior of British Columbia

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ABSTRACT

Forests in the interior of British Columbia are being challenged with unprecedented disturbances, such as insect outbreaks and fires, that compromise the long-term stability of forest stands and resulted in a reduced potential of harvested wood. One tool to off-set the situation is Commercial Thinning (CT), a widely implemented sylvicultural treatment typically for mid-rotation even-aged conifer stands. CT operations will be implemented in pure conifer and mix conifer stands composed predominantly by lodgepole pine, douglas-fir and hybrid spruce stands at mid-rotation age across the Quesnel Timber Supply Area (TSA). This study aims to evaluate the productivity of CT operations, the impacts on stand quality and different ecosystem services and values, including biodiversity, habitat and carbon. On the second part we will study cutting-edge CT technologies and implement different methods of harvesting technology and harvesting layout and thinning type and compare the results and evaluate the implications again on productivity, stand quality and ecosystem services and values. A combination of data from the machine on-board-computers with LiDAR technologies and forest inventories to precisely measure the productivity of the operations and identify the main factors that influence productivity. The final result will be a cost-benefit analysis of CT operations to quantify and help inform how CT can be used as a tool to increase resistance to fires, drought, eruptive insects and windthrow while providing multiple values.

Current State of Forest Operations in Four Biogeographical Regions in Europe to Identify Key Driver for Future Development

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ABSTRACT

In Europe, a wide set of harvesting systems, with different degree of mechanization is known to perform forest operations. Its application is depending on site conditions, silviculture management systems, availability of machinery and working staff, expected and accepted environmental impacts, calculated costs and individual preferences. Individual impacts of different harvesting systems are well studied, however, a systematic overview across Europe is lacking.

Within ONEforest, a meta-analysis of publications, reports, secondary literature and expert interviews on currently applied harvesting systems was performed in four biogeographical regions in Europe: Mediterranean region, Alpine region, Continental region and Hemi-boreal region. Both, regional conditions and impacts of the harvesting systems were analyzed. Based on the findings, key driver, such as developments of climate change, forest owner structure and industrial digitalization, were identified to outlook on potential or necessary development of forest operations within the next decade.

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Characterizing Properties and Bucking Patterns of Eucalyptus Plantation for Optimizing Yield for Smallholders

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ABSTRACT

Eucalyptus plantations are a notable source of income for smallholders and private landowners in Thailand. Eucalyptus plantations provide wood for smallholders' own use as well as income from selling timber. Main uses of Eucalyptus are energy purpose, pulpwood, sawn timber and veneer. Among private Eucalyptus forest owners there is a certain need for decision support tools which can help in optimizing tree bucking according to the available properties of the site (tree diameter, height, spacing, stand volume) and bucking patterns. Precise characterization of plantation properties is key for delivering appropriate timber assortment to markets and optimizing timber value. Modern tree bucking is based on tree taper models which enable the volume and mass estimations of the stem. Aim of our study was to form and test dynamic programming models in optimizing tree bucking of Eucalyptus trees in Thailand. To achieve this, tree taper curves for volumetric models were also necessary for optimization. For implementation, we created a mobile application for android phones (EVO - Eucalyptus Valuechain Optimization) to utilize study results in grass root level. The study was divided into three different sections: A) tree tapers with linear modelling for five DBH diameter classes, B) dynamic modelling for Eucalyptus tree bucking, and C) verification of the modelling results. The dynamic modelling for bucking consisted of target function, which was divided into sub-parts that were optimised according to the set of limitations. The goal of stem level bucking optimization was to assign each tree to be cut a bucking pattern which yields the highest total stem value. This required two components: 1) the stem profile and 2) each possible length-diameter combination of logs with a value reflecting its profitability on the market. The stem diameters and volume were calculated using taper models as a function of the breast height diameter and the height of the tree. For each stem the dynamic programming generated several cutting alternatives of which the highest total-valued bucking pattern was selected. In the verification part, four cases were formed and tested with real-life data collected from Thailand forestry. Our results indicate that both the tree spacing and increment of DBH are significant factors when estimating the profitability. The spacing is controlled at the planting phase and there must be a balance between the density and growth rates because the increased density was decreasing the growth of individual trees at some point of rotation time.

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Terra-mechanical and Statistical Analyses of Four-Wheel Grapple Skidder Performance Data

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ABSTRACT

Studies of skidder productivity typically involve a range of conditions that support specific study objectives related to harvest system, terrain, forest attribute or other aspects of the harvest. Skidder production models often fit the data well because cycle time and productivity are strongly related to load size and skid distance. Changes in skidder design over time have increased load capacity, potential machine speed, and operator comfort. Since the harvest system often limits the observed range in speed and load size, the tradeoffs between those factors have not been a primary focus of production studies. An analysis of 33 studies with 77 estimates of skidder productivity was performed using a typical regression approach and an approach based on the Wismer and Luth terra-mechanical relationships. The regression approach resulted in a good fit of productivity but poorer fits of cycle and element times. Non-linear models developed with the terra-mechanical approach also fit, but had larger values for MSE than the linear regressions. The use of 14 additional studies with 33 estimates as validation data produced a lower MSPE for non-linear TM model when compared to the linear regression models. The TM approach allowed for the tradeoff between speed and load size to be modeled explicitly. We developed a spreadsheet production model to demonstrate the effect of choices made by harvest planners, logging managers, and operators on specific production goals.

Ergonomics and Worker Safety

A Neuromechanical-based Assessment of Manual Pitting Tools during Site Preparation in Forest Operations

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How to Look at Accidents – Accident Causation Models

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ABSTRACT

Accident prevention is an essential safety management concept. There is a generally accepted hypothesis that how we frame accident occurrences is fundamental for analyzing and understanding events and identifying interventions. Our reasoning depends on how we represent a real-world subject matter in our thoughts, which is always a simplification of reality. Accident causation models are conceptual models that frame the way people think about safety, analyze incidents and accidents, and define interventions. While accident causation models have been used in several economic sectors, a systematic introduction and application into the forest sector did not happen yet. The purpose of the presentation is to review accident causation models from a forestry perspective and explore safety management benefits.

The presentation looks at four classes of accident causation models. First, it discusses the "weakest link" model that originated both accident and reliability analysis. Second, it explores sequential chain models, which emerged at the end of World War II, and introduced a probabilistic view on sequential activities, which is useful to identify accident prevention tactics or motor manual forest harvesting work. Third, it looks at human reliability, which proved essential in analyzing large-scale technical systems. Fourth, it discusses systemic accident causation models, which assume that safety is an emergent property resulting from system components' interaction. This view rejects "root cause" or "event chain." Systemic models represent the state-of-the-art and are helpful for the analysis and interaction of system components, in particular (1) human faultiness, (2) work object, (3) context, (4) safety barriers, (5) organization, and (6) the institutional framework. Systematic use of accident causation models can potentially increase safety in the forest sector, which still has very high accident rates.

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Smart Sensors to Detect People in Danger Zones of Forest Operations

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ABSTRACT

Mechanization of forest operations brought a considerable improvement of occupational safety, mainly due to the relocation of manual tasks into closed and protected machine cabins. Forestry is still one of the most dangerous fields of work as mechanization processes cannot always be implemented, for example due to terrain restrictions. Identifying and managing danger zones play an important role for working safely. They are often misjudged or not fully visible and that can lead to dangerous situations and accidents. Danger zones can be from the machine itself (including detaching parts) as well as falling trees or branches. Various technologies exist in the modern digital workplace to detect people in these danger zones and are already in use in industries such as agriculture, construction or mining. In forestry they have been rarely used, often relating to challenging conditions such as difficult terrain, large danger zones (e.g. 90m for the chain shot), possible limitation of reception or uninvolved third parties inside the danger zones. The objective of this paper is to evaluate two sensor technologies, Ultra-Wide Band (UWB) and Bluetooth Low Energy (BLE), for detecting people in the danger zone. Both technologies should make it possible to not only identify people involved in the work, but also uninvolved third parties. Third party people can

include forest visitors that may be identified via transponders, but also using sensors already built into their smartphones.

The proposed study layout is established to approximate operational conditions and carried out at two locations. The first is situated in hilly terrain that often makes it impossible to oversee the entire danger zone (no continuous line of sight). The second is located in steep terrain, where monitoring the danger zone is also particularly difficult. Test-distances are set at 30, 50, 70, and 90m, with a simulated concentric danger zone around a center point. Randomized approaches into the simulated danger zones from different directions are to be made and repeated with different sensors (both UWB and BLE; with transponders as well as sensors built into cell phones) and the detection rate is to be determined. We expect the study to provide information on which of the two technologies (UWB or BLE) is more reliable, has a higher detection rate and is therefore better suited for the use in forestry. Furthermore, it should be determined to which extent sensors already integrated in smartphones are suitable for detection.

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On the Application of Machine Learning Models for Prediction and Explainable, Actionable Insights Supporting Forest Workers Safety

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ABSTRACT

Machine Learning (ML) and Artificial Intelligence (AI) can be used for the prediction of accidents and their effects w.r.t. costs in human life, recovery working hours and resources, and have already been tentatively applied in this area of research. In this work, a dataset containing detailed information about accidents happening in various forest operations from 2005 to 2021, was used to make accurate classification predictions for the fatalities of such accidents. We furthermore achieve promising results when applying regression to evaluate influencing factors of the recovery of working hours lost due to those accidents. After the data cleaning, preprocessing and appropriate encoding stage, ML models such as decision trees, random forests and feed-forward neural networks were used to accomplish the tasks and uncover relevant input factors in sorted order. This is one of the first research works in this domain. With further research and more data, interaction with experts through sophisticated User Interfaces (UI) and state-of-the-art AI models with Explainable AI (xAI) methods can lead to the discovery of causal relationships within these events and lead to actionable insights, ensuring and enhancing safety in the forest and agriculture working environment.

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Vibration and Noise Exposure during Pre-Commercial Thinning Operations: What Are the Ergonomic Benefits of the Latest Generation Professional-Grade Battery-Powered Chainsaws?

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ABSTRACT

Creating safer working conditions and reducing the strain for employees should always be one of the main driving forces for the development of new work tools. With regard to professional forest works, the intensive application of chainsaws is, despite all technological progress, still a health risk for their operators. This study takes a closer look at the improvements made in this respect by the - at the time of the study - latest generation of battery powered chainsaws. Therefore, the vibration and noise exposure caused by the STIHL's battery powered MSA 220 C and the combustion driven MS 201 C were compared during a pre-commercial thinning operation, which was performed by a professional operator in a twenty-year-old hardwood stand. The vibration levels, measured at the front and rear handle with a tri-axial accelerometer, were assigned to five different work elements using a video documentation. The noise levels were assessed in one-minute intervals with a dosemeter.

The measured daily vibration exposure of 2.42 m/s^2 caused by the MSA 220 C means a notable reduction of more than 45% compared to the MS 201 C which caused a daily vibration exposure in the neighbourhood of the daily exposure limit value set by the EU directives for health and safety requirements. Still, the exposure created by the MSA 220 C should not be neglected as it is very close to the daily exposure action value set by the same directives. Using the MSA 220 C leads to a daily noise exposure of 89.2dB(A) compared to 95.8dB(A) when using the MS 201 C, which equals a reduction of the noise dose by 78.4%. But the exposure caused by the MSA 220 C still exceeds the upper exposure action value set by the EU directives for health and safety requirements, making the use of hearing protectors mandatory for both chainsaws. Consequently, battery powered chainsaws are a huge improvement over their combustion driven counterparts when regarding vibration and noise exposure as well as exhaust fumes. Therefore, they should be preferred whenever possible to improve the working conditions and reduce health risks. But the health risks battery powered chainsaws still possess should not be underestimated.

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Comparison of Work Safety Issues in Southeast Asia Countries: Reflection from FSC Certification Audits Findings

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ABSTRACT

Southeast Asia is the world's third largest area of tropical rainforest, forests cover greater than 200 million hectares, containing some of the most valuable resources and habitats on earth. As well as an important source for timber production and rural employment for the region. Over the last 25 years, the global area of certified forests has grown rapidly and voluntary forest certification has become recognized as an effective tool to engage international markets in improving sustainability within forest management units. FSC has been active in Southeast Asia since the early 2000s. However, the uptake of forest certification in Southeast Asia has remained low compared to other regions in the world.

The purpose of this study was to compare the current work safety issues of forest management in Southeast Asia countries. Six case study countries: Cambodia, Indonesia, Lao PDR, Malaysia, Thailand and Vietnam were included in this study. The secondary information regarding the health and safety related non-conformities (NCs) were collected from auditing reports prepared by a certification Body (CB) between 2016 and 2021. Materials were taken from FSC certificate public dashboard (https://fsc.org/en/fsc-public-certificate-search). All NCs related to Principle 4 (Community relations and worker's rights) were selected, described, grade (i.e., major, minor, observation), and information sources (i.e., document review, field visit, or stakeholder's interview) were matched against the FSC standard. Furthermore, the NCs description was grouped according to risk factors i.e., personal factors, equipment-related factors, job-related factors, environmental factors, and organizational factors. The study reveals noticeable characteristics between the countries. In terms of number of certificate holders, Vietnam has the greatest number of certified forests, followed by Indonesia, and Thailand, respectively. However, considering the total certified area, Indonesia had the largest area which was greater than 85 percent of overall study area. Moreover, the study discloses that the most important risk factors are organizational factors, followed by equipment-related factors and personal factors, respectively. Majority of organization factors that mostly failed were incorrect working systems, inadequate control, and difficulties in supplying PPE. Where, key failure of equipment-related factors was not using PPE. Besides, Personal factors were mainly caused by insufficient knowledge on the job. Eighty percent of overall certified forests were issued NCs related to Principle 4. Greater than 60 percent of findings were based on document review and site inspection.

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Review of Rope End Connectors Available for Forest Applications

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ABSTRACT

According to the STANDARD EN 14492-1, only simple aluminum ferrules and/or "Flemish Eye" with aluminum ferrules according to EN 13411-3 are permitted as rope end connectors for winching ropes in forestry applications. In general, four variants of rope end connections are permitted for winches, whereby in addition to the two variants listed above, asymmetrical rope locks according to EN 13411-6 and symmetrical rope locks according to EN 13411-7 as well as metal and synthetic resin casting according to EN 13411-4 are permissible.

As the end connectors with aluminum ferrules currently approved in forest applications are not satisfactory, a series of rope tests with different end connectors was started in this project. The aim of this project is to create a solid basis for revising the relevant standards and to enable safe work. In this presentation the results of the investigations are shown and discussed.

Keywords: end connector, rope end connection, anchoring, winches, traction aid winches, steel rope, synthetic rope, wire rope, fibre rope, cable

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Frictional Performance of Forestry Ropes Bent Over Tree Stems

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ABSTRACT

When anchoring ropes in various forestry applications, the forces that occur are transferred to tree anchors through rope friction. As a rule, to reduce the force of the outgoing rope, the anchor and guy ropes are looped around the anchor tree several times. Since the holding force per wrap is mainly determined by the friction between the rope and the wood, knowing the coefficient is essential for a secure anchorage. The analysis of rope friction thus guarantees an improvement in occupational safety in the forest.

To determine the specific coefficients of static and sliding friction of current steel ropes and synthetic fiber ropes on anchor trees, direct tests were planned with common forestry ropes in combination with frozen and non-frozen wood and wood from different seasons. Since old tree stumps (dry wood) are also used as anchors, tests with wood at different degrees of drying should also be included in the series of tests.

Based on a series of preliminary tests, a test construction was developed with which the planned tests can now be carried out with wood from different seasons. The results of the preliminary tests and the subsequent tests in the summer season are discussed in that presentation.

Keywords: rope friction, anchoring, yarders, traction aid winches, anchor trees, steel ropes, synthetic fiber ropes

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A Neuromechanical-based Assessment of Manual Pitting Tools during Site Preparation in Forest Operations

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ABSTRACT

Despite the physical workload and ergonomics concerns raised, manual pitting operations are still predominant in silvicultural operations. Even though there are modernized pitting tools, these are not always feasible or appropriate under certain operational or economic conditions. The pickaxe and mattock are some of the most popular agricultural and forestry pitting tools used to date due to their low cost and acceptable effectiveness, especially for smaller-and medium-sized timber growers. Other tools have been introduced and explored such as manual and motor-manual augers, the inverted A-auger and even hoes in suitable conditions. Manual tools are still often favored in especially developing countries due to the availability of labor in rural areas and financial feasibility of doing so. It is therefore important to investigate and understand the ergonomic risks possibly related to the use of some of these tools. The study aims to investigate and compare the use of the most used manual tools (pickaxe and mattock) in South African forestry pitting operations.

A pilot study was conducted using wireless wearable sensors and an integrated neuromechanics software platform to collect kinematic and electrophysiological data from a healthy 21-year-old male. An even terrain was used to pit three 20 cm x 20 cm pits consecutively with each tool, alternating only after the three were completed.

The results showed higher activation levels on the right side (operator's dominant side) of all the muscles, with less difference between the left and right sides of the lower back (40.2 %) and glutes (30.8%) for both the mattock and pickaxe. The highest difference was in the lats (70.1 %), and upper traps (69 %). The identified possible ergonomics risks include high exertion force on the middle and lower trapezius on mostly the dominant side; awkward static and dynamic working postures (forward bending during) repetitiveness of unilateral motions and exertion of mostly on one side, and low recovery periods due to pits being 1-2 m apart, therefore operator moves from one pit to the next fast. The study recommends investigation of alternative methods using different tools that allow for bilateral muscular activity, dynamic postures to reduce ergonomic risks that could impact the sustainability of labor force and decrease absenteeism due to lower back pain. A full study will investigate a larger sample and other manual tools to compare which tool will reduce ergonomic risks and potentially be used interchangeably in manual pitting operations.

Steep Slope Logging

An Integrated Approach for Production Performance Analyses of Winch-assist Harvesting in Western Canada

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Winch Assist Wheeled Grapple Skidder Operations in a Steep Terrain: Productivity of Two New Zealand Case Studies

Rien Visser, Raffaele Spinelli, Mathew Pedofsky

Analysis of Grapple Yarding Operations Using On-board Computer Systems in British Columbia

Mathea Euler-Rolle, Omar Mologni, Steffen Lahrsen, Dominik Röser, Karl Stampfer, Christoph Gollob

A Comparative View on Cable Yarding Performance

Stephan Böhm, Christian Kanzian

Fuel Consumption and Time Use in Alpine Cable Yarder Operations

Raffaele Spinelli, Natascia Magagnotti, Giulio Cosola, Benjamin Engler, Stefan Leitner, Renato Vidoni

A Multiple Sensor Based Approach to Assess the Tensile Forces Distribution and Stability of a Spar Tree

Luca Marchi, Francesco Zanotto, Omar Mologni, Stefano Grigolato

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An Integrated Approach for Production Performance Analyses of Winch-assist Harvesting in Western Canada

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ABSTRACT

Winch-assist harvesting systems have become a common solution for steep slope logging operations. This is particularly true in Western Canada, where several machines manufactured in New Zealand, North America, and Europe have been used for the last decade. While a significant research effort has been made to support technology uptake, system implementation and operability, and best practices development, there is still a limited understanding of the production performances of these systems in their various configurations and applications.

Some of the main issues for production analyses on winch-assist harvesting in conditions typical for Western Canada are the monitoring of whole-tree harvesting operations (lacking the benefits of direct tree volume data at the stump provided by cut-to-length mechanized harvesting) and the need for simultaneous and integrated monitoring of coupled machines. The latter especially applies to the anchor machine winch systems (dynamic systems) that dominate the local market.

This study proposes an integrated approach for automatic production performance analyses of whole-tree winch assist harvesting based on anchor machine winch systems. The approach focuses on the instrumentation of the primary and anchor machines with dedicated on-board computer systems (FPDat II), the integration with Lidar-based or conventional forest inventories, and the development of dedicated criteria and algorithms for data processing and calculation of production metrics, including tethering time, productivity, and utilization rates. These production metrics are calculated for each harvest unit compartment, daily work log, shift, and block. The results will show the approach and criteria used, the application and platform for large-scale, long-term monitoring and benchmarking, as well as a few example applications and field validations from harvest sites located in Western Canada.

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Winch Assist Wheeled Grapple Skidder Operations in a Steep Terrain: Productivity of Two New Zealand Case Studies

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ABSTRACT

Winch-assist systems are commonly used to expand ground-based operations onto steeper terrain. In New Zealand, the new systems are able to complete harvesting operations previously only possible with cable yarders. An investigation was carried out in two locations with the following objectives: 1) to evaluate the benefits of a winch-assisted skidder operation on slopes that challenge conventional skidding; 2) to determine the productivity of this system and 3) to carry out a soil disturbance assessment. The first site was in Emerald Forest, about 30km south-west of Gisborne. There a Falcon winch assist machine and a six-wheeled Tigercat 635G skidder where studied, collecting data for 120 cycles. The second site was in Castle Downs Forest, about 90km north of Invercargill. There, the study covered 121 cycles of a Tigercat 632E skidder coupled to a TimberMax winch assist unit. In Emerald forest, the skidder paths followed the same main trail from the landing for 150m before diverging down different sides of the ridge. Skidder Path 1 had a maximum slope of 33 degrees (65%) and was 300m long. Skidder Path 2 had a maximum slope of 30 degrees (58%) and was 315m long. In Castle Downs Forest, two paths were identified and on the lower slope at 16 deg (29%) and the productivity study was completed with and without winch-assist. In Emerald Forest, the delay free skidder productivity over the study period was found to be 65.4 m3/PMH. In Castle Downs Forest, productivity reached 95 m3/PMH at 100m, dropping to 40 m3/PMH at 300m. The slower skidder speed when using the winch was offset by higher average payloads and eventually resulted in an 8% productivity gain under the winch-assist treatment. Soil disturbance assessment was carried out using the line transect method. In Emerald Forest, ‘deep disturbance’ (reaching deeper than 15cm) was found on 13% of the inspection points and ‘shallow disturbance’ on 24%. Some of the deep disturbance was eventually attributed to the tracked felling and bunching machine. In the Castle Downs Forest considerable effort was made to reduce the level of soil disturbance, and ‘no disturbance’, or slight ‘mixing of top soil’ were found on 50% of the inspection points, while a further 40% was covered in slash. The level of deep disturbance was low (less than 2%) and mainly restricted to the primary extraction trails that could be rehabilitated post-harvest by pulling slash back over.

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Analysis of Grapple Yarding Operations Using On-board Computer Systems in British Columbia

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ABSTRACT

Cable yarding is a key extraction system in mountainous areas, where forest stands are on slopes that does not facilitate ground-based operations. The most common cable yarding system in the coastal mountains of British Columbia is grapple yarding with swing yarders working in a running skyline configuration. These cable systems have been used for decades in the province, but evidence of their production performances is very limited, particularly in the transition of the timber harvesting land base towards more second-growth stands.

To enhance the monitoring and visibility of the fiber supply chain, the forest industry is moving to digitalized solutions. While technological solutions for machine tracking and productive time analysis (e.g., FPDat) are extensively used on several harvest systems and applications, they are very limited for cable systems, particularly for grapple yarders in running-skyline configurations. To overcome this limitation, this study tested the use of the FPDat II on-board computer systems integrated with remote sensing based enhanced forest inventories for productivity and utilization analysis of grapple yarding operations. The validation of productive time, as well as the related area and volume allocation for productivity analysis, was based on direct field observations and data collection, including video recording for detailed timing and daily drone flights for observation of area covered. Delivered volume, harvest plans, and satellite images were also used for reconciliation of inventory data across the harvested area.

The results will contribute to the uptake of state-of-the-art automated data collection in cable yarding operations, highlight the potential and limitation of on-board computer systems for production performance analyses of cable yarding operations and will provide evidence of productivity of typical second-growth grapple yarding operations in British Columbia.

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A Comparative View on Cable Yarding Performance

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ABSTRACT

Cable yarding is a well-established practice for wood extraction in mountainous regions in most parts of the world. Wood extraction by cable is primally relevant in steep terrain, where fully mechanized harvesting systems like harvester-forwarder combinations cannot operate. Recently also in flat terrain the interest in indulgent silvicultural treatment that is gentle on the soil is growing and consequently promoting the usage of cable yarders. Since yarding operations are resource-intensive, the performance of the employed systems is of great interest for decision makers. Work- and time-studies are a comprehensive domain in the scientific field of forest engineering to create productivity models for cost estimation, simulation, system development as well as other decision support systems or simply to compare different harvesting systems.

The present work investigates 57 work studies on cable yarding operations, published in the scientific literature, in regards of assessment-methods to establish a knowledge base on cable yarding performance models. As a first step, a comprehensive literature-research was performed to identify relevant studies. Information about the investigated extraction-campaigns in matters of site-specifics, stock-specifics, the employed equipment alongside the work-study-methods as well as the statistical approaches for model creation are collected. In a next step, the gained data and the associated models were systematically analyzed to compare different yarding systems in regards of their performance. A set of 65 models was selected for this purpose. Productivity of the investigated systems ranges from 1.53 m³;/PSH to 32.0 m³/PSH and has a mean value of 8.47 m³/PSH. The delay free cycle time ranges from 3.27 minutes to 20.99 minutes and has a mean value of 7.16 minutes.

A meta-analysis was performed with the data, that is presented in the found literature, to test several hypotheses concerning the influence of different parameters on the performance of yarding-systems. Various relationships are so strong, that regression analysis with the meta-dataset, which is mostly containing presented mean-values, results in significant correlations.

The delay free cycle time is affected by the yarding distance and by the terrain slope. The productivity is significantly higher for uphill yarding (8.81 m³/PSH) than it is for downhill yarding (6.17m³/PSH). There was not found a significant effect of the extraction method (cut-to-length, tree-length, full tree) on the productivity.

The diversity in problem formulation and the corresponding diversity in methodical approaches accounts for limitations in comparability of performance. The consultation of guiding literature on forest work studies can promote comparability between studies.

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Fuel Consumption and Time Use in Alpine Cable Yarder Operations

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ABSTRACT

Due to their peculiar work mechanics and conditions, cable yarders have a very large potential for energy recovery, and it is clear that new models will be increasingly fuel-efficient. However, best results are obtained if the yarding operation is optimized as a whole - not just in its yarder component. A first step in that direction consists of determining reference fuel use figures for the different components of a yarding operation. To that end, the Authors monitored 5 yarder operators in the Italian Alps, collecting detailed fuel and time use data for 12 operations - each corresponding to one individual sale. Overall, the dataset represented 12 operations that covered 40 ha and produced 6090 m³ of timber. That task required 8500 worker hours and 28900 l of diesel fuel. 33 cable lines were set up, with a mean span of 370 m (tower tip to end mast). The data included all time and fuel consumption required for turning trees in the forest into logs stacked at a roadside yard. Fuel and time were accurately allocated to the following tasks: relocation; set up and dismantle; production; crew commute; major delay events. Concerning production, fuel use was further divided between: felling; extraction; processing and/or loading; two-staging (when performed). To our knowledge, this is so far the only scientific study offering real-life data about the fuel consumption and time use of European yarding operations. Moreover, our data represent typical small scale operations conducted by private companies, which are prevalent in the Alps. The study offers a detailed breakdown of fuel and time use, as well as reference figures for fuel consumption per m³- by task.

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A Multiple Sensor Based Approach to Assess the Tensile Forces Distribution and Stability of a Spar Tree

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ABSTRACT

In recent years, a growing interest by the scientific community in the assessment of the actual tensile forces excerpted in cable supported forest operations can been observed. Analyzing the magnitude of the loads withstood by the ropes has multiple goals: to determine the level of safety of the ropes with respect to their potential mechanical failure, to compare the real field-data with available theoretical predictive methods commonly used by practitioners, to provide the basis for more refined analytical models. Moreover, thanks to the rapid progress in the technology employed from the sensors and load cells manufacturers, quality and details of the measurements has been greatly enhanced. Consequently, recent works started to employ multiple load cells to simultaneously monitor tensile forces at different points of the same cable. Alternatively, multiple sensors were also used to take real-time measurements of a main line and the guylines of a cable yarder.

In this context, the present work focused on the analysis of the forces applied to a standing tree used as intermediate spar in cable yarding operations by exploiting multiple load cells simultaneously recording data from all the ropes attached to the tree. In detail, one load cell was secured to the strap supporting the jack, two load cells in the guylines opposed to the jack and one on the front guy. A motion sensor was attached to stem base to evaluate the tree movements. An additional clamped on load cell was mounted at the anchor of the skyline.

Six outhaul and inhaul cycles involving known payloads were simulated at two values of the skyline pretension (i.e., the tension observed with an unloaded carriage placed in proximity to the tower yarder). Ten more loads including the lateral skidding phase were also simulated. A GNSS sensor with RTK technology was employed to precisely define the position of the carriage. Results were compared with consolidated design rules available from best-practice guidelines and safety manuals. Results confirmed that there is an effect of the load distribution among the guylines according to the position of the carriage as well as the direction of skidding. Finally, the tested employed load cell technology could be easily used by the forest operators to control in real-time the safety level of all the ropes simultaneously.

Digitalization and Automation

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Michael Starke

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Towards Automated and Fossil Free Operations in Swedish Forestry

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ABSTRACT

The presentation will describe how Skogforsk together with the rest of Swedish forestry works with automation, part automation and remote-controlled logging- and silviculture operations. Examples from projects will be presented, i.e. Auto2 (Automation for terrain transport with forwarder), Autoplant (ongoing project to develop solutions for autonomous scarification and planting) and Remote Timber (remote controlled loader at periphery logyards). Skogforsk's technical laboratories, especially the remote lab will be given attention. Early attempts to reduce CO2 emissions aiming at fossil free forest operations will also be discussed, i.e. electric log trucks with gross vehicle weight above 64 tones.

Constant development of productivity with less environmental impact, that also contributes to improved performance and higher quality, is vital to the sector's competitiveness and operational systems undergo constant change, most recently because of digitalization and automation. Today, increased automation/part-automation and remote control in logging and other forestry work are the most promising development areas. In this context Skogforsk's technical laboratories are strategically important development environments. Currently, scarification and planting are mainly carried out with a two-stage operation where planting is using manual methods. Problems of recruiting seasonal personnel, rising costs, and a certain lack of quality in parts of the work processes are driving greater mechanization and automation of the scarification and planting operation.

The forestry sector is a significant transporter of goods in Sweden and to attain the goal of 70 percent fossil-free goods transport by 2030, alternatives to diesel must be studied. Electrification of log trucks with a gross vehicle weight exceeding 64 tons are under development gives hope of possibilities to a gamechanger to reduce fuel consumption and CO2 emissions in roundwood transportation.

To sort out the most promising solutions in a vast flora of opportunities for automation, part automation and fossil free operations advanced system analyses will be used, using both simulation and optimization based on machine studies and large datasets of historical logging operations pared with supply and demand in the industry.

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Traversability Analysis Using High-resolution Laser-scans, Simulation, and Deep Learning

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ABSTRACT

Traversability is of major importance in forestry, where heavy vehicles, weighing up to 40 tons when fully loaded, traverse rough and sometimes soft terrain. Forest remote sensing is becoming available at resolutions where surface roughness and slope can be determined at length-scales smaller than the forest machines. Using 3D multibody dynamics simulation of a forest machine driving in virtual terrain replications, the interaction can be captured in great detail. The observed traversability is then automatically a function of the vehicle geometry, dynamics, and of the local terrain topography relative to heading. We express traversability with three complementary measures [1]: i) the ability to traverse the terrain at a target speed, ii) energy consumption, and iii) machine body acceleration. For high traversability, the latter two should be as small as possible while the first measure is at maximum. The simulations are, however, too slow for systematically probing the traversability over large areas. Instead, a deep neural network is trained to predict the traversability measures from the local heightmap and target speed. The training data comes from simulations of an articulated vehicle with wheeled bogie suspensions driving over procedurally generated terrains while observing the dynamics and local terrain topology. We evaluate the model on laser-scanned forest terrains, previously unseen by the model. The model predicts traversability with an accuracy of 90\% on terrains with 0.25 m resolution and it is 3000 times faster than the ground truth realtime simulation and trivially parallelizable, making it well suited for traversability analysis and optimal route planning over large areas. The trained model depends on the vehicle heading, target speed, and detailed features in the topography that a model based only on local slope and roughness cannot capture. We explore traversability statistics over large areas of laser-scanned terrains and discuss how the model can be used as a complement or in place of the currently used terrain classification scheme.

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Multi-log Grasping in Simulations Using Deep Learning

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ABSTRACT

In cut-to-length forestry, a harvester cuts trees into more or less ordered log piles of variable size, which are collected by a forwarder and transported to road sites for further transport by truck. The unstructured environment in the forest poses great challenges for automation, with the level of automation being lower in forestry than in other fields of robotics. In this work we explore automation in forwarding with a focus on multi-log grasping, which is of great importance for productivity and energy consumption compared to automated loading of a single log at the time. Depending on the weight of the logs and their position relative to the vehicle, the optimal number of logs to pick will vary, with the lift capacity of the crane being lower further away from the base. To pick as many logs as possible without exceeding the lifting power of the crane, depending on the positioning, is thus a challenge. Part of this challenge is to determine where on the log pile a probable advantageous gripping position is, and how to grip, given the physics of the forwarder and the logs, and some limited observations of the log states. Reinforcement learning (RL) has been used to control a forestry crane manipulator [1]. We consider if RL is also a feasible technique for the complex case of loading multiple logs on uneven terrain in an efficient and robust way. The collection of visual data in a forest environment is hampered by obstacles and external conditions. We explore if one can rely on interoceptive sensor data combined with sporadic RGB-D (colour and depth) images, instead of a continuous image stream.

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Autonomous Forwarding - Results from a Successful Field Demonstration

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ABSTRACT

Automation has been suggested to contribute to many benefits in forestry, as cost-reductions, increased safety and a way to managing labor shortage. However, pace of progress towards partly or fully autonomous forest machines has been slow. Reasons for this is mainly the challenging environment that need to be mastered, the complex and demanding tasks to be carried out, and also the comparably low budget due to the low volumes of forestry machines sold annually. However, there are recent advances that indicate that the pace might speed up.

In this presentation we provide insights and results from the demonstration of the world's first autonomous forwarding, conducted in the fall 2022 by the Artic Off-Road Robotics Lab (the AORO Lab). The task consisted of loading logs without knowing how many logs that would be present or where they would be located. The machine system consisted of a 10-tonnes heavy experimental cabinless forwarder, equipped with a stereo-camera based computer vision system, GNSS-navigation, and a sensorised but yet conventional forwarder crane. The vision system managed to locate and position logs with decimeter accuracy and the grapple was positioned at the desired location with centimeter precision. Altogether, this resulted in successful loading of logs, without any human intervention or guidance.

Even though both the task and the environment in the demonstration was simplified compared to what could be expected during conventional forwarding, the demonstration is considered an important proof-of-concept. Hence, it show that it is technically feasible to construct a large, hydraulic machine system that can manage the task of finding and loading logs all by itself. Naturally, there are many improvements required before reaching the levels of

autonomous functionality that will be of practical use. The planned and prioritized future developments are discussed.

Development and Validation of a Novel Smartphone-based Activity Recognition Model for Forest Equipment

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ABSTRACT

Activity recognition modelling using smartphone Inertial Measurement Units (IMUs) is an underutilized resource defining and assessing work efficiency of mechanized forest operations. In this study, a smartphone-based activity recognition system for tracked mastication equipment working in Ponderosa pine (Pinus ponderosa) plantations in North Idaho, USA was developed and validated. During treatments, data from integrated smartphone sensors were collected across three sampling frequencies (10, 20, and 50 hertz (Hz)) in addition to two downsampled data sets (10 and 20 Hz) derived from the 50 Hz data. Time domain features were calculated across 4 sliding window widths (1, 5, 7.5 and 10 seconds) and two levels of window overlap (50% and 90%) resulting in 40 unique modelling parameter combinations. Random forest machine learning algorithms were trained and evaluated each set of parameters to determine the best combination for accurate activity recognition. 5 work elements (masticate, clear, move, travel, and delay) were classified with the performance metrics for individual elements of the best model (50 Hz, 10 second window, 90% window overlap) falling within the following ranges: area under the curve (AUC) (95.0% - 99.9%); sensitivity (74.9% - 95.6%); specificity (90.8% - 99.9%); precision (81.1% - 98.3%); F1-score (81.9% - 96.9%); balanced accuracy (87.4% - 97.7%). Smartphone-based activity recognition effectively characterized individual work elements of mechanical fuel treatments. This study is the first example of a smartphone-based activity recognition model developed for ground-based forest equipment. The continued development and dissemination of smartphone-based activity recognition models may assist land managers and operators with ubiquitous, manufacturer-independent systems for continuous and automated time study and production analysis for mechanized forest operations.

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Automated Cycle Time Determination from Machine Sensor Data

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ABSTRACT

The demand for increased efficiency in timber harvesting has traditionally been met with an increase in the level of mechanisation and continuous technical improvement of machinery. Active and passive sensors enable improvements in timber harvesting efficiencies, fuel economy and work safety.

Today, these sensors provide the data required for vehicle operation, which are recorded by GPS - supportet data loggers. Manufacturers of highly or fully mechanised timber harvesting machines have used these technologies to improve the maintenance and control of their machines, optimise harvesting and measure fuel consumption to a limited extend as well as for evaluating time. However, the recording of machine sensor data, especially in a systematic form and in a central database or cloud solutions that can be accessed via suitable interfaces, is a very recent trend. The data is usually recorded over longer periods of time and with high resolution and therefore hold considerable potential for scientific investigations and a better understanding of the interaction between productivity and operational parameters. However, the analysis of long-term data requires a more efficient determination of cycle time. In this context, it is important to determine the reliability with which the cycles can be identified automatically.

For this reason, the time consumption at cycle level during a timber harvesting operation on a slope under typical conditions of the Austrian Alps was determined in three different ways. Firstly, a classical manual time study was carried out, secondly by an automated cycle duration determination based on machine sensor data and finally based

on video recordings by cameras mounted on the yarder. Video recordings are considered the most usefull way to verify data and therefore served as a reference. The cycle duration from the machine sensor data should be more reliable than the classical manual timing study. In blending different data from different data loggers of the same yarder, usable datasets could be provided to proof this hypothesis. Manufacturers in this scientific corporation mount the data sensor as standard, which gives a new perspective on datamining in a wide technical range and especially on using it for scientific research. Thus, this study can be considered as the first suitable basis for further analyses of machine sensor data, especially for large, long-term data sets.

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SuperNav – Sub-meter Positioning in the Forest under Difficult Conditions

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Abstract: The precise location of forestry machines is of fundamental importance for sustainable, soil-conserving and equally efficient and safe timber utilization. However, with global navigation satellite system (GNSS) receivers available to date, reliable positioning in the sub-meter range and in real time in forest stands is not possible, as the environment prevails adverse conditions. Considering multipath effects and signal attenuation caused by moving tree canopies, humidity and moisture in the foliage, oftentimes sloping terrain and low network reception, forest environments pose a great challenge to the accuracy and precision of satellite navigation systems. The development of a sub-meter navigation system and subsequent integration into a forestry vehicle are the main goals of the project ”Sub-meter positioning in forestry under difficult SatNav conditions”, SuperNav for short. The goal of the paper is to give an overview of the state-of-the-art technology for the forest environment and to present the approaches of the SuperNav project to reach the sub-meter position for forestry machines.

Keywords: GNSS, Forest, Alternative binary offset carrier (AltBOC), multi-receiver-multi-antenna design, machine steering

1. Introduction

The accurate positioning of vehicles and workers in the forest is a focal point of the forestry digitization processes. Digital harvest planning and positioning of forest machines with sub-meter accuracy and in real time is essential for sustainable, soil conserving, efficient and safe forest utilization. A forestry-oriented navigation system providing sub-meter accuracy can be applied to precisely plan and construct new skid trails, find and restore LOSt skid trails as well as mark individual trees and woodpiles. Additionally, transport routes can be optimized and monitored.
In recent years, providing accurate positioning and navigation in the forest was identified a seminal development in optimizing the wood supply chain by research and the industry. Hence, commercial global navigation satellite system (GNSS) receivers and real-time kinematic (RTK) base station rover systems have been released as an integrated technology also for forestry operations. However, due to adverse conditions prevailing in the forest, e.g. signal attenuation, diffraction and poor carrier-to-noise density ratio (C/N_0), these approaches do not deliver the required sub-meter accuracy in real time. The development of a sub-meter navigation system and subsequent integration into a forestry vehicle are the main goals of the project ”Sub-meter positioning in forestry under difficult SatNav conditions”, SuperNav for short.

Developing and field-testing a GNSS-based system effective in compensating the unfavorable conditions for satellite positioning prevailing in forests is the aim of this research project. As established, shadowing, diffraction and a poor C/N_0 ratio are the major disturbance factors for positioning technology in forests. By utilizing innovative GNSS antenna technology, optimized signal processing and complementary sensor fusion with inertial as well as odometry sensors, the introduction of continuous real-time positioning with high accuracy is expected. This would result in significant improvements for forest owners, forestry operations, forestry and wood processing companies in terms of occupational safety, reliability in complying with soil protection as an aspect of environmental precaution and meeting certification requirements, and economic efficiency. By using digitally available accurate positioning data in real time, forestry machines can, on the one hand, be reliably moved along existing skid roads during timber harvesting. On the other hand, sub-meter accurate positioning contributes significantly to the efficient, scheduled and precisely located generation of new skid roads. The physical movements of the forestry machines can be directly intersected with existing digital maps and thus be used in forestry planning and control. In addition, the precise recovery of previously recorded skid roads after a storm event is crucial to efficiently process storm-damaged timber and ensure soil protection. Being a focal point of reforestation, soil protection can be facilitated by reliably accurate positioning systems. Further soil compaction due to new or deviating skid roads could be prevented.

The remaining paper is structured in three sections. Section 2 gives an GNSS introduction and highlights the main disturbances which leads to a reduced position accuracy in the forest. Additionally, a state of the art analysis about current GNSS technologies and studies for the forest is provided. The Section 3 explains the different aspects of the SuperNav project, from the GNSS antenna to the GNSS receiver. Finally, Section 4 summarizes the project and gives an outlook.

2. Background

2.1 GNSS Introduction

GNSS uses satellite constellations enabling positioning, navigation and timing data by providing autonomous geo-spatial information with global coverage. GNSS is the general term accounting for different types of global satellite positioning systems, such as the United States' Global Positioning System (GPS) (NAVSTAR), Europe's Galileo, Russia's Global'naya Navigatsionaya Sputnikovaya Sistema (GLONASS) and China's BeiDou Navigation Satellite System (BDS), [Langley, 2017]. GPS was the first GNSS, launched in 1978 and globally available since 1994. Given a line-of-sight (LOS) between a terrestrial receiver and four or more satellites, GNSS enables reliable and precise location data anytime and anywhere on the globe irrespective of local weather, [Abdi, 2022]. Each satellite broadcasts unique radio signals on two or more frequencies between 1.2 and 1.6 GHz (the L-Band) modulated with pseudo-random noise (PRN) and a navigation message, [Langley, 2017]. The frequency range of the L-Band allows for sufficient positioning precision due to low attenuation in the atmosphere. The signal emission on at least two different frequencies compensates delays in the ionosphere, [Langley, 2017]. A modulation of the radio wave, the PRN, is applied to use the same frequency band with several signals with low interference code-division multiple access (CDMA) and to create a unique identification for each satellite. It also enables the measurement of signal transmission time, [Langley, 2017]. Among other information the navigation message entails the Ephemeris [NovAtel, 2015] needed for the position calculation of the satellite, and time parameter and clock correction [Langley, 2017]. Using this information, the receiver on the ground attributes the signals to the respective satellites and obtains its own geographic position by measuring the distance to the orbital positions of at least four satellites and triangulating this, [Abdi, 2022] or [NovAtel, 2015].

A receiver determines the position, velocity, and time (PVT) by processing the received satellite signals from one or more antennas connected with the receiver, [NovAtel, 2015] or [(ESA), 2011]. Depending on the application, shape, structure and functions of antennas and receivers vary. The most common applications of GNSS include transport on road, maritime routes and rail, aviation, search and rescue, agriculture, scientific purposes such as geodesy, environmental monitoring [Martins, 2014], and engineering [Paziewski and Crespi, 2020], autonomous driving [Joubert et al., 2020] and consumer applications including navigation and leisure activities [Paziewski, 2020] or [NovAtel, 2015]. A variety of position methods with corrections are available for high-precision applications. precise point positioning (PPP) and RTK are among the most established techniques of improving accuracy and precision of PVT, [Langley, 2017]. In contrast to RTK, PPP does not require a bidirectional communication link like an internet connection, [Kouba et al., 2017]. These methods rely on different approaches [Langley, 2017] and

can provide an accuracy at cm-level [Lkan et al., 2016], hence the combination of both may yield reliable and constant high-accuracy positioning. Modern GNSS receivers are often able to acquire signals from different satellite navigation systems, raising the number of received satellites and with that the availability of the position solution, [NovAtel, 2015]. Using as many satellites as possible as well as receiving a broad range of frequency bands speeds up in general the process of gaining high accuracy positions.

Although globally available and highly reliable, navigation satellite systems are susceptible to a variety of disturbances producing errors in accuracy and precision. Signal attenuation and shadowing caused by natural and man-made obstructions, such as tree canopies, topography or buildings, as well as ionospheric delays, radio interference and multipath effects are among signal degrading factors [MacGougan et al., 2001]. One of the most severe disturbing elements are multipath effects, induced by the reflection and diffraction of satellite signals. A signal reflected by the ground or an object or diffracted by a sharp edge arrives at the receiver via multiple paths, [Braasch, 2017] or [Suzuki et al., 2020]. This results in a distortion of the signal and can significantly deteriorate the performance of the positioning by up to 100 meters [Braasch, 2017]. The environment of the receiving antenna affects the magnitude of multipath effects, where rough surfaces cause diffuse reflection and planar surfaces are the most problematic [Braasch, 2017]. Using a choke-ring antenna [Suzuki et al., 2020] and specific antenna placement [Braasch, 2017] contribute to the mitigation of multipath effects. The combination of GNSS with inertial sensors for aircraft and vehicles via sensor fusion is already established for systems with high demands on accuracy and robustness. Current components of the research are the deepest possible integration of the sensor signals, since measurement errors can be described most precisely and thus modeled directly during the measurement recording.

2.2 State of the Art

GNSS receivers are often designed for use in environments where the GNSS antenna is mounted in an open sky-view for a good signal reception. Utilization in forest environments is not a prevailing application of GNSS technology. Considering multipath effects and signal attenuation caused by moving tree canopies, humidity and moisture in the foliage, oftentimes sloping terrain and low network reception, forest environments pose a great challenge to the accuracy and precision of satellite navigation systems.

Positioning in forest environments is an issue addressed by a variety of previous studies using static tests to examine the influence of several environmental factors such as seasons, forest types, dense and sparse vegetation, cLOSed and open sky conditions, [Lee et al., 2020] and [Mahato et al., 2020]. Aside from the selected environment, the results vary due to the deployed devices, length of observation and use of processing tools. The studies are able to substantiate reduced positioning accuracy and precision under forest canopies.

With an observation period of 15 minutes a mean accuracy of 0.95-3.48 m was achieved in the study of [Næsset and Gjevestad, 2008]. In this study the number of trees correlated significantly with the horizontal positioning accuracy. [Danskin et al., 2009] examined static positioning performance in different seasons and present better results during winter (leaf-off conditions and especially frost). Testing the accuracy of survey- and consumer-grade receivers in different forest types, [Andersen et al., 2009] confirm significantly smaller errors in open stands for survey-grade receivers. Consumer-grade receivers yield an accuracy of 3-7 m across all stands.

A few studies focus on dynamic positioning accuracy and precision under forest canopies. Here, the results vary depending on the deployed instruments, applied GNSS, use of corrections and environmental conditions. The research of [Abdi, 2022] investigated the accuracy and precision of a consumer-grade GPS receiver in road mapping during all four seasons in Iran. The best accuracy and precision (ca. 25 m) was achieved in spring, which could be attributed to the absence of leaves combined with atmospheric conditions typical for spring. The indications of accuracy during dynamic measurements correlate with the statement of [Yoshimura and Suzuki, 2019] that sub-meter accuracy has yet to be realized. [Kaartinen et al., 2015] simulated a moving harvester with an all-terrain vehicle (ATV) equipped with GNSS receivers and an inertial measurement unit (IMU). The ATV was driven along an 800 m forest road divided into plots which provided different forest parameters. GNSS measurements alone did not yield an accuracy in the sub-meter range, however, Differential GNSS (DGNSS) coupled with an IMU achieved 0.6-0.8 m. The implemented methods, however, involved post-processing of the data. Hence the stated accuracies were not achieved in real-time. The authors of this study emphasize the importance and future potential of accurate positioning data of wood harvesters, in particular real-time roundwood data collected during the felling process and thus developing wood procurement more efficiently.

Figure 1: Tree canopy in the black forest, Germany

Since the study of [Kaartinen et al., 2015] focused on the movement of a receiver through the forest, current research and product development should involve real forestry machinery, specifically harvesters. Considering various factors, such as the height of the receiver off the ground, near-field influences induced by steel, electronics and a moving crane arm with a felling head, and a harvester specific motion pattern, results on accuracy and precision are likely to vary from past research. In order to investigate and advance positioning technology, the conditions specific to forests and forestry operations need to be recognized.

3. Methods

Since the development and testing of an GNSS-based system that compensates for the unfavorable conditions prevailing in forests for satellite positioning is the aim of this research project, various aspects are investigated. The first aspect is the GNSS antenna itself. A better directional characteristic will improve the reception of the signals. The ability to receive a variety of GNSS system and frequencies also makes more signals available for further processing. The second aspect is the GNSS receiver. Using sensor fusion, e.g. with an IMU, or advanced frequencies, like the Galileo alternative binary offset carrier (AltBOC) signal raise the availability and precision of the PVT solution. Additionally, a multi-receiver-array setup is under investigation.

3.1 Forest Antenna

For GNSS signals, the forest does not provide an optimal environment. Signals are shadowed, attenuated or deflected by the trees or moisture in the trees. This leads to non-LOS (NLOS) reception, multipath (NLOS together with LOS reception) or a complete LOSs of signal tracking. Fraunhofer IIS will develop and produce a prototype antenna with a new directional characteristic to counteract the attenuation of high-frequency satellite signals. It will counteract the particularly high attenuation caused by the tree population in the elevation range 30° - 60°. The

basic idea is to shape the directional pattern in such a way that it is not ideally cardioid-shaped having the main beam direction towards the zenith, as in the case of a classic geodetic rover antenna, but flattened providing more sensitivity at 30° elevation throughout the GNSS frequency range, see Fig. 2.

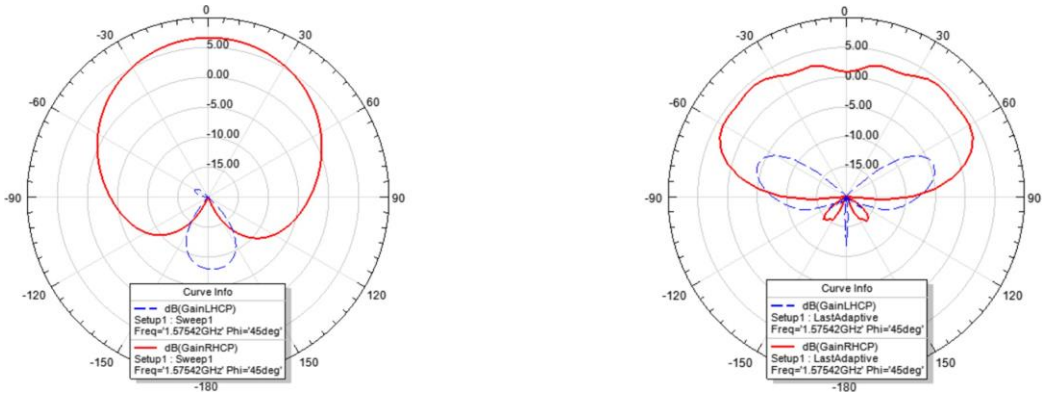


Figure 2: On the left side a typical directional characteristic of a GNSS antenna, on the right side a possible SuperNav antenna for the forest with less sensitivity in zenith but more at 60° (attention: in the antenna world zenith is 0° and horizon is 90°).

3.2 Multiple-Receiver-Array

Fraunhofer IIS wants to increase the availability of the carrier phase solution through a multi-antenna, multi-receiver approach and thus achieve an improvement in the position solution, [Overbeck, 2016]. For the investigations into the multi-antenna, multi-receiver approach, a geometric structure with several antenna-receiver combinations is set up, see Fig. 3.

For this setup, a multi-signal and multi-constellation GNSS receiver with an open software interface ”GOOSE”, developed by Fraunhofer IIS, is used [Garzia et al., 2016] [Overbeck et al., 2015]. The baseband board is equipped with a Xilinx 7-series field-programmable gate array (FPGA) supporting 60 hardware channels in real time including GPS, Galileo, GLONASS, and BeiDou, [Seybold, 2022]. Through its open interface, the software can be re-programmed and adapted for the multi-receiver- array.

The idea behind such the multi-receiver-array is that a certain satellite cannot be seen by one receiver, but can be seen by the other two receivers. Cooperative signal tracking can thus reduce signal dropouts due to shadowing. In addition, such a system can be supported by acceleration values and rotation rates.

3.3 Tight-Coupling

The combination of GNSS with inertial sensors (acceleration and angular rate sensors) for aircraft and vehicles via sensor fusion is already established in systems with high requirements for accuracy, availability and robustness, [Lashley and Bevly, 2013], [Pany et al., 2005]. Current components of the research are the deepest possible integration of the sensor signals, since measurement errors can be described and thus modeled most precisely directly during the measurement acquisition. The basis of the fusion is usually Bayesian estimation algorithms that use a motion model of the object for a prediction of the states (e.g. position and velocity) and the sensor data for a correction, [Groves, 2013]. A harvester in the forest performs very complex movements compared to most aircraft and vehicles, it has more freedom of movement and the forest floor is usually uneven. Therefore, the established motion models are to be extended in order to be able to better describe a harvester. Furthermore, the estimation algorithms are to be adapted to the improved GNSS positioning in the forest that is to be developed.

Orientation estimation by inertial sensors is only relative to take-off orientations and, due to the independence of the sensors from external influences, only stable for a short time. Therefore, orientation estimation with inertial sensors

should be supported by other sensor systems. Often the first choice for support is an electronic compass (magnetic field sensor). Since a harvester consists to a large extent of metals, which themselves cause magnetic fields, a compass in and on a harvester will be disturbed by these. Deep integration with GNSS signals helps to minimize sensor errors and thereby increase stability. In addition, sensors such as laser, radar and stereo cameras can also be used to determine relative movements based on fixed features (as reflectors) in the environment. Their use to support position and orientation estimation therefore makes sense. Furthermore, the harvester sensor system is being considered for use in the fusion process. For this purpose, vehicle information is to be made available to the positioning algorithm via a controller area network (CAN) interface.

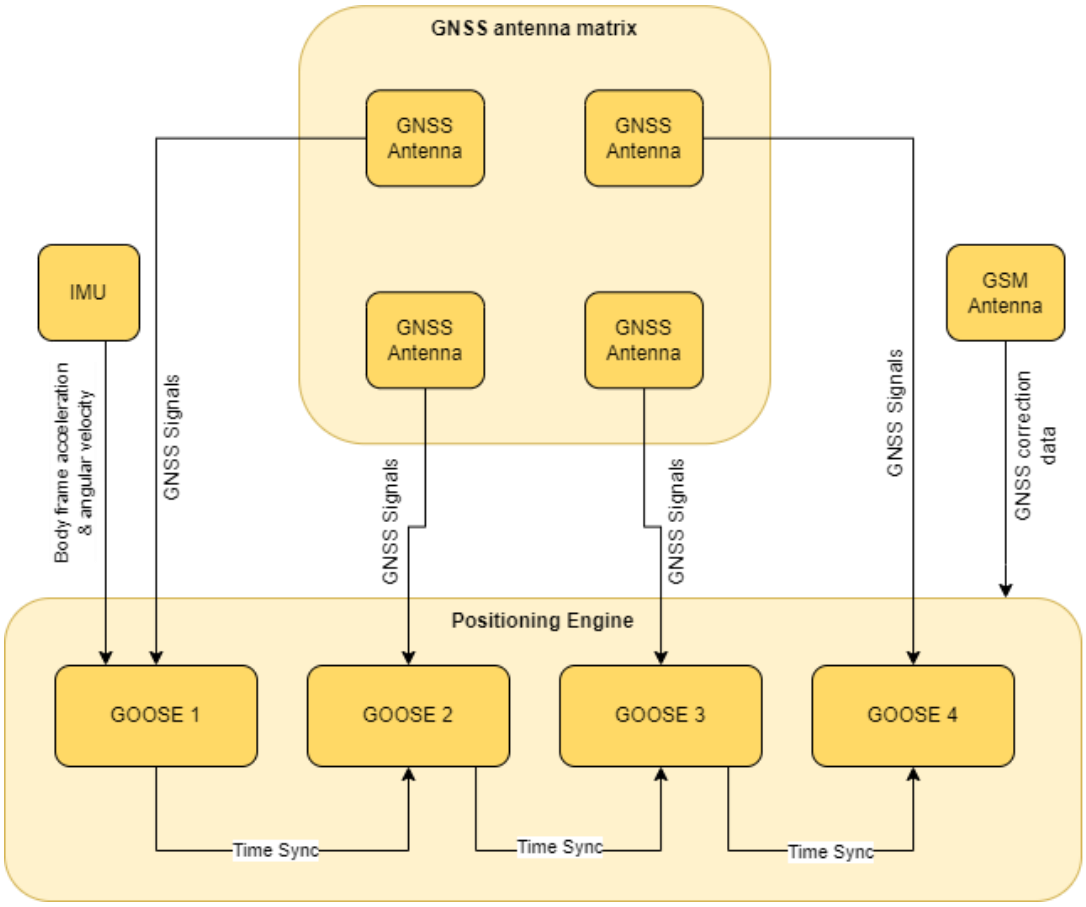


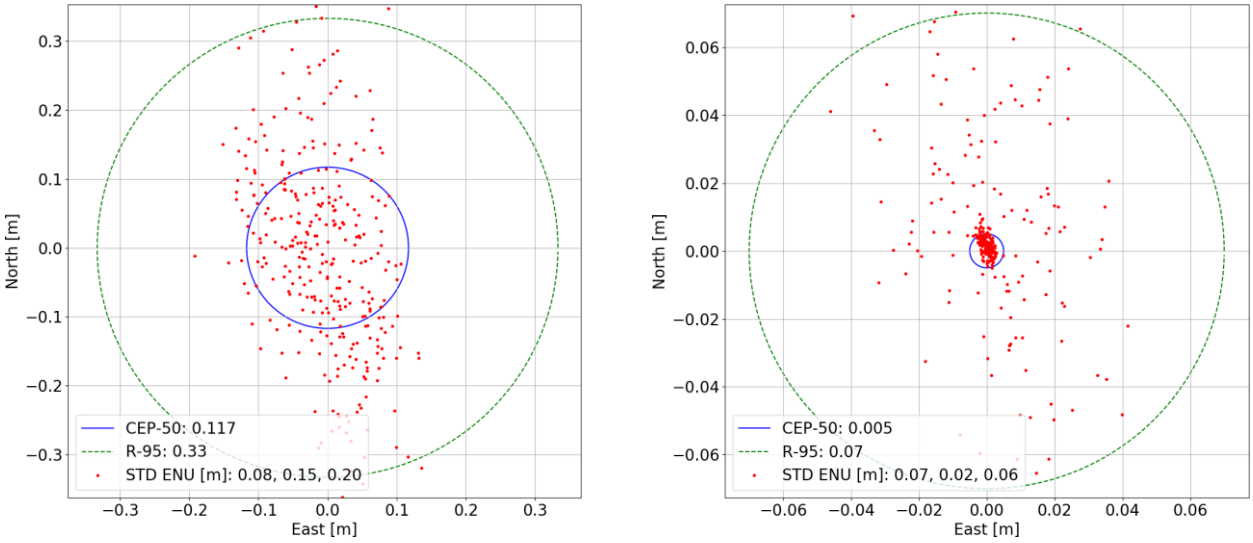
Figure 3: SuperNav system of four GNSS antennas and receivers

For the fusion algorithms, a motion model of the harvester is to be created based on the degrees of freedom due to the construction, the theoretical locomotion on uneven forest soil and based on measurement data. Based on the motion model of the harvester and the newly developed algorithms for a GNSS in the forest, algorithms for a cLOSe to deep coupling of GNSS with inertial sensors will be implemented. The cLOSe coupling fuses measured values from GNSS (the distances to the satellites) and IMU (accelerations and rotation rates) into a position solution. With deep coupling, the measured values from the IMU are fed into the satellite navigation receiver for signal tracking of the satellite signals. With the help of the accelerations and rotation rates, even shadowed and poorly receivable satellites can be tracked.

3.4 AltBOC

A general problem in the forest is that the signals are partially shadowed by trees and can therefore only be received with little signal power. For this reason, measures must be taken in the receiver to correlate the signal as best as possible. Especially the Galileo AltBOC signal [J.A Åvila Rodriguez, 2011] with the highest bandwidth of 54 MHz,

highest correlation gain and the associated robustness against multipath signals and high position accuracy already through the code phase in the decimeter range seems to be particularly suitable for the environment in the forest. Figure 4 shows the theoretical performance of Galileo E1b compared to Galileo E5 AltBOC with the circular error probable (CEP)-50 and a circle where 95% of the values would fall in (R95) in East-North position diagram. These measurements where done with a Spirent GSS9000 signal generator, connected to the GOOSE receiver. A static scenario without any atmospheric was setup and carried out twice to generate the position results for both signals independently. This allows the direct comparison as both solutions have the same constellation of the satellites, only the used signal for the PVT generation is different. 95% of all measurements with Galileo E5 AltBOC are located in a circle with radius of 7 cm compared to E1b with a radius of 33 cm. 50% of all measurements with Galileo E5 AltBOC are located in a circle with radius of 0.5 cm compared to E1b with a radius of 11.7 cm. This shows the superior performance of Galileo E5 AltBOC compared to E1b, as it has less noise on it. A similar improvement is expected with real signals, where multipath, NLOS, shadowing, and other signal degradation influence the reception.



(a) Galileo E1b (b) Galileo E5AltBOC

Figure 4: Position plots with respect to reference point at [49.48°, 11.13°]

4. Conclusions and Outlook

Digitization is the future of the forestry sector offering smart solutions for most forestry related processes, such as planning, harvesting, marking and transportation – from the single tree to the sawmill. Hence it requires targeted development of technologies tailored to the needs and challenges of the industry. Regarding the application of new technology in the forest, positioning and navigation are central aspects. Providing high accuracy and precision is of essence to improve the implementation of tasks in the forest and contribute to an efficient, smart and user-friendly forestry industry of the future. The devices used in this project, that is GNSS, IMU and odometry, provide complementary advantages, hence are able to compensate each other's positional divergence in the forest. The deep coupling of GNSS and IMU, involving Galileo's AltBOC-signal as well as developing specifically adapted antennas and algorithms is a promising approach to counteract the adverse conditions in forest environments.

Within this project 4 different approaches are evaluated, if they could substantially support the sub-meter position solution within the forest:

Forest antenna
Multiple-Receiver-Array
Sensor fusion using tight-coupling
Galileo E5-AltBOC signal processing

The results of different measurement campaigns using cable rail system and later integrated in a harvester will give advice, which approach is worth to be integrated in a later product and which one should be dropped. After the SuperNav-project the approach decision should be settled by more harvester tests. And in parallel to the product development of the positioning system the application software needs to be further developed to gain most possible advantage from the sub-meter position in the forest.

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Digital Fingerprint: Marker Free Tracking of Tree Logs from Harvest to the Sawmill

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ABSTRACT

This project aims to develop, test and validate a traceability system for timber which is practically applicable, provides a reliable proof of origin and is unforgeable due to marker free tracking. The fingerprint technology uses inherent wood microstructures that serve as uniquely recognizable patterns to identify individual log parts and enable tracking throughout the chain of custody. This is achieved by automated recording of the wood "fingerprint" during felling and when received at the sawmill with built-in camera systems, thus avoiding additional processing times. This joint project sees the deployment of a robust camera system on a harvester and at a sawmill, coupled with state-of-the-art computer vision approaches to supply optimum recognition rates under the harsh conditions of the wood process chain. Ultimately this novel tool will enable a clear assignment of log parts to the original tree and thereby provide a control mechanism for accurate accounting, incentivize increased wood mobilization particularly for the private sector, support certified sustainable timber origin and overall help to improve logistic.

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The Future of Harvest Mechanization and Automation Internationally

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ABSTRACT

Globally about four billion m3 of roundwood is annually harvested, and half of this is industrial timber production. In some countries, mechanization of industrial timber production has just started. In other countries, mechanization have more or less come and passed, leaving room for development efforts towards higher levels of automation and teleoperation. There are certain key factors that have shown to be related to the level of mechanization. Generally, a high Gross Domestic Product favor a high degree of mechanized harvesting, while high shares of steep terrain and publically owned forest land imply the opposite [1]. Furthermore, easy terrain conditions regarding slope, roughness, and bearing capacity as well as economic development can be argued to enable higher levels of automation [2]. Using official national data and earlier studies of e.g. slope [3], predictions can be made about the present situation, and, with some assumptions, also about the future of mechanization and automation in different parts of the world. Of course, there is no crystal ball for harvest operations or technical development, but, drawing from mentioned studies, some things can be quantified and support conclusions about what is the main line of development in a certain region. As an example, Nordic harvest operations are almost completely mechanized since at least 20 years, and while struggling with high (operator) costs, intense development of autonomous technology take place. At the same time, many countries in Eastern Europe experience a fast mechanization, to large extent employing cut-to-length harvesting equipment from the Nordic countries. This will inevitably lead to a future where mechanized harvesting in Eastern Europe stand technically ready for automation if the social and environmental factors allow it. An even earlier start of autonomous harvesting is likely in countries that have large-scale plantation forestry with easy terrain conditions and large machine fleets, suitable for semi-autonomous teleoperation.

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Simulation-to-reality Transfer to Control a Forwarder with Active Suspensions through Deep Reinforcement Learning

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ABSTRACT

Automating the loaded and unloaded driving of a forwarder has the potential to reduce operational costs by up to 10% in cut-to-length logging [1], but remains a challenging and unsolved task. The complex interaction between the vehicle and terrain requires the controller to perceive its surroundings and the state of the vehicle to plan for traversal. As a consequence, the state space is high dimensional and the system dynamics cannot be formulated in closed form or easily approximated. Under such conditions, where learning to act in the environment is easier than learning the system dynamics, model free reinforcement learning with deep neural networks as policy has seen recent success in robotics. We use deep reinforcement learning for control of a 16-tonne forwarder with actively articulated suspensions. To efficiently gather generalizable experience, the control policies were safely trained in simulation while varying several domain parameters. Each policy is trained during what corresponds to roughly one month of real-time. In simulation, the controller shows the ability to traverse rough terrains reconstructed from high-density laser scans and handles slopes up to 27 degrees. To compare the simulated to the real performance we transfer the control policies to the physical vehicle. Our results provide insight on how to improve policy transfer to heavy and expensive forest machines.

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Timber Loading Productivity of Remote Controlled Excavator-based Grapple Loader through Image of Monitor

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ABSTRACT

Forest operations like timber harvesting have already been mechanized to reduce hazards to the worker and increase productivity. However, timber harvesting operations have still been considered potentially dangerous and expensive on steep terrain. Teleoperation, to control the timber harvesting machine at a distance, has the potential to improve the safety, productivity and efficiency of harvesting operations on steep terrain. To verify the effects of teleoperation, an experimental prototype system of a monitor image-based teleoperation was constructed using a real forestry machine. In this study, the productivity of excavator based grapple loader, which is one of the most used mechanized harvesting equipment in the timber production, was analyzed using time-study method. Factors such as skill and age of operators, influencing loader productivity in timber loading operation were also evaluated by statistical analysis. Productivity analysis results showed that less experienced operators were more productive than experienced operators for teleoperation through image of monitors in the operator cabin. These results are shown to be unfamiliar to the monitor image and different loading operation pattern by operators. According to the results, the monitor image-based teleoperation system of forestry machine need to improve the resolution and installation position of camera. It was expected that additional studies will be needed for real-time remote control of forestry machine in the future.

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Concept and Implementation of a Deep Learning-Based Android App for Waterlogged Area Detection in a Modular Industry 4.0 Context

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ABSTRACT

Forest road maintenance and road condition surveillance can be implemented in different ways. With the creation of a deep learning-based algorithm to visually identify waterlogged areas, a further approach of road condition monitoring was introduced. To make this information source available for use, an implementation concept is presented, to collect, store, maintain and visualize the collected data. The detection algorithm was thereby implemented in a mobile application and connected with a remote data service to maintain and provide the data for further use. An additionally developed dashboard helps to visualize the collected information and provides the necessary tools to trace the information exchanges as well as to test application scenarios of use.

Keeping a structural digital twin of a forest road in mind, the information network of this concept is structured to be modular extended, to integrate further information sources or sensor values to generically build up the information network needed to support wholesome road maintenance or surveillance scenarios.

Wildfires and Forest Operations

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Spatially Optimal Fragmentation of Patches Susceptible to High-Severity Wildfire: Management Trade-Offs

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ABSTRACT

Increasing size and severity of wildfires have challenged forest resilience in the western United States in recent decades. High-severity wildfires have the potential to inhibit forest resilience by eliminating seed sources of desirable tree species over large areas and may consequently promote ecosystem type changes. Furthermore, footprints from high-severity fires may regenerate densely and eventually reburn, leading to footprint expansion through positive feedback over time.

Land managers planning at the landscape scale require tools to address patches predicted to experience high-severity, stand-terminating fire while simultaneously considering other management objectives including economic and operational feasibility. In this study, patches at risk of experiencing high-severity fire and subsequent regeneration failure are identified and fragmented with restoration treatments using a spatial heuristic. The effectiveness of patch fragmentation is assessed using reduction of core areas (areas not expected to receive seed rain from heavy-seeded tree species after fire) as a metric for success. Multiple criteria for designating patches are evaluated. Tradeoffs between patch fragmentation and other management objectives are examined by varying weights placed upon objectives. A case study on the Umatilla National Forest is presented using inventory data supplied by the United States Forest Service.

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A Mix of Active and Passive Restoration Improved Abundance, Richness and Drought-tolerance of Ground Vegetation After a Forest Fire in Germany

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ABSTRACT

The forest fire risk is increasing in Germany, particularly in dry areas with vast planted forests of conifers. The composition of ground vegetation after a stand-replacing fire is vital for success in forest restoration and amelioration of microclimate. Therefore, we aimed to compare ground vegetation composition and key functional traits between different forest restoration interventions after a fire, combining active and passive restoration approaches. In the summer of 2021, three years after the extensive fire of a pine plantation in 2018 in Treuenbrietzen, Brandenburg (Germany), a vegetation inventory was conducted. Two hundred ten randomly selected plots were located along a gradient from passive (no intervention) to active restoration (full salvaging, intensive site preparation, and planting), resulting into seven treatments. The composition and cover of the ground vegetation was recorded. In addition, the similarity between treatments for herbaceous plants, seedlings, and saplings was tested based on Bray-Curtis Dissimilarity. Pairwise Wilcoxon Rank Sum tests for species diversity, richness, and moss cover were conducted to explore similarities between treatments. Finally, the functional traits of the herbaceous and woody vegetation between treatments was investigated and summarised for each treatment. The similarities of herbs, seedlings, and saplings between treatments varied signficantly between burnt forest with no intervention (100% passive restoration), moderate intervention (50% salvaging, less-intensive site preparation and planting in patches of groups), and heavy intervention (100% salvaging, intensive site preparation, and high-density row planting). The entirely salvaged treatment showed the lowest herb diversity among the burnt areas. Conversely, the highest herb diversity was found in treatments without intervention. Moss cover and richness were highest in treatments with no intervention and lowest in the entirely salvaged treatment. Treatments with moderate and high intervention showed the highest share of moss pioneer species. Functional trait analysis revealed fast-growing annual herb layer and drought-tolerant woody plants for treatments with intermediate intervention. Treatments with no intervention as well as treatments with intensive intervention displayed more heterogeneity in functional trait diversity in persistence of herb layer and drought adaptation of woody plants. Our results indicated that vegetation diversity and cover declined with an increase in the intensity of active restoration. However, a combination of active and passive restoration approaches, such as moderate salvaging, site preparation, and planting of trees in small patches instead of occupying the entire site, can mitigate the loss of vegetation diversity and maximize proportion of fast-growing annual herbs and drought-tolerant woody plants.

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Examining Spatial Distribution of Wildfire Activity in the Mediterranean Region, Turkey

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Abstract: The size and number of forest fires in the Mediterranean region have increased drastically in the last decades, bringing significant ecological, economic and social consequences. As the main part of Mediterranean ecosystems, wildfire frequently occurs during summertime, especially in the dry season. However, the current situation of climate change, desertification, and human activities make the Mediterranean ecosystem more sensitive to wildfires. Therefore, understanding the role of drivers in wildfires is vital to adapting society and wildlands to the new fire reality. In this study, the spatial distribution of wildfires (2001–2020) within the boundary of Antalya Regional Directorate of Forestry, a Mediterranean fire-prone area with variable climate regimes, increased human pressure, and heterogeneous landscapes, were investigated. We focused on two land types; lands without roads managed for wilderness characteristics (including conservation and protected areas with fewer forestry activities) and lands with an extensive road system managed for multiple uses, including resource extraction. It is assumed that the density of the road network affects the probability of wildfire occurrence; the results of this quantitative analysis help explore the relationship between spatial location and size of the wildfire and the roads were presented. The findings of this study have been useful in understanding the role of roads as a direct (or indirect) cause of wildfires in the Mediterranean region.

Keywords: fire extent, forest road, wilderness, Mediterranean fire-prone area, wildfire

1. Introduction

Wildfires are one of the key disturbances that shape the forest ecosystem by changing species composition, structure and heterogeneity of the vegetation causing significant environmental, economic, and social losses (Zumbrunnen et al., 2011, Narayanaraj and Wimberly, 2012, Zumbrunnen et al., 2012 Narayanaraj and Wimberly, 2013, Yacom et al.,

2019, Johnston et al., 2021, Kolanek et al., 2021). Although the fires are part of many ecosystems such as in those Mediterranean, in which wildfire frequently occurs during summertime, especially in the dry season, the current situation of climate change, desertification, and human activities (i.e., land use changes) make the Mediterranean ecosystem more sensitive to wildfires (Zambon et al., 2019). Thus, it is important to identify and understand drivers of the fire regimes at the regional and local scale in order to develop useful prevention strategies and to encourage proper mitigation action (Zumbrunnen et al., 2011, Johnston et al., 2021)

A variety of factors have an impact on fire regimes (Fire regimes are influenced by a wide variety of factors) (Krebs et al., 2010, Chen and Jin, 2022). For instance, climate and weather through high temperature, low precipitation, and wind cause fuel drying and increase fire intensity and occurrence. Also, the wind accelerates the fire's spread (Pyne et al., 1996, Zumbrunnen et al., 2011). Additionally, topography, fuel types and loads, and human activity affect fire intensity and spread, the occurrence of the fires, and the size of the fire and burnt area (Narayanaraj and Wimberly, 2012, Ricotta et al., 2018). Numerous studies have examined the influence of these factors on fire regimes and found a significant relationship between them, as expected. (Krebs et al., 2010, Chen and Jin, 2022, Akay and Şahin, 2019). In particular, human activity plays a significant role in wildfires such as indirectly shaping fuels and vegetation through land use, and directly setting or controlling fire (Pyne et al., 1996, Ricotta et al., 2018). **FAO reported that (2007**), human-caused fire, accident or set intentionally, corresponds to more than 50% of forest fires in the world, and this rate reaches over 90% in the Mediterranean regions.

Roads are an important anthropogenic factor that significantly affects spatial patterns and size of the fire by promoting the spread, frequency, and intensity of fire disturbance in the forested landscape (Miller et al., 1996, Laschi et al., 2019). They can act as fuel break and help fire suppression activities (Bilici, 2009, Laschi et al., 2019, Yocom et al., 2019). On the other hand, studies were found that roads increase the frequency of human-caused fire ignition due to an increase in forest accessibility (Narayanaraj and Wimberly, 2012, Narayanaraj and Wimberly, 2013, Akay et al., 2017, Zambon et al, 2019). Based on these assertions, this study was examined impact of road density on spatial distribution of the wildfires between 2001-2020. To do that, two different land types; lands without extensive roads managed for wilderness characteristics (including conservation and protected areas with fewer forestry activities) and lands with an extensive road system managed for multiple uses, including resource extraction were compared.

2. Material and Methods

2.1 Study area

Our study areas are located within the boundary of Antalya Regional Directorate of Forestry, a Mediterranean fire-prone area with variable climate regimes, increased human pressure, and heterogeneous landscapes. The impact of the road density was examined in two different areas: Köprülü Canyon National Forest Enterprise Chief (Planning unit) and Akbaş and Karabük Forest Enterprise Chief (Forest Planning Unit) (Figure 1). Köprülü Canyon National Forest was declared as natural conservation areas in 1973 due to its cultural and natural heritage. The area of the NP is over 36614 ha located in steep terrain, located in 85 km of the north-east of the Antalya, and dominant species of the NP is Turkish pine (Pinus brutia), Black pine (Pinus nigra) and Mediterranean cypress tree (Cupressus sempervirens). Köprülü Canyon National Park (KCNP) is one of the most important nature protection areas in Turkiye and in the world with its endemic species, landscape values, rare geomorphological structure, water resources and cultural values, as well as its geographical structure including Mediterranean Forests and high Alpine eco-systems. Also, KCNP has the ruins of the Selge city, founded at the end of the 2000 BC during the Dorian migrations according to historian. KCNP is the one of the longest canyons in Turkiye with its length (14km) and wall height exceeding 100 m. The NP is an important ecotourism destination which offers many recreational activities such as rafting, hiking, natural observation, rock climbing, fishing and camping. The average number of visitors daily is around six thousand in the summer. Due to its legal situation, KCNP mainly is managed as protected area with limited forestry activities. The recreational use, hydrological function, biodiversity and cultural values in KCNP is take into account for the planning not wood production.

Akbaş and Karabük Forest Enterprise Chiefs (Forest Planning Units), adjacent to KCNP, is managed for multiple uses, including mainly wood production. The dominant tree species are Turkish pine (Pinus brutia), black pine (Pinus nigra) at higher altitude and pine nut trees or Mediterranean stone pine (Pinus pinea) around agricultural areas. The elevation is lower compared to KCNP. Planning unit includes agricultural and development areas. These two study

areas considered to be wildfire hotspot like many region in Mediterranean fire-prone area with variable climate regimes, increased human pressure, and heterogeneous landscapes.

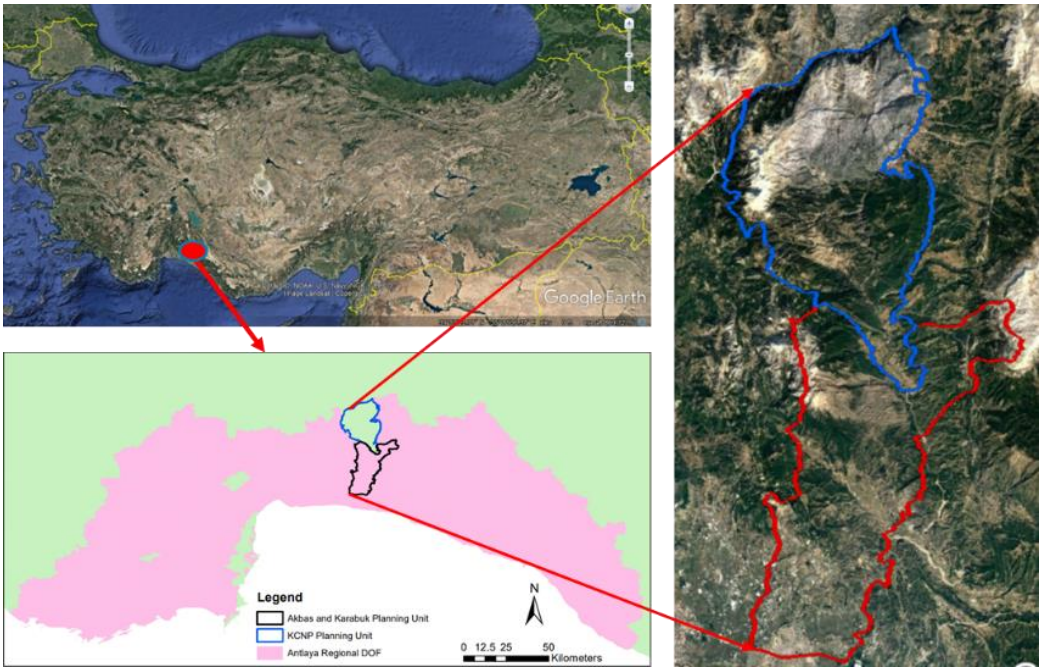

Figure 1. Study area

2.2 Material and Methods

A data set of wildfire events that occurred in KCNP and two Forest Enterprise Chiefs between 2001-2020 and road network were obtained from Antalya Regional Forest Directorate (Figure 1). For each record, dataset includes area of the fire (as polygon) and date. However, the data does not have ignition point and cause of the fire. For analyzing, relationship between fires and road network, density map was generated using Kernel density analysis (Line density m/ha with 75 x 75 cell size) in ArcGIS 10.8.X.

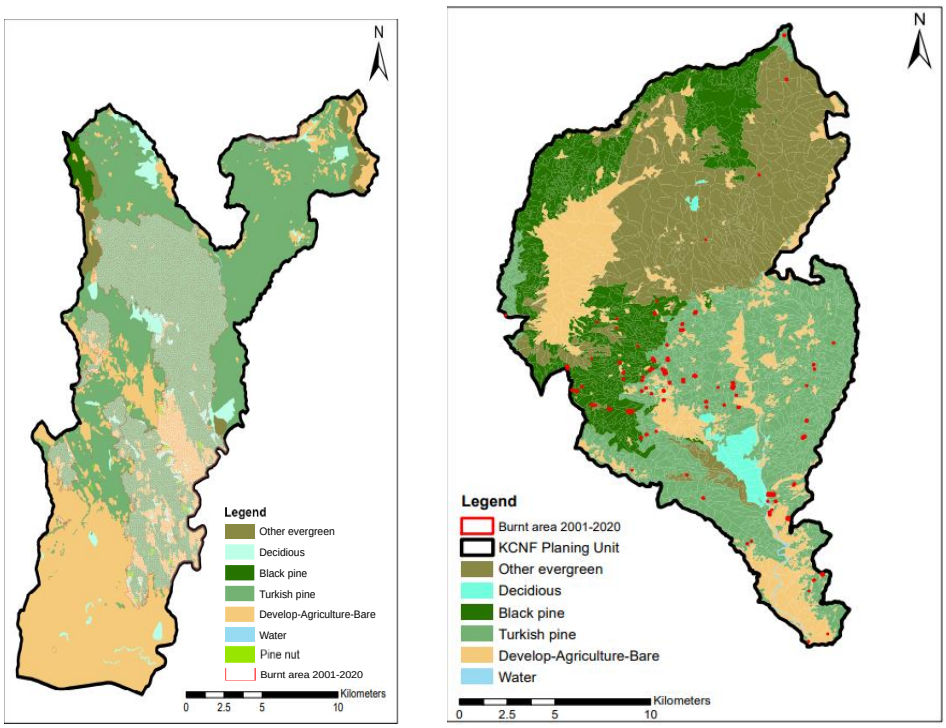

Figure 2. Burnt areas in KCNP and Forest Enterprise Chief with Land use maps

Road network in forested ecosystem is necessary for management activities and fire suppression (Akay et al., 2017, Laschi et al, 2019). However, distance to road and road density increase the risk of the wildfires along with size of the burnt area (Laschi et al., 2019, Akay and Şahin, 2019). In Turkiye, the optimal road density is determined according to forestry activities, especially for wood production and resource extraction. However, optimal road density does not take into account the optimal value of road density in relation to forest fire fighting needs. For example, suggested road density for volume of assets (m3/ha) for >250 and <250 in even aged forest forms 20 m/ha and 10m/ha, respectively (Table 1) (Demir et al., 2009). This range can be changed based on forest forms such as required road density in uneven-aged forest form is 30m/ha and less than 6m/ha in disturbed and coppice forests.

Table 1. Optimal road density based on volume per hectare in forest areas according to the code of General Directorate of Forestry (OGM)

Volume of Assests (m3/ha)	Road Density (m/ha)
0-100	10
100-250	10
>250	20

On the other hand, several studies suggested optimal values of road density related to forest fire fighting needs. A detailed review can be found in a study by Laschi et al. (2019). According to that, the methods were developed to determine optimal road density based on fire risk (Figure 3).

Reference	Road Density, m ha^{-1}		
	High fire risk Difficult conditions	Medium fire risk	Low fire risk Easy conditions
Croisé and Crouzet, 1975	13–17	–	9–11
De Montgolfier, 1989	25	12.5	6.25
Fabiano and Marchi, 1991	17		
Potočnik et al., 2008	25		
Psilovikos et al., 2011	22	–	12.5

Figure 3. Suggested optimal values of Road/Trail density in relation to forest fire fighting needs (Laschie et al., 2019)

For this study, the road density map generated using kernel density analysis was classified using the threshold value that consider both road density value from the code of OGM and road density value from previous studies (Table 2). The road density value for the classification, developed by De Montgolfier (1989), was applied in our study. Then, classified road density map was intersected with burnt area map to examine distribution of the burnt area within classified road density map.

3. Results and Discussion

During the period 2001-2020, there were 83 fires occurred with the average 4.24 ha burnt area in KCNP, while 143 fire was occurred with the average 80.67 ha burnt area within the boundary of Forest Enterprise Chiefs (Figure 4).

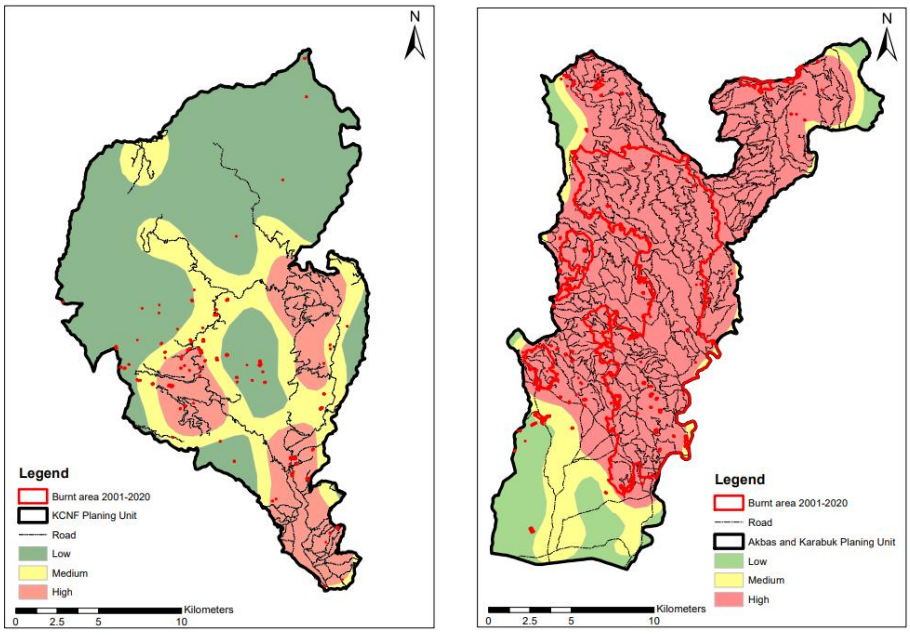

Figure 4. Road density class mapping of KCNP (left) and Forest Enterprise Chiefs (right) along with road burnt areas

Table 2 indicated that more than %50 of the NP was in low road density class, but only around 19 of the NP was classified in high road density class. Still, burnt areas in high class almost doubled the burnt are in low road density class. Surprisingly burnt area in low class was quite similar to burnt area in medium road density class. When evaluating percent coverage of burnt are within road density class, it showed quite similar results with burnt area

within road density class. The number of the fires was the highest in the High class as expected, but Low-density class had more fire than medium class.

Table 2. Spatial distribution of the burnt area within Road density classes in KCNP

Road density class	Area (ha)	Area (%)	Burnt area (ha)	Number of fires	% Coverage of burnt area within road density class
Low	20282.63	56.78	8.15	27	0.04
Medium	8628.75	24.16	8.29	23	0.10
High	6810.75	19.07	16.19	33	0.24
Total	35722.13	100.00	32.63	83	0.09

When evaluating spatial distribution of the burnt area within road density classes in Akbas and Karabuk Forest Enterprise Chiefs (Table 3), the High-Road density class was covered %75 of the total area of Forest Enterprise Chiefs. The area of the Low and Medium density class was almost equal. However, number of the fires in medium class doubled the number of the fires in low class. Also, the number of the fires in high class was equal to more than %80 of total number of the fire. Similarly, burnt area within the high road density class was covered more than %40 of the total area of high-density class.

Table 3. Spatial distribution of the burnt area within Road density classes in Forest Enterprise Chiefs

Road density class	Area (ha)	Area (%)	Burnt area (ha)	Number of fires	% Coverage of burnt area within road density class
Low	4119.75	12.02	7.17	7	0.17
Medium	4240.13	12.37	180.49	16	4.26
High	25928.44	75.62	11174.01	122	43.10
Total	34288.31	100.00	11361.67	145	33.14

The examination of influence of the road density on two different land types; lands without roads managed for wilderness characteristics (including conservation and protected areas with fewer forestry activities) and lands with an extensive road system managed for multiple uses, including resource extraction, showed that the greater incidence of fire and extent of fire were observed in the land with high road density class. Our finding indicated similarities with previous studies that denser road network has strong relation to fire occurrence (Miller et al., 1996, Narayanaraj and Wimberly, 2012, Zambon et al., 2019, Zumbrunnen et al., 2011). In contrast to our study, study by Johnson et al. (2021) indicates that size of the burnt area in lands with less road network are greater compared to lands with an extensive road system. The impact of the human activities (direct or indirect) on fire occurrence is undebatable, but other driving factors behind fire activity need to be examined in future study. For instance, fuel type and load (stand type, canopy closure and age of the stand) are highly related to extent of the fire (Küçük et al., 2005, Küçük and Bilgili 2007, Narayanaraj and Wimberly, 2013) and did not examine in our study. However, it can be observed that Forest Enterprise Chief areas has more fire sensitive fuel types (compose of mainly Turkish pine with high canopy closure) (Küçük et al., 2005, Küçük and Bilgili 2007). In KCNP, there are many disturbed stand types, meaning canopy closure less than %10 and area of the Turkish pine stand is smaller. Also, area of the human settlements is greater at Forest Enterprise Chief areas, which can increase the probability of fire ignition, compared to KCNP areas. Moreover, based on the view of the local foresters and people, visitors of KCNP are more cautious within the boundary of the NP, but not using road network of the Forest Enterprise Chiefs to access to NP. For future study, other driving factor such as climate, fuel types and load and topography, other human activities, behind the wildfire needs to be examine for both study area and Antalya Regional Directorate of Forestry in which wildfire risk is high.

4. Conclusion

Based on most complete available road network database, we examined the impact of road network on spatial distribution of wildfire on two different land types in the Mediterranean Region. For this study, road density map was classified based on the fire fighter needs instead of traditional volume assets in Turkiye. The results of the study showed that the size of the burnt areas was greater in high road density class. This study only considered influence of the road network rather than fuel type, topography and climate and weather that are other significant drivers of the fire. Still, using a new classification threshold for road density might be useful and contribute to future fire studies.

5. Acknowledgement

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How Forest Road Reengineering Improves the Effectiveness of Firefighting Activities?

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Abstract: In the world, thousands of hectares of forests are fire damaged annually which cause significant biological and ecological impacts on forest resources. Along the coastal zone from the Mediterranean region to Marmara region in Türkiye, forests are mostly classified as first-degree fire sensitive forests. To fight forest fires effectively, the time that the initial response team reaches the site via ground transportation should not exceed the critical response time in which the fire is most likely to be controlled. The forest areas that can be reached by the initial response team within certain time can be estimated based on road length and average fire truck speed which is reflected by the road types. The lack of technical standards used on forest roads limits the fire truck's speed and increases the fire access time. Improving forest road standards can increase the design speed, thereby expanding the forest areas that can be reached within the critical response time. In this paper, it was aimed to investigate the effects of road reengineering on expanding accessible forest areas. Firstly, the accessible forest areas within the critical response time were determined by considering the existing road conditions with limited standards. Then, the possible increase in the accessible forest areas was investigated if the road standards were improved. Network analysis-based GIS techniques were used to determine the additional forest areas that ground team can reach once the road standards are improved. The study area was located within the Antalya Forestry Regional Directorate where forests are mostly sensitive to forest fires. It was found that the accessible forest areas in critical response time increased by 57% if the road standards were improved. This result revealed that forest road reengineering can contribute the effectiveness of firefighting activities as promptly accessible areas by ground team could be considerably expanded.

Keywords: Forest roads, road reengineering, forest fires, ground team

1. Introduction

In the last century, especially rapid population growth and consumer demands have increased the pressure on forests, which is one of the renewable natural resources. The most obvious reflections of this pressure on forest resources are forest openings, irregular cutting and forest fires (Ertuğrul, 2005). Forest fires, approximately 95% of which are

estimated to be of human origin, destroy forests, affect the sustainability of forest resources, and cause significant biological and ecological damage to vegetation (Bilici, 2009). In addition, the economic value of the trees damaged by the fire greatly decreases and they become resistant to insects and fungi after the fire (Akay et al., 2007). The sustainability of forest resources is seriously affected by forest fires, especially in arid regions covered with fire-sensitive trees (Demir et al., 2009). Mediterranean ecosystems are highly susceptible to forest fires due to the composition of plant species and the arid climatic conditions in summer. Forest fires damage an average of 4,000,000 hectares of forest area in the world and 550,000 hectares of forest area in the Mediterranean basin (Eker and Abdurrahmanoğlu, 2018). In Türkiye, approximately 12 million hectares of forest area is sensitive to fire along the coastline starting from the east of the Mediterranean region and extending to the Marmara region (Akay et al., 2012). An average of 1250 fires occur annually and approximately 21,000 hectares of forest area are damaged (GDF, 2013). In Summer 2021, large size forest fires occurred in several places in Türkiye including Antalya, Köyceğiz, Marmaris etc. It was reported that total of 160,000 hectares of forest land has been damaged during these fires (Akay and Taş, 2022).

Effectiveness of firefighting activities is of great importance in reducing possible losses due to forest fires. The teams working in firefighting are gathered in five groups: initial response team, reserved fighting team, mobile team, fire truck team and aerial support team (Akay et al., 2008). In order to be able to respond effectively to forest fires, especially in areas that are highly sensitive to fire, the travel time of the fire trucks and ground team involved in the firefighting to the fire area should not exceed the critical response time, when the fire is more likely to be brought under control at the first stage (GDF, 2008). For this reason, the optimum route should be determined in real time, which will enable the team that will move from the fire station to the fire area promptly after the fire notification is received (Akay and Şakar, 2009).

Forest roads are key infrastructures that provide access to forest areas for the conservation of forest resources. Approximately 66% of forest roads in Türkiye are B-type secondary forest roads (Akay et al., 2020). These roads are of limited standard and often require major repairs each year to ensure continued access to forest resources. In B-type secondary forest roads, the standard platform width is 4 m, the ditch width is 1 m. The inadequacy of technical standards (platform width, curve radius, curve width, etc.) used on these roads, the lack of engineering structures and superstructure affect vehicle traffic negatively (Buğday and Menemencioğlu, 2014). Increasing the design speed by improving the technical standards of these roads will make significant contributions to the expansion of accessible forest areas during the critical response time. For this reason, improvement of road standards and firefighting activities should be evaluated together. Although improving road standards may cause some additional costs during road construction, maintenance and repair costs will be significantly reduced in the long run (Akay et al., 2021).

In this study, GIS-based network analysis method was used to evaluate the effects of improving road standards, especially in forests with high fire risk, on the amount of forest areas that can be reached during the critical response time by initial response team. The study was implemented in Antalya Forestry Regional Directorate (FRD), which consists of forests highly sensitive to fire. Network Analyst method in ArcGIS software was used to identify accessible forest areas during the critical response time for two scenarios where existing forest roads and forest roads with improved standards were considered.

2. Material and Method

2.1 Study Area

The study was implemented in Şelale Forest Enterprise Chief (FEC) within the border of Antalya. Şelale FEC is approximately 25524 ha with approximately 48% (12218 ha) covered by forest areas. The forest areas in the study area are classified as first-degree fire sensitive forests. There are four firefighting teams located in Şelale FEC (Figure 1). According to the information obtained from Antalya FRD, there is a road network of approximately 512 km (309 km forest road, 183 km gravel and 20 km forest road) within the borders of the study area.

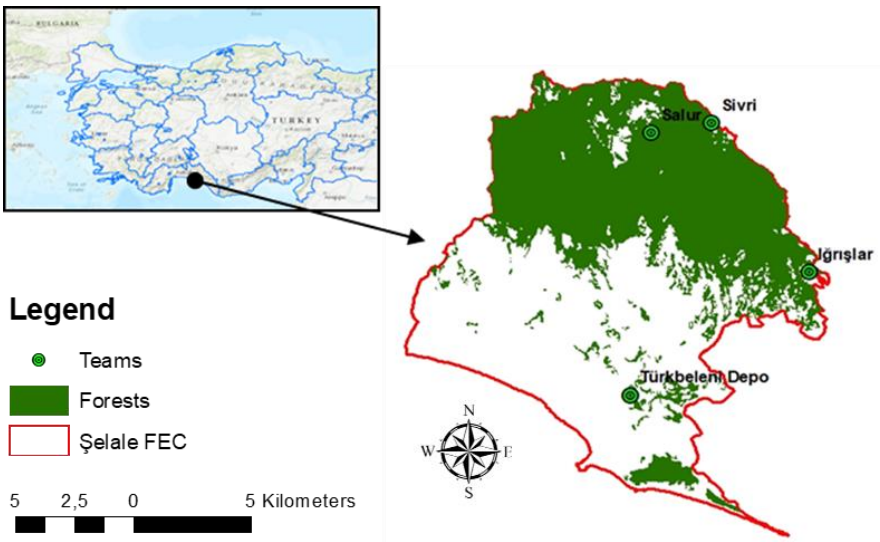

Figure 1. The location of Şelale FEC and firefighting teams

2.2 GIS Database

To identify accessible forests during critical response time using GIS-based network analysis method, numerical data layers were generated showing the road network, land use classes, and location of initial response teams. In this process, topographic maps, forest management maps and forest protection maps to be obtained from Antalya FRD were used as base maps in ArcGIS. The road network data layer was produced by digitizing the road network in the study area using 1:25000 scale topographic maps. For each road section, the average travel time of the fire trucks carrying the team was determined based on road type, road length, and the average speed of the truck. Road types in the study area are divided into three groups as asphalt, gravel and forest roads (B-type secondary forest road) (Figure 2).

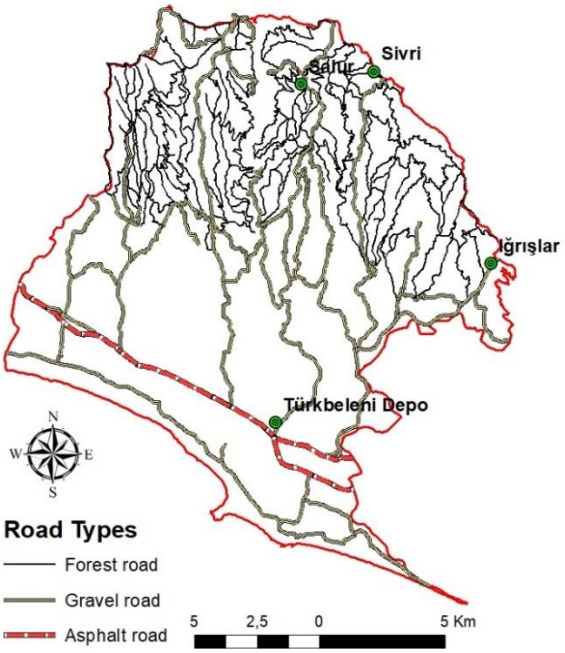

Figure 2. Road network

The vehicle speed information recommended by the previous studies (Bilici, 2009; TIBD, 2010; Akay et al., 2012) were taken into account in determining the average fire truck speeds according to the road type. In the study, the average fire truck speed for asphalt, gravel and forest roads was 60 km/h, 50 km/h and 30 km/h, respectively. For the second scenario where improved forest road standards were considered, the average fire truck speed was estimated as 40 km/h (Akay et al., 2012). Finally, the travel time for each section was calculated using the following formula (Şakar, 2010):

$$t_i = \frac{l_i}{v_i} 60 \qquad (1)$$

where t_i, l_i and v_i are total travel time for section i (min), length of section i (km) and average truck speed for section i (km/hr), respectively.

In order to develop the forest map, stand type maps obtained from the management plans of the Antalya FRD was used classified in ArcGIS software. Then, a new data layer was produced showing the forest areas in the study area. Finally, digital data layers for the locations of firefighting teams and previously burned forest areas were developed.

2.3 Determination of Accessible Forest Areas

In the solution process, firstly, considering the existing road network in the study area, the forest areas that can be reached by the initial response team were determined according to the critical response time. In the second scenario, the possible increase in accessible forest areas for forest roads with improved standards enabling high vehicle speeds was determined.

The network analysis method is widely preferred in solving such transportation problems involving the determination of the optimum route. In network analysis, various parameters such as length, cost and travel time can be assigned to links on the network. The shortest or most convenient path is chosen by searching for the route that minimizes the sum of the total link parameter values (Zhan, 1997). In this study, the New Service Area method, which is based on network analysis under Network Analyst in ArcGIS software, was used to evaluate accessible forest areas during the critical response time for two scenarios.

The critical response time varies depending on the degree of fire sensitivity in an area (GDF, 2008). Table 1 shows the critical response times estimated by General Directorate of Forestry (GDF) based on long-term statistical data collected during wildfire events. The degree of fire sensitivity is determined by the fire coefficient, which is reflected by the number of annual fire cases and burned areas. As the number of fires and the amount of burned area increased, the sensitivity to fire increases (Küçük and Ünal, 2005).

Table 1. Critical response times for fire sensitivity ratings (GDF, 2008)

	Sensitivity Degree of Forest Fire				
	I	II	III	IV	V
Response time	20 min	30 min	40 min	50 min	50 min

The new Service Area method works similarly to the GIS buffer analysis. In this method, a service point is first located in the network system and considered as a center point that can be reached to other parts of the network according to a user-defined total connection value threshold. This accessible area includes the service area. In this study, the locations where the initial response teams are located represent the service area points, and the service areas represent the forest areas that can be reached within the total link value defined by the critical response time. High-risk forest areas that teams can reach within the critical response time were determined with this approach for both scenarios. The additional high-risk forest areas that can be reached by improving road standards were determined by taking the difference of accessible forest areas in the second scenario and the accessible forest areas in the first scenario. In the study, the data about the previously recorded forest fires in Şelale FEC between 2001 and 2020 were obtained from Antalya FRD and a map showing fire damaged areas was generated (Figure 3). Then, the accessibility of the fire damaged areas were investigated for two scenarios.

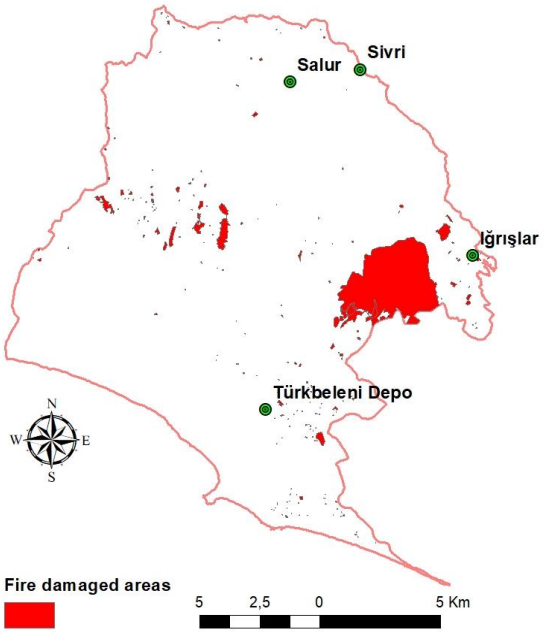

Figure 3. The map of previously fire damaged areas in Şelale FEC

3. Results and Discussion

In this study, the areas that can be reached by the firefighting teams within a critical response time were determine for two scenarios. The accessible areas reached by the ground transportation within 20 minutes were searched as the forests in the study area are first-degree sensitive to the fires. The results indicated that about 44% of the total area was accessed promptly in the first scenario, while accessible areas increased up to 66% in the second scenario (Figure 4). It was found that the firefighting teams can reach about 43% of the forest areas in the critical response time in the first scenario. On the other hand, about 68% of the forest areas was accessible by the ground teams in the second scenario with improved standards (Figure 5).

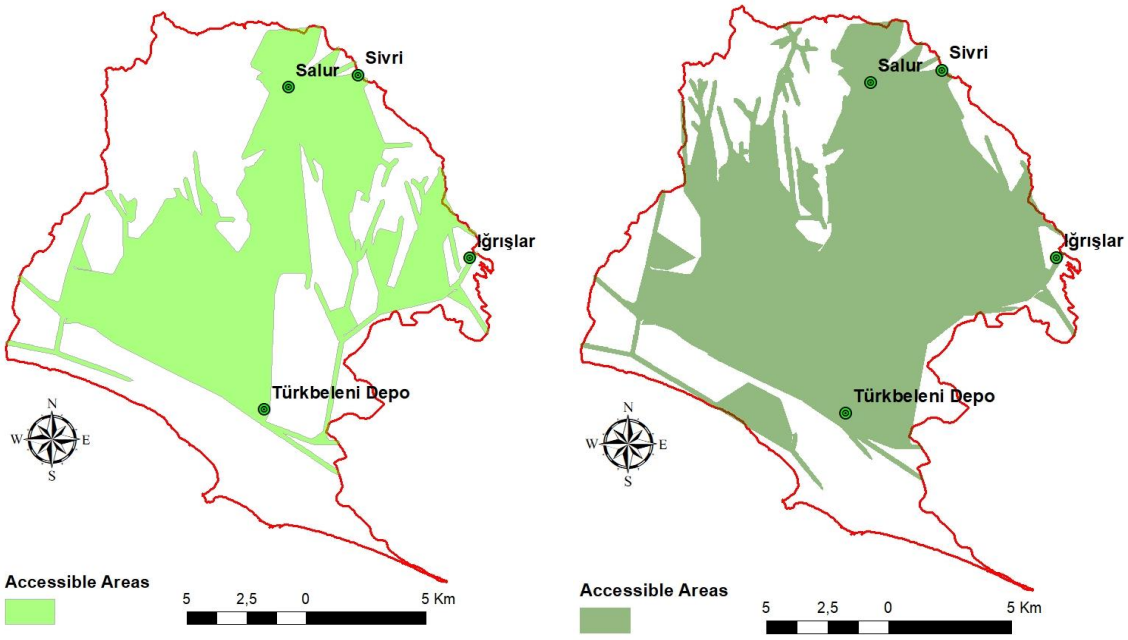

Figure 4. Accessible areas in Scenario I (left) and Scenario II (right)

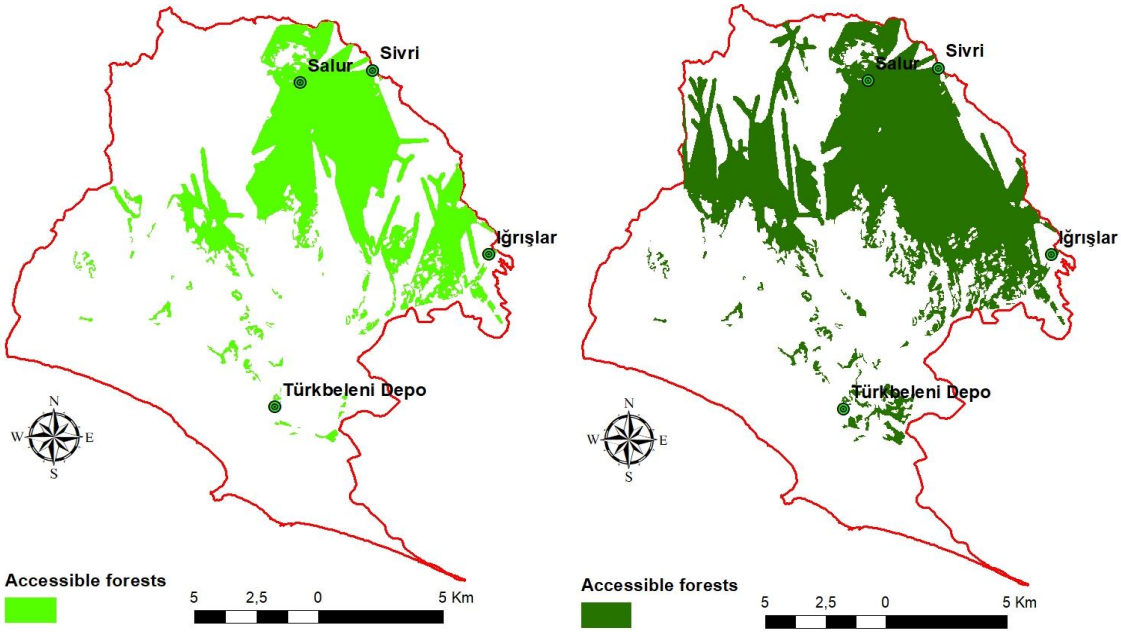

Figure 5. Accessible forest areas in Scenario I (left) and Scenario II (right)

At the final stage, accessibility of potential forest fire areas was investigated for two scenarios based on the fire damaged map indicating the areas that were damaged by forest fires occurred between 2001-2020 in the Antalya FRD. The results indicated that about 60% of the previously fire damaged areas could be accessed by the firefighting teams in the first scenario, while it was 75% in the second scenario (Figure 6).

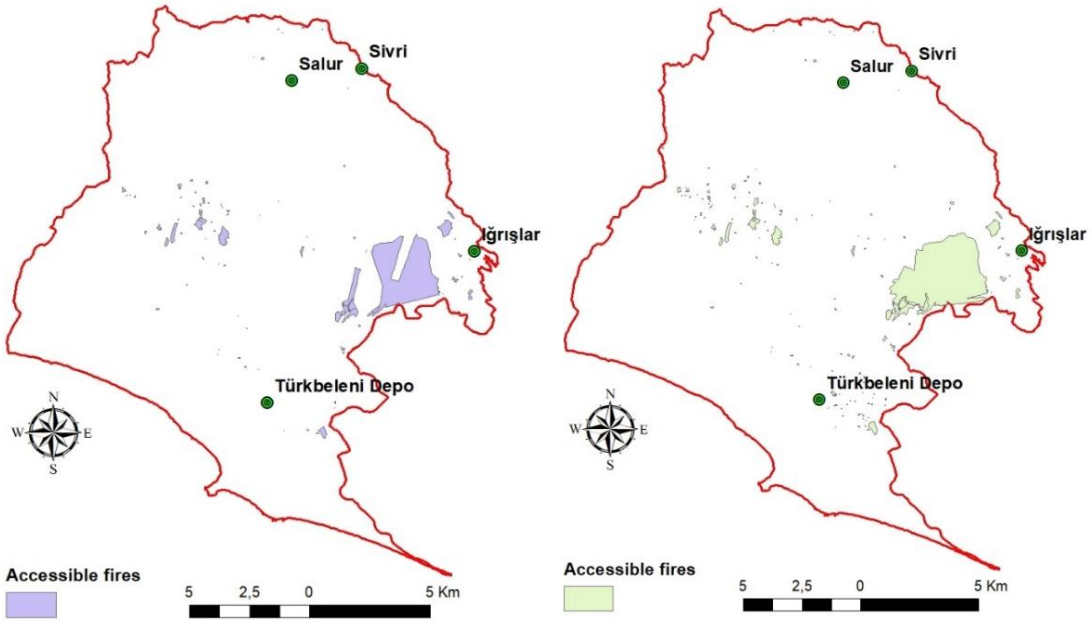

Figure 6. Accessible fire areas in Scenario I (left) and Scenario II (right)

4. Conclusions

In order to minimize the impacts of forest fires on forest ecosystems, firefighting teams promptly reach fire areas through on-ground transportation. Building new roads or increasing the design speed on current roads can increase the accessible forest areas in critical response time. In this study, network analysis based GIS techniques were used to increase the effectiveness of firefighting activities by utilizing forest roads with improved standards. The results indicated that accessible areas by the ground-based firefighting teams in the case of improved forest roads were 51% more than that of existing road standards. When considering forest areas in the Şelale FEC, accessible forest areas increased by 57% in the second scenario. Besides, it was found that the previously fire damaged areas that were accessed by the initial response team in the second scenario was 24% more than that of the first scenario. The results from the sample application suggested that increasing the design speed on improved roads would reduce the fire access time of the ground teams which leads to increment in the accessible forest areas, as well as potential fire damaged areas, in critical response time. In the following studies, two scenarios should be compared in terms of potential economic consequences of improving forest road standards. In the first scenario, annual major repair costs of existing forest roads would be calculated based on unit costs. In the second scenario, the cost of road improvement activities (i.e. road construction, road structures, road surface construction within the scope of major repairs) and annual maintenance costs would be calculated based on unit costs. Then, the economic value of the wood raw materials in the additional forest areas, which can be accessed by improved road standards in the second scenario can be determined.

5. Acknowledgment

The authors would like to express appreciation for the support of the sponsors (Project Number: TUBİTAK-TOVAG 221O309).

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An Assessment of Productivity and Volume Recovery of Mechanised Harvesting in a Pine Fire Salvaging Operation in the Eastern Cape, South Africa

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ABSTRACT

Large scale fire salvage operations are increasing in South Africa due to an increase in the number and severity of disastrous fires in the South African forestry industry. These fire occurrences can be caused by arson, honey harvesting, lightning and failed fire protection initiatives, such as uncontrolled escaped fires while burning breaks or harvesting residues. Over the past three decades, the severity of fires has been exacerbated by factors such as climate change and conflicts between forest landowners and communities. When fires occur, they can disturb or destroy infrastructure, forests and in some instances lead to loss of life. After fires occur, plantation forests are under severe stress and need to be harvested quickly to recover high value from the market because the burnt trees may deteriorate rapidly.

Mechanised harvesting options are often preferred for the harvesting of burnt compartments because of high productivity and safety. Although fires occur frequently in South Africa, there is very little information available regarding the productivity and log volume recovery of mechanised harvesting systems operating in burnt mature and premature compartments. Different forestry stakeholders conduct post-fire salvaging operations with little knowledge of what productivity and log volume recovery to expect in these conditions. This research examined the productivity and log volume recovery of mechanised cut-to-length (CTL) and full tree (FT) harvesting systems in a post fire salvage operation in pine mature and premature stands in the Eastern Cape province in South Africa. Time and motion studies were conducted to assess productivity and logs produced were measured to determine log volume recovery. The research found that when harvesting a tree with the average volume of 0.72 m3, the mean harvester productivity is 60.5 m3/PMH, and when harvesting a tree with an average tree volume of 0.14 m3, mean feller director productivity is 22.7 m3/PMH. However, the log volume recovery (utilisable stem volume) rate for the CTL harvesting system was 84% and for the FT harvesting system was 58.1%. Concerning extraction, the forwarder and grapple skidder extracted an average of 49.3 m3/PMH and 38.7 m3/PMH, respectively, at an average extraction distance of 100m. Volume recovery was estimated by the grower company at 95.7% for CTL harvesting and 97.5% for FT harvesting. This research provides information to the forest industry (growers and contractors) about salvaging burned pine plantations with different age and damage severity. The information will assist in making decisions for equipment and system selection.

Environmental Impacts

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Estimation of Soil Pressures Based on the Pressures in the Hydraulic System for a Legged Forestry Machine

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An Analysis of Best Management Practice Modifications in West Virginia

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Assessing the Compactability of Forest Soils Using Impact Compaction Tests and Soil Tensiometers

David H. McNabb

Forestry Best Management Practices, Ground Cover Analysis, and Erosion Potential Comparison between Conventional Clearcut Harvesting and Biomass Harvesting Operations in the Southeastern USA

Manisha Parajuli, Tom Gallagher, Richard Cristan, Dana Mitchell, Marissa Daniel, Timothy McDonald

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Assessing Soil Disturbance from a Tethered Feller-Buncher on Steep Slopes in Northern California

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Abstract: The implementation of tethered harvesting allows for the expansion of mechanized timber harvesting operations onto steeper slopes. Recent updates to the California Forest Practice Rules have explicitly removed the slope limitation for timber harvesting equipment, provided it's tethered. California is now witnessing the reintroduction of ground-based timber harvesting equipment on steep slopes. Previously, operating equipment on steep slopes was considered detrimental due to the potential for soil disturbance. However, tethered equipment interacts with the soil in a new way due to the use of a winch. Relatively few studies have attempted to quantify soil disturbance with this new practice. The goal of this study was to quantify the severity and extent of soil disturbance from tethered felling on steep slopes in Northern California. The severity of compaction was determined by comparing the change in bulk density from an undisturbed area beside a machine trail to the bulk density collected between the track treads and under the track tread of a tethered feller-buncher trail. Extent of soil disturbance was assessed through visual classifications of soil disturbance based on a relative scale considering: rutting, mounding, and mineral soil exposure. Soil samples were collected along the machine trail at 7.6 meter intervals at three different depths: 10 cm, 20 cm, and 30 cm. The greatest average increase in bulk density compared to the undisturbed samples occurred under the tracks at the 20 cm depth (+12%), followed by the 10 cm depth (+11%). The soil collected between the track treads changed very little from the undisturbed soil on average, but had the greatest increase and decrease in bulk density (+98%, -100%). The greatest visual disturbance ratings fell under the tracks. While literature suggests that the soil and site characteristics such as slope, rock volume, and organic matter influence how susceptible a site is to soil compaction and the extent to which soils are visually disturbed, this study did not find compelling enough evidence to support such findings.

Keywords: Winch-assist, Logging, Timber harvesting, Steep terrain, Compaction

1. Introduction

Timber harvesting in California has progressed into prioritizing the sustained productivity of timber while avoiding excessive soil disturbance, which can adversely affect forest productivity and cause other environmental problems (Detenbeck et al., 1970; Patric et al., 1984; Yoho, 1980). Maintaining soil health should be considered when implementing management decisions to avoid potential decreases in forest production or problematic sediment transport to water courses. There are several soil properties that influence the capacity of any individual forest to produce resources, but only a few can be influenced through management decisions. The land manager becomes responsible for improving or maintaining soil properties while obtaining resources from the forest to meet an increasing demand. Soil degradation can cause a reduction in tree growth and vigor over multiple cycles of timber production.

Soil properties, such as bulk density or structure, can be influenced through natural forces such as geology, climate, and slope or by human intervention (Powers et al., 1999). Changing soil properties can lead to compaction, or the reduction of pore space in soil (Adams & Froehlich, 1981) which can lead to higher bulk density and reduced infiltration (Akram & Kemper, 1979; Cambi et al., 2015). The mechanization of ground-based timber harvesting has led to heavy machines traversing forest soils, which is a major factor in causing soil compaction (Horn et al., 2007). Compaction can potentially be long-lasting (Håkansson et al., 1988) depending on physical characteristics of the soil (Busse et al., 2021; DeArmond et al., 2019; Page-Dumroese et al., 2021).

The efforts to prevent long term degradation as well as the efforts to increase timber harvesting efficiency are not mutually exclusive. There are several methods to reduce or prevent soil disturbance, such as limiting the area that is traversed by machinery, preventing machine track or tire slippage, and avoiding the formation of ruts. Consolidating the area that is traversed by heavy machinery into fewer trails reduced the overall area that is impacted by machinery (Adams & Froehlich, 1981; Ezzati et al., 2012; Horn et al., 2007). Consolidating machine trails is beneficial because soil has the greatest increase in compaction after the initial machine passes (Froehlich et al., 1980a; Han et al., 2006). Machine slippage is associated with the formation of puddling through rearranging the clay particles in a way that decreases water infiltration and discourages root movement (Davies et al., 1973; Koenigs, 1963). Rutting also decreases water infiltration due to the sealing that occurs at the bottom of the ruts (Page-Dumroese et al., 2021). Taking precautions such as using the right type of machinery for soil conditions present or using traction aiding devices (e.g., chains, band tracks, tethering, etc.) allows land managers to efficiently harvest timber without compromising soil quality.

Tethered, or winch-assisted, timber harvesting is a relatively new development that has allowed for the expansion of mechanized timber harvesting onto steep slopes. Tethered timber harvesting is the process in which machine trafficability is aided through the use of a winch and cable system; either attached to the machine descending the slope or an established anchor. Tethered timber harvesting has recently been adopted into the California Forest Practice Rules and can now be applied without a slope limitation, but there are not many studies exploring the potential soil disturbance, especially in the Pacific Northwest (The California Department of Forestry and Fire Protection, 2020). Tethered timber harvesting has the potential to improve the efficiency and safety of timber harvesting on steep slopes (Visser & Stampfer, 2015). Mechanizing steep slope timber harvesting also has the advantage of increasing the range of grade that machines can traverse without slipping (Sessions et al., 2017; Visser et al., 2014). Although there is an increased risk of soil disturbance with ground-based equipment on steep slopes (Agherkakli et al., 2010; Najafi et al., 2009), some of the features of tethered timber harvesting may be favorable for reducing soil disturbance associated with ground-based timber harvesting, such as: traversing a substantial area, slippage, and rutting. For example. tethered machines reduce the likelihood of the machine wandering and creating more skid trails due to the cable generally deterring any movement that strays too far from the original trajectory of the machine. Limiting the wandering that would occur if there were not a cable attached to the machine leads to a reduction in the area of the harvesting unit that is traversed by heavy machinery. Tethered timber harvesting can potentially reduce slippage because the winch generally decreases the ground pressure by improving the traction, but the extent to which tethering will alleviate ground pressure and improve traction will depend on various site-specific factors (Sessions et al., 2017). Increasing traction can also help reduce the amount of rutting, depending on the soil conditions (Sessions et al., 2017). One study suggested that the presence of rutting was not more prevalent in an area logged with tethered timber harvesting than an area that was manually logged (Evanson et al., 2013), but the presence of rutting is very dependent on soil conditions (Sessions et al., 2017).

The purpose of this study is to quantify the extent and severity of soil disturbance of a timber harvesting operating

utilizing a tethered feller-buncher in the Northern California region.

2. Methods

2.1 Site Description

Samples were collected from a forested tract owned by Green Diamond Resource Company, located about 50 kilometers north of Korbel, CA. The site, "Unit A" was designated to be harvested with tethered machinery due to the grade, which ranged from 16 to 80 percent (Table 1). The machine trail had uneven terrain that occasionally intersected legacy skid trails that were formed in 1967 during the last stand entry. The area was comprised of the Hugo soil series (Fine-loamy, mixed, superactive, mesic Typic Dystroxerepts). The texture was predominantly a gravelly to very gravelly loam. The soil generally has good drainage, high permeability, and a moderate erosion hazard rating (NRCS, 2021). The parent material consists of sandstone and shale, with a boulder field (rocks with a diameter greater than 600 mm) covering approximately 15 meters of the machine trail. The moisture content on the day of the operation averaged seven percent and ranged from 1 to 39 percent.

The site also showed evidence of instability due to some erosional features that were formed since the previous stand entry. Previously installed drainage diversions caused a slope failure. Some of the erosion features in the unit were caused by Class two or three stream crossings that were filled in to serve as skid trail crossings. This increased vulnerability of the soil and was likely a consideration leading to using tethered machinery. Of the 9 hectares in Unit A, 6.5 hectares were designated to be harvested with the clear-cut method, one acre was designated to be harvested using the selection method, and five acres were designated to not be harvested due to the geologic instability caused by previous entries.

The study was based on one trail that was designated by the machine operator (**Error! Reference source not found.**). Once the length of the trail was established, the sampling interval was calculated. To uphold a sampling intensity of 31 transects, the spacing of each sampling transect was set at 7.6-meter intervals. At each sampling transect, soil was collected from between the track treads, under one of the track treads, and beside the track. The soil collected beside the track served as a proxy for undisturbed soil. The change in bulk density, or compaction, was assessed by comparing the change from the disturbed soil to the undisturbed soil (i.e., outside track). In addition, soil was collected from three depth intervals: 10, 20, and 30 cm. Bulk density soil samples were collected using a slide hammer fitted with a 90.59 cm^3 cylinder (AMS Inc., American Falls, Idaho, USA).

2.2 Description of Operations

Unit A was harvested in July of 2021 with a Tigercat LX830D self-leveling feller-buncher that was tethered to a Summit Winch-assist machine (e.g., a winch that was fitted on an excavator that served as an anchor at the top of the harvest unit) (Figure 2; Table 2). The feller-buncher traversed downhill and started the preliminary felling to clear a trail down the slope. Most of the felling occurred as the feller-buncher ascended back up the slope. Once the trees were felled, they were placed on the side of the main trail. As the feller-buncher maneuvered through the uneven terrain, the operator made several short deviations from the main trail to access more trees. Essentially, the felling process was completed with approximately two passes of the machine down the length of the trail. Minimal deviations from the initial machine trail were ideal to prevent the cable attached to the feller-buncher from being caught on standing trees.

Table 1. Stand characteristics for the harvest unit as described by the timber harvest plan

Preharvest Stand Characteristics	
Average age:	55 years
Average slope:	40%
Elevation:	670 meters
Species composition:	84% Douglas-fir 10% hardwoods 5% redwood
Stocking volume:	99.13 m^3/ha
Basal area per acre:	16.7 m^2
Average DBH:	76.2 cm

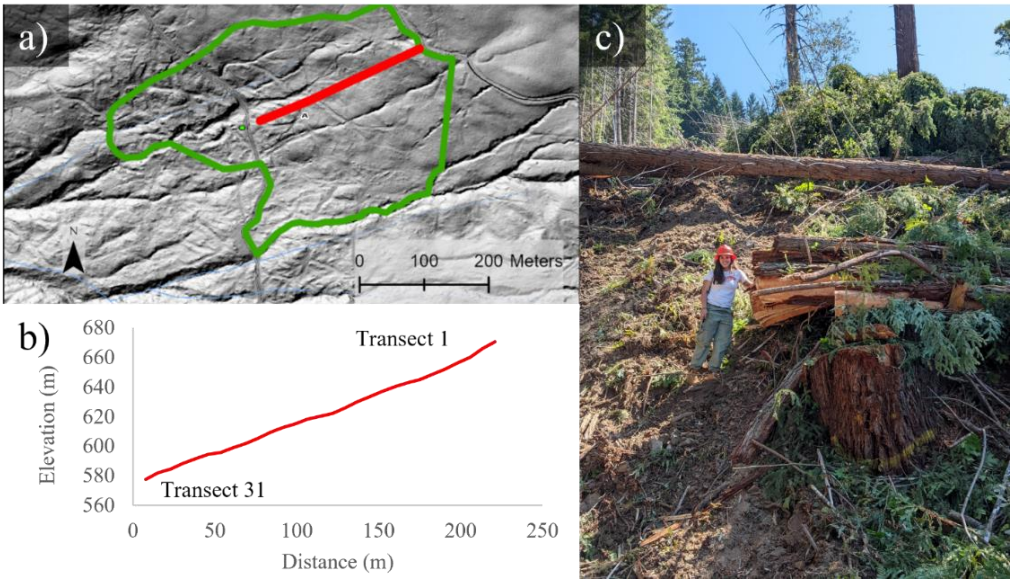

Figure 1. Maps of the harvest unit showing: the LiDAR map with the trail that was studied highlighted in red(a), a profile map (b), and the view looking up the trail from the bottom, or transect 31 (c)

Table 2. Specifications for the Tigercat LX830D

Tigercat LX830D	
Tracks width:	330 cm
Single track width:	63.5 cm
Track length:	513 cm
Boom length:	843 cm
Height:	371 cm
Weight:	34,473 kg
Tail swing radius:	206 cm
Track grouser height:	7.5 cm

Figure 2. The Tigercat LX830D (left) tethered to the excavator-based Summit Winch-assist machine (right) at the ridge of Unit A.

3. Data Collection and Analysis

3.1 Extent of Disturbance

The extent of soil disturbance caused by tethered feller-buncher was quantified using a relative visual scale based on a Forest Service soil disturbance scale (Napper et al., 2009), grading five positions across the trail at 7.6-meter intervals along the length of the trail: below and to either side of the track tread and between each track. The ratings of the scale ranged from zero to three, with zero representing undisturbed areas and three representing the areas that had the highest visual disturbance. The qualifications for visual disturbance included rutting, mounding, or bare mineral soil exposure. The rating for each position was averaged. The disturbance rating was observed with othered measured factors to determine if any factors had any relationship with high visual disturbance.

3.2 Severity of Disturbance

Soil disturbance severity was rated by the likeliness to degrade soil quality due to compaction or erosion. The severity was assessed by determining the compaction from the undisturbed soil and disturbed soil. The compaction was assessed by determining the bulk density of the soil samples. Other factors that could potentially have an effect on bulk density, such as soil moisture, organic matter, rock content, texture, and slope were measured. Bulk density samples were collected from each sampling position at each depth from each transect along the length of the trail.

Once soil samples were extracted, each sample was weighed in a tin can, dried at 105° C until desiccated, and weighed again. The rocks were sieved out of the sample, weighed, then the volume was determined by calculating water displacement. The rock content was determined by comparing the weight of the rocks to the weight of the dry soil sample. The fine earth fraction of the soil was run through a soil splitter to obtain a subsample which was weighed then ignited in a furnace at 375° C until the organic matter was removed, then weighed again to determine the organic matter content (Ball, 1964).

The compaction, or change in bulk density, was determined by comparing the differences between the bulk density of the soil collected between or under the machine track tread to the soil collected outside of the machine track using paired t tests using the statistical software Minitab (version 20.3). The change in bulk density was regressed against organic matter, rock content, slope, and initial bulk density to identify any potential relationships using Microsoft Excel (version 2207).

4. Results and Discussion

4.1 Extent of Disturbance

The visual disturbance ratings collected at each sampling interval showed that the highest overall disturbance was found under the tracks, but there was high disturbance found throughout every sampling location (Figure 3). The high ratings, especially outside of the tracks, are likely due to lasting effects from the previous entry over 50 years ago, showing that the implications of soil disturbance can take a long time to fully recover from previous timber harvesting methods, including excavation of skid trails on steep slopes using blades. Evidence of previous skid trails are still visible from the LiDAR imagery (Figure 1a). When the transects which were rated as having the highest overall disturbance ratings were compared to the transects that had either the highest compaction or greatest loosening, there was no apparent correlation. There doesn't seem to be an apparent cause behind the areas that were rated with the highest visual disturbances compared to the lowest disturbance ratings.

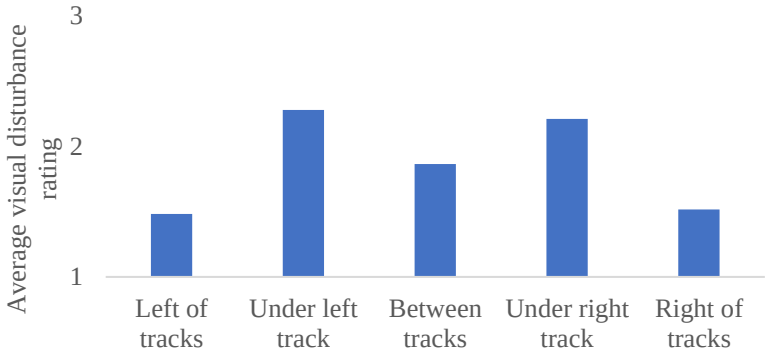

Figure 3. Average visual disturbance ratings of the visual assessment of soil disturbance. The disturbance rating scale ranges from 0 to 3, with 0 representing areas that appear undisturbed and 3 representing the highest relative disturbance, including deep rutting or mounding.

4.2 Severity of Disturbance

Bulk density samples from between machine tracks and under the tread of machine tracks were collected (**Error! Reference source not found.**). The bulk density measurements values showed a pattern of increasing with depth at each sampling position. The bulk density values were highest under the tracks, which can be expected considering the stress from the machinery is distributed under the tracks (Dyrness, 1965; Han et al., 2009; Hatchell et al., 1970; Hwang et al., 2020).

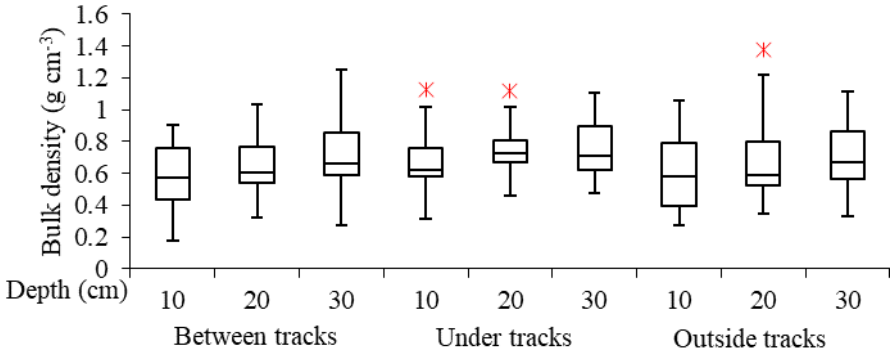

Figure 4. Boxplot comparing the interquartile ranges of bulk density values (g cm^{-3}) of soil collected from three different positions after a tethered feller-buncher felled and bunched trees along the trail. The asterisks denote outlier values. There is a trend of bulk density increasing at greater depths.

Generally, the average bulk density did not change when comparing the soil from under the tracks to the soil outside of the tracks due to the combination of soil samples that either increased or decreased in bulk density (Table 3). There was a substantial amount of variability of soil characteristics within the sampling corridor for the three sampling positions: between the track treads, under the track treads, and beside the trail (Table 4). The sampling corridor was only 236 meters, but there was high deviation from the average values of the measured soil and site properties. When looking at the differences between the soils that compacted and the soils that were loosened, there are not very many noticeable differences of the measured soil properties. Compaction was anticipated, but many samples were loosened.

The relationships between organic matter, rock content, slope, and initial bulk density with regards to changes in bulk density were explored (Figure 5). While the relationship was weak, there was a positive relationship between change in bulk density and organic matter. This result was unexpected because soils with a relatively higher organic matter have been shown to have lower bulk densities (W. A. Adams, 1973; Dexter, 2004; Federer et al., 1993; Heuscher et al., 2005). The presence of organic matter also acts as a buffer by reducing the ability of a soil to compact (Ekwue & J. Stone, 1995), especially in soils that are highly susceptible to compaction (Zhang et al., 1997). However, the data points seem to be slightly skewed by outliers. The rock content also had an influence on determining change in bulk density. Because bulk density was analyzed based on the fine earth fraction (less than 2 mm), as rock content increased, the bulk density decreased. The negative relationship between rock content and fine earth bulk density is potentially caused by the larger rock fragments preventing the finer soil from packing together or changes in soil behavior due to the spatial variability of the rock fragments and changes in the ratio of fine earth and rock fragments, which would interact with water and nutrients differently than soil would behave without rock fragments (Poesen & Lavee, 1994; Stewart et al., 1970). Slope had a weak, positive relationship with change in bulk density. These results contradict a similar study where compaction had a lessened effect with steeper slopes (Garren et al., 2019). The bulk density collected from outside the tracks (i.e., undisturbed) had a negative relationship with the change in bulk density of the soils between and under the tracks. This is expected because soils with initially high bulk densities are less susceptible to compaction (Froehlich et al., 1980; Han et al., 2006).

Table 3. Average bulk densities of samples collected after tethered operations for each sampling position ("Outside tracks" "Between tracks" and "Under tracks") for each depth. P-values are results from comparing the disturbed and undisturbed samples using a paired t-test

	Average bulk density (g cm^{-3})			p-value	
Depth (cm)	Outside tracks	Between tracks	Under tracks	Outside vs between tracks	Outside vs under tracks
10	0.59	0.59	0.65	0.993	0.145
20	0.66	0.66	0.73	0.921	0.140
30	0.70	0.72	0.75	0.605	0.235

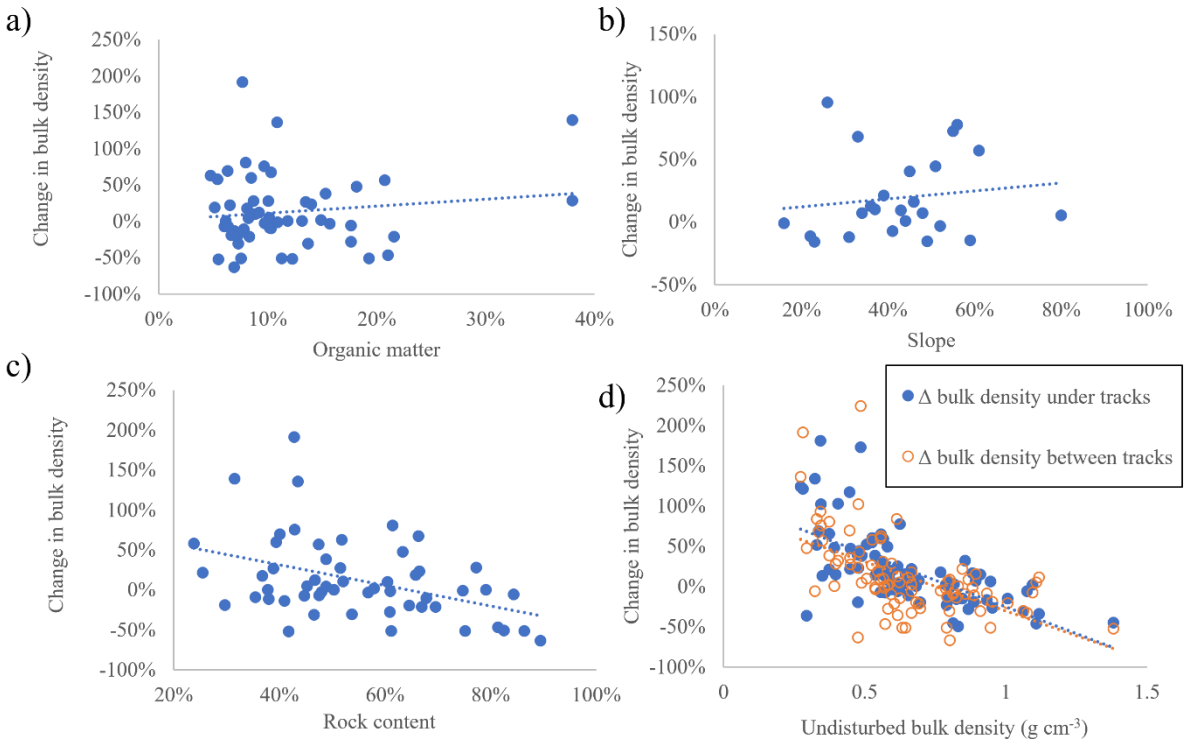

Figure 5. Scatterplots showing the relationships between the change in bulk density and organic matter (a), rock content (b), slope (c), and bulk density (d). The equation and R^2 value for each regression are a) y = 0.9545x + 0.0191, R^2 = 0.017; b) y = 0.3137x + 0.0602, R^2 = 0.019; c) y = -1.2912x + 0.833, R^2 = 0.18; d) y = -1.328x + 1.072 R^2 = 0.4234 (under tracks), y = -1.2222x + 0.9166, R^2 = 0.31 (between tracks)

Table 4. Range of soil and site properties of the harvesting unit collected after the timber was felled and bunched

Variable	Sample position	Depth (cm)	Mean	Standard deviation	Minimum	Maximum
Bulk density (g cm^{-3}) / Bulk density change (%)	Between tracks	10	0.59/ 1	0.19/ 45	0.17/ -92	0.90/ 98
		20	0.66/ 2	0.16/ 33	0.32/ -71	1.03/ 54
		30	0.72/ 3	0.23/ 36	0.27/ -100	1.25/ 68
	Under tracks	10	0.65/ 11	0.18/ 36	0.19/ -66	1.12/ 80
		20	0.73/ 12	0.16/ 33	0.44/ -60	1.11/ 74
		30	0.75/ 9	0.18/ 31	0.48/ -60	1.11/ 95
	Outside of tracks	10	0.59	0.22	0.27	1.06
		20	0.66	0.23	0.34	1.38
		30	0.70	0.21	0.33	1.11
Organic matter	Between tracks	10	11.54	5.15	4.75	21.56
		20	10.12	6.16	4.65	37.98
		30	8.94	3.91	4.06	19.41
	Under tracks	10	11.20	7.87	5.46	48.50
		20	9.22	3.35	3.90	19.42
		30	8.48	3.33	2.48	18.55
	Outside of tracks	10	13.55	7.75	3.67	34.57
		20	10.40	4.69	3.83	22.35
		30	9.24	3.63	3.78	17.71
Rock content	Between tracks	10	56.94	16.76	29.68	89.43
		20	51.10	14.96	23.79	86.39
		30	52.22	16.34	20.12	87.32
	Under tracks	10	54.58	15.75	25.69	88.07
		20	49.34	13.14	22.71	72.66
		30	48.58	13.71	22.15	77.52
	Outside of tracks	10	54.37	18.40	13.03	79.00
		20	52.81	14.89	27.72	80.60
		30	52.62	15.95	26.13	86.00

5. Conclusion

The extent and severity of soil disturbance of a tethered harvesting operation were determined through ratings of visual disturbance and comparisons of bulk density. The results of the visual disturbance ratings for a trail that was harvested with a tethered feller-buncher indicated that there was high visual disturbance under the track tread. There were no apparent indicators of factors that led to high visual disturbance. The changes of bulk density from the undisturbed soil collected outside of the machine trail and the soil collected under and between the track treads were measured, showing no significant changes. Rock content and undisturbed bulk density showed the strongest relationships for predicting change in bulk density, with increasing bulk densities and increasing rock contents being less susceptible to compaction. This study found that the soil disturbance of a tethered felling machine with approximately two passes was not detrimental at this scale. Future research may be warranted in the potential effects of the churned exposed soil resulting from heavy machinery, especially with steep slopes.

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Estimation of Soil Pressures Based on the Pressures in the Hydraulic System for a Legged Forestry Machine

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Abstract: Harvesting operations with wheeled forestry machines can bring great harm to wet soils due to the machine weight and wheel slip. Factors such as the reduction of wheel slip, machine weight and total area affected by forestry machines are crucial in protecting soils. The accurate measurement of the pressure introduced by forestry machines to the soil, without harming the structure of the ground nor making assumptions of the tire or ground behavior, poses a challenge. Within this article a method to calculate the contact soil pressure, of a portal advancing mechanism for sensitive soils is presented. The results are then further evaluated based on simulative results. B y using the kinematics of the legged machine, it becomes possible to determine the soil pressure without making rough assumptions of the legs or the ground. The kinematic allows to measure the forces of the hydraulic actuators that are holding the legs in position. Through this, a direct calculation of the force which is transferred to the ground can be made. To determine the forces of the hydraulic actuators in a movement cycle, a coupled simulation of the kinematic and hydraulic system is set up. Using the determined pressures in the cylinders the exerted force on the ground is calculated. The developed calculation method has been set up in such a manner that the results can easily be compared to real world test data in future studies. In addition, the effects of this particular legged forestry machine on the ground will be compared to other machine types under the consideration, that with this new concept no slip is expected. Using this approach, the soil pressure and the impact on the ground of a legged forestry machine can be evaluated in an early stage of development.

Keywords: portal advancing mechanism, soil pressure, simulation, hydraulics

1. Introduction

Wood as a sustainable construction material and energy source is gaining an increasing importance in the public. Therefore, sustainable forestry operations are also gaining in importance. For sustainable forestry operations it is necessary to reduce soil damage as much as possible, because this damage has a direct influence on the productivity of the surrounding forest (Williamson and Neilsen, 2000; Cambi, Certini, Neri, Marci, 2015). To reduce damage on sensitive soils, the harvesting season takes place during cold periods while the ground is frozen (Rittenhouse, Rissman, 2015). With cold periods becoming rarer (Rittenhouse, Rissman, 2015), it is important to develop forestry machines which can harvest all year long.

In fully mechanized forestry operations with wheeled and tracked forestry machines, sensitive soil gets damaged through machine weight as well wheel or track slip. Soil damage will be higher in areas consisting mostly of wetlands in comparison to areas with dyer and firmer ground (Cambi, Certini, Neri, and Marci, 2015). By reducing the weight of forestry machines, the induced damage can be reduced as the compaction of the soil is minimized. One issue of compaction is its negative effect on the ability of the ground to absorb water (Cambi, Certini, Neri, and Marci, 2015). A second possibility to minimize the negative effects of forestry machines on the environment is the reduction of slip between drivetrain and ground, resulting in less tearing of the ground. Current research is mainly focused on developing technologies to reduce the slip (FNR, 2021a). Non-wheeled or tracked machines present the most promising technologies, as the machines have the potential of reaching zero slip. With no slip and only a compaction of the ground at specific points instead of along the entire skid lane, regeneration rates will be higher, and the forest can grow in a more sustainable and healthy way (Williamson and Neilsen, 2000; Cambi, Certini, Neri, and Marci, 2015). Furthermore, this can lead to more robust forests against environmental influences like erosion, as ruts on the skid track, which are known to increase erosion, are removed (Christopher and Visser, 2007). (FNR, 2021b)

For state-of-the-art wheeled machines, accurately determining the contact pressure of tires requires a great effort, because the contact area depends, among other things, on the dynamic tire diameter (Marusiak and Neruda, 2018). Different methods exist to quantify the impact of forestry machines on the soil. For example, in (Marusiak and Neruda, 2018) different models for calculating the contact pressure were compared with measurements made by sensors which were built into to the ground under the skid trail. With this measurement method it is only possible to get a contact pressure at a specific point of the trail. Also, the modeled pressures differ from each other as well as from the measurements made by the sensors. A further method to evaluate the pressure introduced to the ground is presented in (Nolting, Brunotte, Lorenz and Sommer, 2006). In this study, a hole beside the skid trail had to be dug, as to be able to set the pressure sensors under the skid trail. This method is invasive and limited to a specific point on the skid track, whilst also providing measurements of pressure in different depths (Horn, Vossbrink and Becker, 2004; Riggert, Fleige, Kietz, Gaertig and Horn, 2016). Altogether one can say, that there is not an established non-invasive method in literature to determine accurately contact pressures.

In this article, the effects of the portal advancing mechanism on the soil is evaluated. In contrast to wheeled machines, it can be assumed, that the introduced vertical forces of such a movement mechanism are the main reason for soil damaging effects. To quantify the impact of the portal advancing mechanism, the pressure introduced through the feet of the machine need to be determined. Using the kinematics of the machine, a theoretical calculation model is developed, with which the ground forces can be derived from the pressures in the hydraulic actuators. As this movement mechanism is still in an early stage of development, real world measurement data cannot be used to validate the theoretical calculation methods of the ground impact. Therefore, a simulation is used to generate first data and to validate the developed calculation method. Finally, the determined ground pressures of the portal advancing method are compared with values of other forestry machines found in literature.

2. Portal Advancing Mechanism

In this work the portal advancing mechanism is considered, which is a non-bionic principle for locomotion on sensitive wet and flat soils. The movement mechanism emerged out of the development of the so called "Portalharvester" in (Knobloch, 2017). The walking frame consists of two bases ("standing bases", SB), each with three hydraulic controlled legs, and a traversing bridge, which has an folding joint in its middle, connecting the two bases, as can be seen in Figure 6. A moveable upper carriage equipped with an engine and a forestry crane is mounted onto the bridge. As the legs of the mechanism are hydraulically telescopic, they take up as little space as possible during the walking process and keep the center of gravity close the top of the base. The bridge's inclination can be adjusted by ± 10 degrees at each base to compensate for a slope of the terrain. The portal advancing mechanism allows to move over terrain without wheel slip, so that only vertical forces must be compensated by the forest soil. Furthermore, the ground area that is affected by the machine is reduced in comparison to a state of the art wheeled or tracked forestry machine. (Knobloch, 2017)

Figure 6. Representation of the portal advancing mechanism with a harvester crane. (Knobloch, 2017)

2.1 Movement Cycle of the Portal Advancing Mechanism

To get a better understanding of the machine and the impact on the ground, it is necessary to first understand the movement sequence the machine goes through to complete one full step. First of all, the upper carriage is moved over one base, so that the half of the bridge opposite to the upper carriage can be folded up using the joint located in the middle of the bridge. In this configuration the bridge can rotate around the vertical axis of the base located bellow the upper carriage. To fulfill one complete step, the bridge is unfolded after the rotation is complete. All six legs are once more in contact with the ground again. Thus, the movement cycle can be divided into four parts:

1. Moving the upper carriage ($t = 2 \ldots 7\ s$)
2. Folding the bridge ($t = 8 \ldots 23\ s$)
3. Rotating the bridge ($t = 23 \ldots 32\ s$)
4. Unfolding the bridge ($t = 32.5 \ldots 44\ s$)

The normalized positions of all actuators involved in the movement for one full step are shown in Figure 7. As the movements of the three legs of one base are all parallel, they are shown as a single actuator ("Leg Cylinder"). It takes 42 seconds to complete a full step. In the first movement step, between $t = 2 \ldots 7\ s$ all six legs of the portal advancing mechanism are on the ground. As the inclination actuator moves out between $t = 8 \ldots 12$ s the three legs opposite to the upper carriage are lifted. In the time after that ($t = 14 \ldots 18$ s) the airborne legs are folded up. All the weight of the machine now remains on the opposite three legs. While the bridge is folded ($t = 18 \ldots 23$s), the machine's center of gravity moves to the rotation axis of the base. In consequence the complete weight will be distributed more equally onto the legs. The rotation starts after the folding is complete at $t = 23$ s. The bridge starts in a position between two legs and ends, after 9 seconds of rotation, over the third remaining leg at $t = 32$ s. After the rotation of the bridge is complete, the bridge starts to unfold itself. During the descent of the bridge, the extraction and lowering of the three airborne legs begins. At $t = 44$ s, all six legs are on the ground again and the load of the machine is once again carried by all six legs.

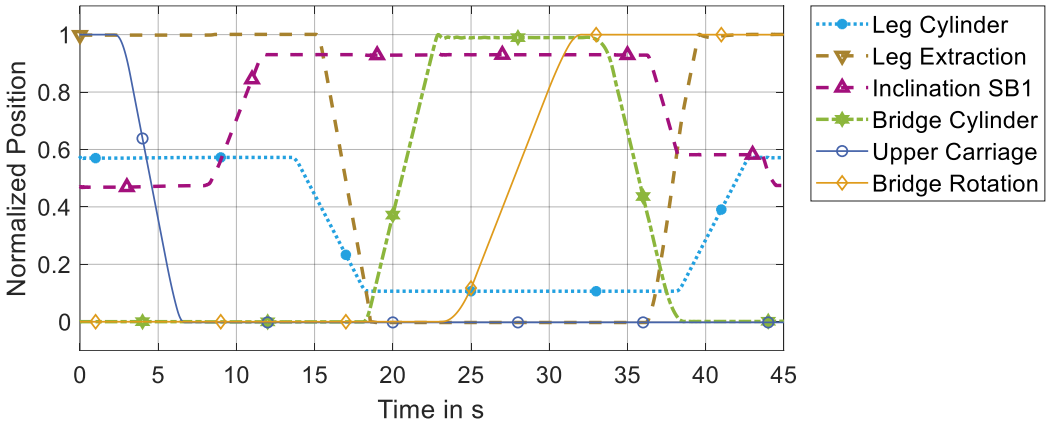

Figure 7. Relative positions of the actuators through one movement cycle.

3. Model Development and Comparison

3.1 Kinematic-based Calculation Method

To determine the relation between ground force and the hydraulic cylinder force, a free cut of the leg is made. The acting forces on the leg are depicted in Figure 8. At point A the leg is attached to the base. On the right side, the contact to the ground through a foot is simplified as shown. It is assumed, that the force vertical to $F_{z_{Foot}}$ and $F_{r_{Foot}}$ has no impact on the cylinder force and therefore this simpler 2D view can be used.

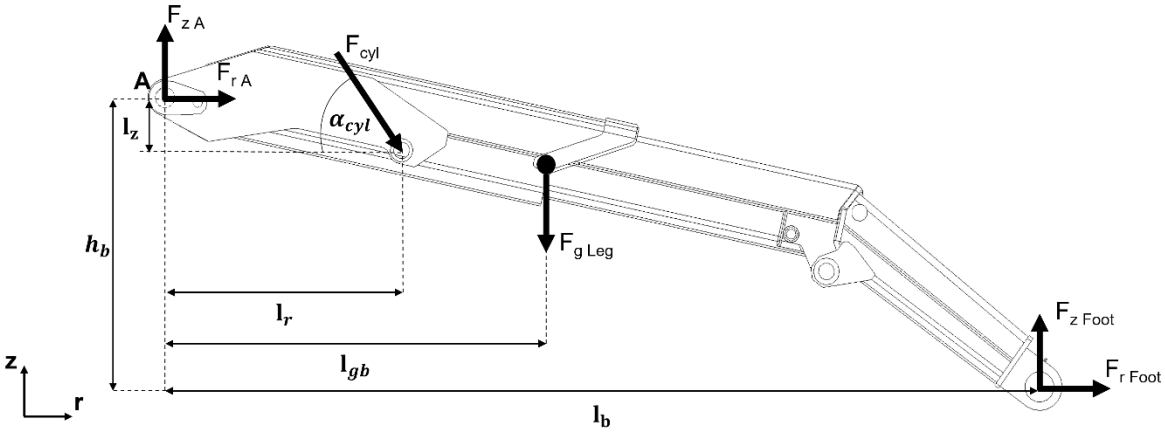

Figure 8. Free cut of one leg of the portal advancing mechanism

To determine the relation between hydraulic pressures in the hydraulic cylinder and the ground force $F_{z_{Foot}}$, only the equilibrium of torque around point A is used. The equilibrium can be written as follows:

$$0 = F_{z_{Foot}} l_b + F_{r_{Foot}} h_b - F_{g_{Leg}} l_{gb} - \sin(\alpha_{Cyl})\, F_{cyl} l_r + \cos(\alpha_{cyl})\, F_{cyl} l_Z \qquad (1)$$

α_{cyl} describes the angle in which the cylinder stands relative to the r-axis, $F_{g_{Leg}}$ the weight force of the leg, F_{r,z_A} the bearing forces of the leg and $F_{r,z_{Foot}}$ the simplified ground forces of the foot.

The different distances l_i are defined in Figure 8. This equation does not yield one clear result. Therefore, the

following second assumption is made: It can be assumed that all horizontal forces of the portal advancing mechanism, caused by inertia, are taken up by the force vertical to $F_{z_{Foot}}$ and $F_{r_{Foot}}$. Using this assumption, $F_{z_{Foot}}$ can be calculated and the force along the r-axis of the ground becomes zero:

$$F_{r_{Foot}} = 0 \tag{2}$$

To calculate the force of one cylinder the following equation is used:

$$F_{cyl} = p_{piston}A_{piston} - p_{rod}A_{rod} \tag{3}$$

By rearranging equation (1) and taking (2) and (3) into account, the wanted relation between the vertical ground force and the hydraulic pressures can be determined by using the following equation:

$$F_{z_{Foot}} = \frac{\left(p_{piston}A_{piston} - p_{rod}A_{rod}\right)\left(l_r \sin\left(\alpha_{Cyl}\right) - l_z \cos\left(\alpha_{cyl}\right)\right)}{l_b} + \frac{l_{gb}}{l_b} F_{g_{Leg}} \tag{4}$$

The contact pressure p_{ground}, which is introduced to the ground by the force $F_{z_{Foot}}$ of a single leg, can easily be calculated by dividing the force by the area of a foot A_{Foot}:

$$p_{ground} = \frac{F_{z_{Foot}}}{A_{Foot}} \tag{5}$$

To further simplify the system, the changes of distances, induced by a change in the length of the hydraulic cylinder, based on the compression of the hydraulic fluid, is assumed to be so small, that it can be neglected. Consequently, all distances l_i and the angle of the cylinder in Figure 8 are assumed to be constant.

With the developed equation, the pressure introduced to the ground by one foot of the portal advancing mechanism can be calculated through the hydraulic pressures in the cylinder of a leg. To evaluate the calculation method without real world data a simulation of the movement mechanism is used. The simulation is shortly described in the following section.

3.2 Simulation Model

To reduce development time and to avoid expensive mistakes a co-simulation is a proven tool in the product development process (Marthaler, 2021; Völker, 2011). To model the mechatronic system of the portal advancing mechanism, a holistic simulation model is set up. It consists of a multibody model of the kinematics coupled with a model of the hydraulic drive train. Such a coupled simulation has advantages in the modelling and the computing efficiency (Völker, 2011). In coupled simulations, each sub-model can use a specified solver for its task. The communication between the sub-models is managed by a master-solver. The system is coupled by the exchange of the system variables *force* and *position/velocity* between the two sub- models. Thereby, the movements of all joints are calculated in the multibody model under the effect of external forces. The calculated positions and velocities are then handed over to the model of the hydraulic drive train, where parts of the external forces are calculated and returned to the multibody model. (Völker, 2011)

Starting point for the parametrization of the model is the geometrical data of the mechanism and manufacturer specifications for the hydraulic actuators. This results in the dimensions for the kinematics, as well as the weight of the bodies. For the multibody model only motion relevant rigid bodies are used and reduced to simple geometrical shapes. These are then parametrized with the corresponding mass. In the hydraulic model only the cylinders for the legs and the inclination are modeled to reduce the complexity of the simulation. The pressures in each chamber of the cylinders are directly measured through attached sensors. The movement of the hydraulic actuators is controlled by simple time-depended signals, to create the wanted movements. These signals represent the openings of the valves and therefore the velocities of the hydraulically operated actuators. With only three of the six functions

necessary for one movement cycle modeled in the hydraulic part, the other actuators must be controlled directly by a signal which represents the movement. To get these movements, separate simulations were run with simplifications like the neglection of the ground contact. The results of these simulations were then used as the movement input for the joints. Thereby, the input for the bridge cylinder was modified with a transfer function with PT1 behavior to get a more realistic movement.

The ground contact of the portal advancing mechanism is modeled through a spring-damper-model in the vertical axis for each leg. Additionally, a simplified friction model with stick-slip effect is incorporated for the horizontal axes. The spring rate represents the toughness of the ground. For the generation of the first data, a flat and hard ground, like a paved surface, is assumed to reduce relative movements of the mechanism introduced through the compression of the springs. Therefore, the spring rate is chosen in a manner that the spring compresses about $0.2\ mm$ when the maximum force of a leg acts on it.

3.3 Postprocessing of Simulation Results

To determine the most time-efficient and accurate simulation setup, the relative tolerance of the master-solver of the co-simulation was set to either $1e-03$ or $1e-05$. The value of the vertical ground force over time is used to compare the simulation setups, as can be seen in Figure 9.

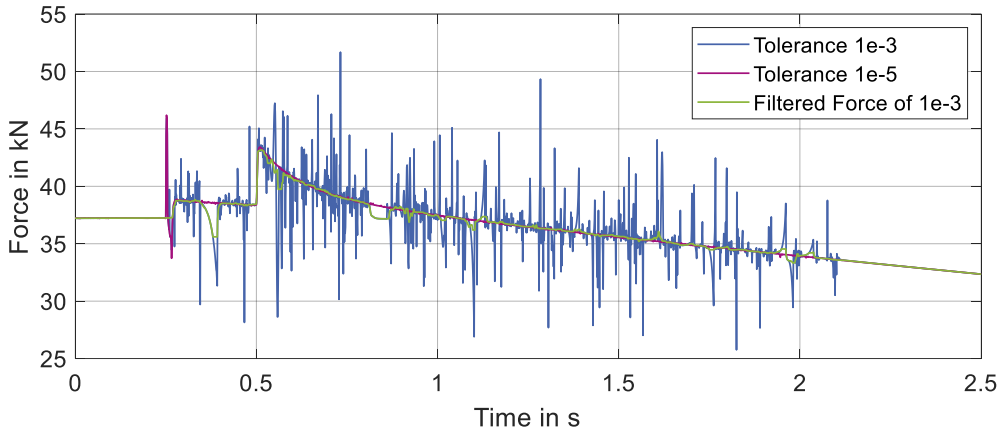

Figure 9. Comparison of simulation result of the vertical ground force over time for two relative error tolerances of the solver and a filtered output.

The overall value of the ground force decreases with a very similar slope in both the simulations with the higher and lower relative tolerance. However, the simulation with a relative tolerance of $1e-03$ shows a large number of numerical artefacts and impulsive jumps. A reason for this might be due to the fact, that the ground model is based on a spring-damper-model, which introduces substantial changes in force through little movements, or the sensitivity for oscillations of the solver.

To keep the computing time low, in this case about 72 hours, whilst also achieving a result, which can be compared to the results of the previously developed calculation model, the simulation results with the higher tolerance of $1e-03$ are filtered. The impulsive jumps in the signal can be seen as noise. To smooth out the noise and to preserve the sharp edges in the curve, a moving median filter is used. This filter can smooth out the impulsive noise and preserves sharp edges (Lawrence, Sambur, and Schmidt, 1975; Micek and Kapitulik, 2003). The result of this filter is pictured as a green line in Figure 9. The result of the applied filter is very similar to those with the lower tolerance of $1e-05$ (red line). Only in places where the unfiltered blue curve constantly differs to the red curve, the filtered values also deviate. The filter response also follows the jump at $t = 0.5$ s. The generated data using a relative tolerance of $1e-03$ and a moving media filter are sufficiently good enough for a comparison between the result of the calculation method and the filtered simulation result, leading to a drastic reduction of computing time in comparison to the simulation run with the lower tolerance. Therefore, for the rest of this study, a relative tolerance of $1e-03$ and a postprocessing step with a moving median filter is used for the generation of simulative data.

3.4 Comparison of Calculation Method and Simulation Results

To verify the assumptions that were made in section 0, the obtained values for the ground force of the leg with the highest load, calculated with equation (4), are compared to the simulation results. In the following all pressures used for the calculation method are obtained from the sensors in the simulation model. The values of the ground force determined by the calculation and simulation are plotted in the upper half of Figure 10. The difference between the values of both models is depicted in the lower half.

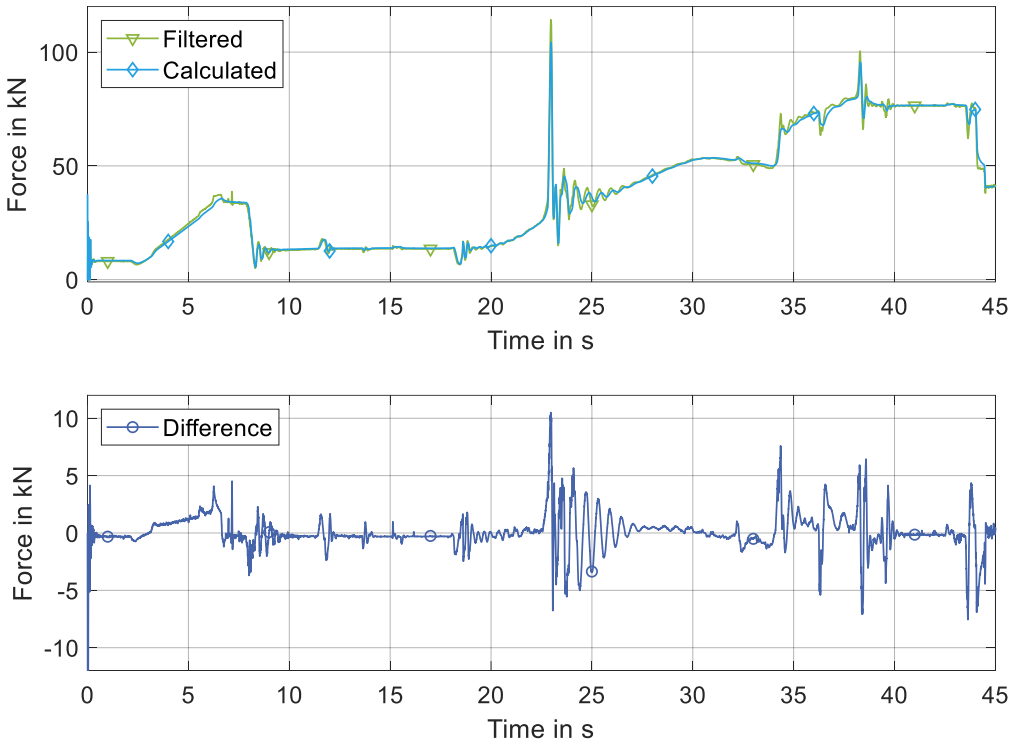

Figure 10. Comparison between the filtered and calculated ground force for the leg with the highest load their difference

The results of the calculation method (eq. (4)) match the results of the simulation to a large extend. At the beginning of the simulation, while the upper carriage is moving and the bridge is folded ($t = 1 \ldots 22$ s), the difference lies between ± 5 kN. Also, similar oscillations can be observed. At $t = 23$ s the biggest deviation of 10.5 kN can be seen. Here, the calculated force reaches a lower value in comparison to the simulated force. This peak happens at the end of the folding movement of the bridge. During this movement, the rotating mass is slowed down and oscillates for a short period of time in the hard stop of the bridge cylinder.

One possible reason for the calculation value to deviate from the simulation is that in the calculation it is assumed that the hydraulic cylinders have rigid distances. In contrast to this, the cylinder can change its length in the simulation, in dependence of the compression of the hydraulic fluid. A further reason for the error could be that for all distances in the calculation the values are rounded. Another likely reason for the errors could be the friction model, which is implemented for each cylinder. In this model, a viscous damping and a static friction force is added to the system, whereby the pressure build-up in the cylinder chambers is influenced with an additional external force. This additional force also influences the pressure level in the cylinder. Therefore, the total force acting along the cylinder is different to the calculated force that is only based on the pressures and the cylinder cross sections.

Boxplots of the deviations for all 6 ground forces are shown in Figure 11. The bases and foots are abbreviated in the following manor: Base: $SB_{1,2}$ and Foot: $F_{1\ldots6}$. As, during the first second, the simulation is in its settling process and the movement only starts after $t = 2$ s, the first second is not considered in Figure 11. The boxplots of the three feet of base 2 (SB2 F1 – SB2 F3) are dominated by outliers, because for 80 % of the time they are up in the air and have

no contact to the ground. For the other three feet, 50 % of all deviations are lower than ± 1 kN and over 95 % are under the ± 3.6 kN mark. In general, the forces calculated with the hydraulic pressure for the three feet of SB1 reach higher values than those obtained from the filtered simulation results. In total, the mean of the calculation lies at 90 N and the median at 240 N above the forces generated simulatively. The greatest deviation can be found at the first leg of SB1, where a force 10.5 kN lower and a force of 7.55 kN higher than the simulated force was calculated. These differences could mainly be based on the friction model for the hydraulic cylinder, as explained above.

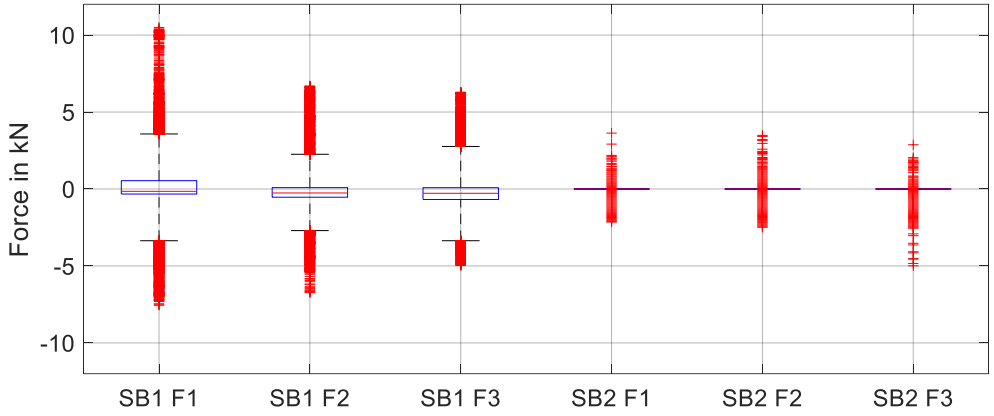

Figure 11. Difference between the calculated and filtered ground force for each foot.

Overall, the deviation between the calculated and simulated values are relatively small. Furthermore, Figure 11 shows, that the assumptions made in section 0 only lead to marginal differences between the calculation and simulation results. Therefore, the following results are based on the calculation method using the hydraulic pressures, as this model will allow for direct comparison with real-world prototype data in future studies.

4. Results of the Calculation Method

4.1 Estimation of the Soil Contact Pressure

In this chapter the results of the calculation model is presented. A cross section area of $0.33\ m^2$ for each foot is assumed to calculate the pressure from the ground force (see eq. (5)). The results for one movement cycle as described in section 0 is pictured in Figure 12. The corresponding forces can be seen in Figure 13. The movement of the upper carriage along the bridge between $t = 2 \ldots 7$ s can easily be identified by the swap of the load from base 2 to base 1. While every foot has ground contact, the pressures for the feet of the corresponding base are similar. Each foot reaches a maximum pressure of around 120 kPa. After the bridge is lifted, the pressure values rise to 180..190 kPa, as the load is now only distributed between three contact points to the ground. While the bridge is folded up ($t = 18 \ldots 23$ s), the pressures of the two feet under the bridge decreases while the pressure for the third, oppositely positioned foot increases. The load is split more equally between the three legs than during the period, in which the bridge is lifted, but not folded. This is due to the fact, that the center of mass now lies closer to the mid of the base than before. The oscillation, introduced by the deceleration of the bridge at $t = 23\ s$, creates a peak contact pressure of over 310 kPa. During the 180 degrees rotation of the bridge between $t = 23 \ldots 32$ s , the load distribution between the three feet changes. The bridge is now positioned above one single leg (SB1 F1). The highest nearly constant contact pressure of one entire movement cycle can be found here ($t = 40 \ldots 43\ s$) as this leg takes up most of the load. Through the positioning of the center of mass over one leg, a pressure of around 230 kPa is introduced to the ground until the bridge is completely lowered, and all six feet take up the load once more at $t =$ 44 s.

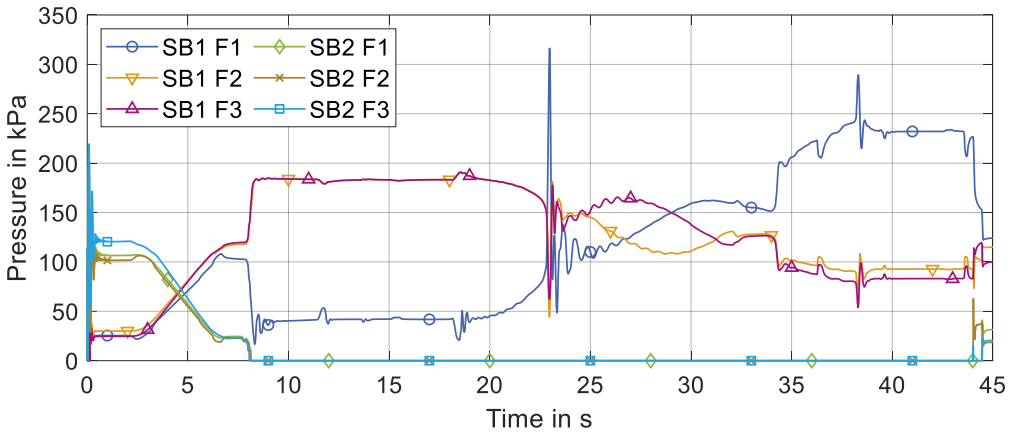

Figure 12. Introduced soil contact pressures of the legs of the portal advancing mechanism during one entire movement cycle calculated with the pressures in the hydraulic system.

4.2 Discussion of the Results

To evaluate the impact of the portal advancing mechanism on the ground, the calculated contact pressures are compared to values found in literature. During one movement cylce, a peak pressure of 310 kPa and a near constant pressure over 5 s of around 230 kPa can be observed.

A wide range of different types of forestry machines have been investigated in literature. The weight of these machines range from 650 kg for a horse to 45 t for a chain-tracked harvester. In (Horn, Vossbrink and Becker, 2004) this range was investigated and maximum contact pressures between 80 kPa and 180 kPa were reported. Similar pressures were determined by (Marusiak and Neruda, 2018) for a wheeled forwarder with a maximal mass of around 10 t. In this study pressures between 100 kPa and 240 kPa were reported. For wheeled machines forestry machines with total masses between 24 to 28 t (Riggert. Fleige, Kietz, Gaertig and Horn, 2016) reported mean contact pressures between 89 kPa to 216 kPa. With around 310 kPa the maximum peak contact pressure of the portal advancing mechanism reaches higher values than found in literature. Furthermore, the near constant contact pressure of around 230 kPa lies in the upper range or even above the values found in literature.

With no slip expected, the shear stress of the portal advancing mechanism can be predicted to reach values near zero or even zero. The major principal stress of the walking mechanism is therefore the contact pressure previously determined. When these values (230…310 kPa) are compared to literature values for the major principal stress, it can be seen, that the mechanism considered in this study introduces a comparatively lower stress to the ground. In (Riggert. Fleige, Kietz, Gaertig and Horn, 2016) principal stresses up to 526 kPa were calculated, whilst in (Horn, Vossbrink and Becker, 2004) the values range from 300 kPa to over 500 kPa. The values from literature are about 2 times higher than the ones presented in this study, if only non-peak pressures are considered. Therefore, it can be expected that the impact of the portal advancing mechanism on the ground is lower than that of classical forestry machinery. If the affected surface is additionally considered, the damage potential to the ground is decreased even further.

5. Conclusions

This article presents a calculation method to determine the contact pressure of a portal advancing mechanism. Results of the calculation method were compared to simulative results. Through this comparison, the calculation approach is verified, and it can be shown, that this approach achieves good results. The calculation shows that the considered legged forestry machine stresses the forest soil with a contact pressure of up to 230 kPa and over 310 kPa in peak points. This peak pressure depends on oscillations introduced to the hydraulic-mechanical system through acceleration or deceleration of the system during the movement cycle. The calculated pressures were compared to values from literature for common forestry machines. From this comparison, it can be expected that the

ground in general will be less stressed and less damaged, because no slip occurs.

6. Acknowledgment

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8. Appendix

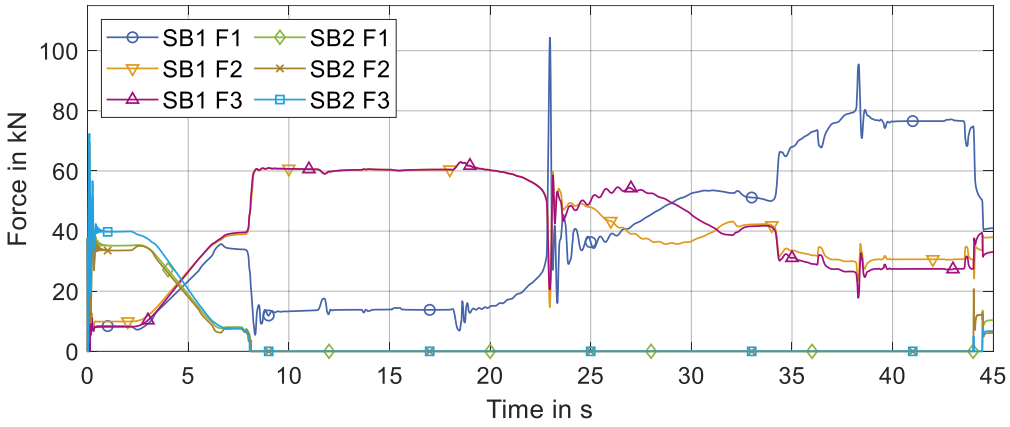

Figure 13. Ground forces through the movement cycle

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An Analysis of Best Management Practice Modifications in West Virginia

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ABSTRACT

Harvesting Best Management Practices (BMPs) are a common tool state governments use to minimize impacts to water, soils, and the residual vegetation on a site. In most cases BMPs are a set of voluntary practices that are collectively agreed upon by government, industry, and stakeholder groups. The loggers that implement these practices on the ground during timber harvesting, use these BMPs as minimum guidelines that they should be following, with many loggers using even more specialized practices that could be required for specific site or harvesting conditions.

Unlike many other states, The State of West Virginia requires all loggers to use the State's BMPs through the State's Logging Sediment Control Act. Loggers must notify the state before starting an operation through the submission of the Timber Harvesting Notification Form. This form includes basic contact and site location information, as well as a list of the primary BMPs that the logger must physically check off that they will follow on the site. In some cases and at some sites, conditions may not allow the BMPs to be implemented exactly like they are stated in the official documentation. In this situation, the logger is provided an opportunity to describe what they will do to meet the intent of the BMP through additional or modified efforts.

This paper will look at approximately 22,000 logging notification forms filed since 2013 to quantify and qualify the types of modified efforts that loggers are implementing to meet the BMP requirements. These listed modifications will be coded into similar practices for analysis with additional grouping based on stated site or operating conditions requiring the modified effort. This analysis will also help quantify the number operations requiring BMP modifications as compared to those stating that they will just follow the minimum requirement. Logging operation infraction reports issued by the WV Division of Forestry foresters on logging site inspections will also be analyzed to identify operations that could have avoided infractions through the use of an upfront BMP modification. Through these analysis, foresters and loggers should improve the use of BMP modifications so that the on the ground practices better meet the specific site and operating conditions.

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Assessing the Compactability of Forest Soils Using Impact Compaction Tests and Soil Tensiometers

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ABSTRACT

Tractive soil strength is a function of soil density and water content. High strength is required for optimum performance and efficiency of forestry equipment and trucks hauling logs. Impact compaction tests (Proctor 1933) may best emulate this type of soil deformation. The differences in the compactability of ten southwest Oregon forest soils from the 10-30 cm depth was assessed at five levels of compactive energy, namely 5, 10, 17, 25, and 35 blow counts (BC) per layer. Soil textures ranged from sand to clay; the finer-textured soils had a wide range of clay mineralogy. The standard compaction test produced maximum soil densities between 0.93 and 1.62 Mg m-3, and optimum water contents between 0.206 and 0.515 kg kg-1. Between 5 and 25 BC, soil density increased by 0.093 to 0.136 Mg m-3; soils with the highest compactability were dominated by montmorillonitic clay minerals. Relative density of native soils (native/25BC) averaged 0.688 and averaged 0.905 at 5 BC (5/25BC). Soil water content at -30 kPa of dried and sieved soil, was on the dry side of maximum density of a 5 BC compaction curve. McNabb et al. (2001) reported operational soil compaction by mostly wheeled skidders in west-central Alberta was not significant u nless soil wetness was drier than -15 kPa when measured on-site with a handheld tensiometer. The average relative density of Alberta native, loamy soils was 0.790 Mg m-3; the relative density was 0.812 for 7 sites that were not significantly compacted, and 0.863 Mg m-3 for the 7 sites that were. Thus, the 5 BC compaction curve for Oregon soils produced higher relative densities than the operational relative densities produced by Alberta skidders weighing 16-18 Mg. However, the water potential of when Alberta soils were significantly compacted is consistent with the shape of a 5BC compaction curve but would have a lower maximum density and higher optimum water content. Handheld tensiometers provide a more reliable reference as to when a soil will be more susceptible to compaction regardless of the soil water content. Soil water potential of wetter soils will also approach zero as the compacted density increases. In this regard, a handheld tensiometer could also prove useful in simple station-to-station monitoring of soil wetness when constructing low-standard, forest access roads.

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Forestry Best Management Practices, Ground Cover Analysis, and Erosion Potential Comparison between Conventional Clearcut Harvesting and Biomass Harvesting Operations in the Southeastern USA

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ABSTRACT

Woody biomass has been recognized as an important feedstock for renewable energy production and the harvesting, processing, and utilization of wood for energy is predicted to grow rapidly in the future. The increased demand for biomass for energy may result in increased utilization of forest residues changing the postharvest characteristics of harvested sites. Increased use of logging residues will reduce the amount of biomass retained in the soil and may lead to soil erosion if best management practices (BMPs) are not implemented properly. Factors such as slope, slope length, canopy cover, onsite storage, soils, rainfall, harvest timing, and BMP implementation can affect erosion rates on a harvest site. Thirty operational harvests in the coastal plain region of Alabama, Florida, and Georgia will be analyzed with 5 conventional and 5 integrated biomass harvest operations (clearcut) in each state. Our study aims to monitor the implementation status of BMPs during and after conventional and integrated biomass harvest operations, as well as comparing residual ground cover and erosion rates. BMP implementation status will be obtained using each respective states BMP manual and implementation survey. The clearcut harvest will be divided into 6 operational categories and the Universal Soil Loss Equation (USLE) will be used to estimate potential erosion rates within each operational area and overall site on the 30 sites. The total area of each harvest site and the area covered by each operational category will be determined from the orthomosaic maps prepared by using drone imagery which will be further used to calculate the weighted average erosion rate from each site. The expected outcome of this study is to determine if there are differences in BMP implementation and erosion between conventional and biomass operations. Ground cover analysis will be used to recommend the percentage of biomass

that should be retained on a site to avoid soil erosion.

Keywords: BMP implementation, logging residues, biomass harvest, conventional harvest, soil erosion

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Evaluation of Soil Disturbance After Small-shovel Logging System in South Korea

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ABSTRACT

Soil disturbance by forest operations is a common mechanized timber harvesting challenge to address sustainable forest objective. In South Korea (hereafter Korea), the small-shovels combined motor-manual felling are widely used in logging in steep terrains although cable harvest systems are feasible. Recently, the environmental issue, such as soil compaction, soil displacement and erosion, and rutting and puddling, has become increasingly important during harvest operations. Therefore, it is very important to understand the effect of small-shovel logging operation on soil disturbance, because the extent and degree of soil disturbance can be a site-specific and logging system. Extent define the amount of land surface alteration in a harvest unit and was assessed using a visual assessment method. Degree define the percent change in a soil physical property and was observed by a core sampling method. We will present data on the soil surface disturbance and compaction from small-shovel logging systems. The results can be an important knowledge to reduce negative effects on soil during small-shovel logging operations. In addition, Our results may provide forest managers with information to make mitigation strategies for soil disturbance.

Biomass and Bioenergy

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Linking Forests & Communities: Opportunities for Bioheat in Central Ontario

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ABSTRACT

Canada is home to 10% of the world's forest and these forests play a major role in both carbon sequestration and storage and in supporting Canada in achieving its commitment to reducing anthropogenic greenhouse gas emissions by 30% by 2030 relative to a 2005 baseline. To date, Canada has largely overlooked the emission reduction opportunities that comes from using forest biomass for larger-scale urban heating plants and district energy systems. By finding applications for forest biomass in lieu of fossil fuels, a reduction can be possible for forest fuel build up or experiencing natural losses such as insects, pathogens and wind. The newer biomass-based heating technologies have long been deployed in Europe, particularly in Nordic and Central European countries. However, in Canada there have been challenges to adopt large-scale biomass heating and the concerns seem to be centered around the capital cost feasibility and long-term forest sustainability. Using a case study approach, this project addresses these concerns through quantitively estimating the implications of managing forests for biomass fuels, designing a supply chain for biomass procurement and then finally a comparison with existing heating utilities. The case study, which is in two phases, focuses on the delivery of wood chips from Central Ontario to a potential biomass energy centre in Haliburton County. The first phase will be an analysis for the heat load demands of 4 distinct theoretical systems for Haliburton Village. The second phase, which will be the focus of this presentation, will be on designing various woody biomass supply chains and identifying the most suitable option based on community needs. The results demonstrate: 1. The different combinations of supply chains available 2. The key technology required for feedstock procurement 3. The factors impacting delivered feedstock cost based and 4. The challenges and considerations that need to be made when establishing a supply chain.

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Applications of Industrial Inventory Control Policy to Biomass Supply Chain Management

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ABSTRACT

The Mid-Atlantic Sustainable Biomass for Value-added Products Consortium (MASBio) is working to deliver a sustainable and economically feasible biomass production system for the manufacture of innovative bio-adhesives, 3D printing resins, biochar and other bio-based products. As a component of this large, integrated regional project, the MASBio team is developing the next generation of multi-feedstock supply chain models to manage biomass supply risk for three important feedstocks: logging residues from timber harvest and purpose-grown willow and switchgrass cultivated on marginal agricultural lands and reclaimed coal mines. Across the global economy, inventory management, also known as inventory control, has become a cornerstone of supply chain management, seeking to maximize supply chain efficiency, profitability, and resilience. However, despite the proliferation of research studies focused on woody biomass supply for energy, fuels and products in recent decades, very few studies in this field employ contemporary inventory control methods to solve biomass procurement and inventory problems. This presentation will provide an overview of various structural inventory control policies applied to biomass supply chains, including base stock, (R,T), (R,Q), and (s,S) policies. Such policies directly leverage key control metrics such as stock levels, review frequency, lead time, yield inflation, holding costs and others. Simulation, mathematical programming, and dynamic programming models are then applied to achieve optimal inventory control under these policies to improve the efficiency and resilience of individual bioenergy and bioproducts facilities under supply uncertainty. The authors provide examples from a single-facility, single-feedstock inventory control perspective and then expand to more complex multi-facility, multi-supplier, and multi-feedstock supply chain systems that account for uncertainty across different spatial and temporal scales. The study concludes with a discussion of some practical implications and future research suggestions for this field.

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The Impact of Weather Conditions on Fuel Consumption of Comminution and Transport of Wood Raw Material in Estonian Conditions

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ABSTRACT

One of the key objectives of the still valid Estonian national energy and climate plan 2030 is the reduction of GHG emission in Estonia by 80% by 2030. But now, to contribute the goals of the European Green Deal, Estonian Government has declared the commitment to reach climate neutral by 2050. Achieving the targets, the use of wood fuels should increase. But the latest prognosis of forest resources indicated, that the harvesting volumes are forecasted to decrease during the coming decades. In the situation of limited resources, the production of wood fuels should take place throughout the year, and the efficiency of production becomes especially important. Among different factors influencing the supply chain are precipitation and air temperature. As a result of data analysis resulted in regression equations that can be used to calculate the fuel consumption required to produce wood chips. During the measurement period, the minimum temperature was -20oC and the maximum was +30oC and the maximum daily precipitation was 30 mm. If the temperature was -10oC and the precipitation was 0 mm then the fuel consumption was during transport 0,566 l/ml3 and chipping 0,533 l/ml3. When precipitation increased 10 mm at the same temperature, fuel consumption during transport was 0,663 l/ml3 and chipping 0,617 l/ml3. Precipitation and temperature affect fuel consumption during transport and chipping. The analysis is based on daily data of the weather, fuel consumption, mileage, produced wood chips and working time.

Keywords: wood chips, weather impact, fuel consumption

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A Methodology to Estimate the Utilization Potentials of Woody Biomass Recovered Fire Management Activities

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ABSTRACT

Wildfires has become one of the dominant contributors of carbon emissions to the atmosphere. Fire management activities such as post-fire salvage logging, thinning and prescribed burning, slash pile removal and burning, and hazard reduction rings around communities can potentially mitigate fire risk on the landscape, while recovering woody biomass for the society, especially remote communites, to build shelter, generate energy, and produce bioproducts such as clothing textiles, in addition to conventional wood products. Efficient uses of the woody biomass recovered from hazardous fuel treatment activities may futher contribute to climate change mitigation and socio-economical well-being, and therefore, quantitative analyses are required. Many existing wood flow and carbon dynamics modelling have been relying on conventional harvesting and production data from sources such as mill surveys and FAO statistics. However, woody biomass recovered from fuel treatment activities is unlikely to have the same species, size and quality compositions as a conventional clearcut harvest.

This study developed a methodology to estimate the fire management biomass quality and size compositions using species, age, geographicaly location (site index, biogeoclimatic zone, timber supply area) and corresponding yield curves, and then allocate the biogenic carbon to appropriate production processes in the MitigAna model, a harvested wood products carbon dynamics model that simulates the fate of biogenic carbon for scenario-based mitigation analysis.

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Using the SDG Action Manager to Address the Sustainable Development Goals (SDGs) in Forest Operations

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Abstract: The Sustainable Development Goals (SDGs), developed in 2015 by the United Nations, are a set of 17 internationally agreed-upon goals that set 169 targets to be reached by 2030 and are part of the Agenda 2030 for sustainable development. The SDGs encompass different aspects of the environment, economy, and social issues. This initiative recognizes, among others, the role of the business sector as a driver of economic growth and job creation. Aligning the companies' processes and activities to the SDGs brings infinite benefits to the company in all three sustainability pillars. By addressing the SDGs along with its processes, a company can diagnose future business opportunities, reinforce corporate sustainability values, enlarge stakeholder relations, maintain policy developments and stabilize societies and markets, as many reporting tools had concluded. However, no study on the Forest Sector has assessed how to identify and define which SDGs a company should and can focus on. This study aimed to assist a forest company in addressing the SDGs along with its operations. In order to do that, a web-based tool, the SDG Action Manager, developed by the United Nations Global Compact and B Lab, was used. The tool and its features were used and analyzed as a case study in a specific forest company in Romania. Through online sessions, the methodology was applied and discussions regarding the SDG Action Manager's applicability and its needed improvements were accessed. As a result, the online tool proved to be useful for this company and assessed and tracked the SDGs that fitted their forest operations. During the assessments, some features' improvements were detected, and recommendations for updates were proposed by the users. In conclusion, the SDG Action Manager is a very helpful, consistent, and intuitive tool. Forest companies that aim to both, start addressing the SDGs in their operations or that already track SDGs but want to improve the management of their targets and objectives, could benefit from using this online tool. Still, more structured research should take place in order to investigate all the benefits to forest operations, and new follow-ups should be carried out to investigate the long-term usability of the tool.

Keywords: Forest operations; SDGs; Sustainable Development; Sustainability Reporting; Web-based tool.

1. Introduction

In 2015, as a result of many previous initiatives and discussions regarding sustainable development and new agendas for climate action, the United Nations, through the UN Department of Economic and Social Affairs, launched the Sustainable Development Goals (SDGs), the 17 global goals that aim to bring prosperity for people and the planet (UN, 2015). During its first 5 years, not much progress towards its implementation has been done on a global scale. Now, with less than 10 years left to deliver practical actions that meet the 169 targets, implementation measures in all sectors must be proposed, in order to develop suitable action plans.

The implementation of the SDGs in the forest sector can develop and scale up sustainable development. Companies will then, be able to face new challenges, build a strong growth strategy, and access new markets. According to research done by Nosratabadi et al. (2019), the competition among companies is now very complex, due to the need

of fitting with SDGs and globalization, resulting in conventional business models struggling to find appropriate solutions to survive. In this context, the alternative concept of SDGs may bring a competitive advantage to organizations by inflating traditional business models to achieve sustainable development while maintaining profitability and productivity. Assessing and implementing actions toward the SDGs´ achievement means promoting sustainable forest services, innovating solutions for low-income markets, expansion of renewable energy options, and developing sustainable forest operations. Previous research has focused on studying the benefits of meeting specific SDGs and reporting it to the external community using reporting tools (Bali Swain & Yang-Wallentin, 2019; Dawes, 2019). However, no study has assessed how to identify and define which SDGs forest companies should and can focus on.

Aligning processes and operations to the SDGs brings infinite benefits to the company in all three sustainability pillars. The three-pillar model of sustainability has been extensively used to explain and promote a tripartite framework that conceptualizes sustainability as involving not only the environment but all aspects of human society. The World Commission on Environment and Development (WCED) studied the future prospects of the human species from a rather holistic perspective and proposed long-term environmental, social, and economic strategies for policymakers, already in the 1980s (Schweier et al., 2019). This framework proposes that sustainability results from pursuing and balancing three dimensions of sustainability: environmental (i.e., preserving ecosystem resilience and environmental quality), social (i.e. maximizing human health and well-being), and economic (i.e., maintaining production of vital goods and services) over the long term (WCED, 1987). Environment, Social and Economic dimensions will benefit from SDGs compliance.

The aim of this research paper was to check whether the SDG Action Manager could be useful for a forest company to assess their forest operations´ contributions towards the SDGs and, as a result, to develop and implement sustainable action plans. This paper is structured as a descriptive case study, where a literature review, materials, methods, results, discussions, recommendations, and conclusion will be presented. The main objective of this study is to analyze the applicability of the SDG Action Manager in a forest company along with its operations, and also:

- To evaluate and interpret the reports generated by the SDG Action Manager System;
- To identify which SDGs the given forest company should focus on;
- To assist the company in setting action plans to meet the SDG targets.

2. Literature Review

2.1 The Sustainable Development Goals

The Sustainable Development Goals (SDGs) are a set of 17 global goals, addressing 169 targets and 232 indicators, created by the United Nations in 2015 as part of the 2030 agenda for sustainable development (UN, 2015). The SDGs encompass different aspects of the environment, the economy as well as social issues. In 2015, the General Assembly of the United Nations formally adopted ‘‘The 2030 Agenda for Sustainable Development” which provides a framework for ‘‘peace and prosperity for people and the planet, now and into the future” (UN, 2015). In this Assembly, all the UN member states agreed in supporting the Sustainable Development Goals as a way to promote the central objective of sustainable development. By 2030, the SDG aims to end world poverty while undertaking actions to tackle climate change and its impacts, balancing economic, social, and environmental development (Rosati, 2018).

Setó-Pamies & Papaoikonomou (2020) claims that the core of the 17 SDGs is to provide a guide to tackle the world’s most pressing challenges including ending poverty and bringing economic prosperity, social inclusion, environmental sustainability, and peace to all countries and all people by 2030. To succeed in their implementation, the SDGs need support from the private sector. According to Global Reporting Initiative (GRI), the success of the SDGs relies on the ability to engage the private sector and untie their innovative power. From the companies’ perspective, addressing the SDGs alongside their operations and reporting this to the external community can bring many benefits such as the creation of accountability, building trust, encouraging collaboration and demonstrating commitment, empowering assessments by third parties, pushing internal performance improvements and acting as a learning tool for others (GRI, 2018).

2.2 Tools and Frameworks to address the SDGs

Based on previous work, it is clear that addressing the SDGs in a consistent way will facilitate the optimization of its implementation and it is essential for achieving synergy among the 17 goals, considering they complement each other (Fu et al, 2019). Along the process of defining the SDGs, many different tools could be used. Allen et al. (2019), for example, adopted a multi-criteria analysis (MCA) framework to assess and prioritize SDG targets, based on their ranking according to ‘‘level of urgency”, ‘‘systemic impact” and ‘‘policy gap”. By using a number of approaches within the MCA framework to consider target feedback and interlinkages, and mapping policy alignments and gaps, the authors show how MCA can provide an assessment approach to support national planning and reporting (Allen et al, 2019).

In recent years, many initiatives started developing guidelines and frameworks to support and assist in SDGs implementation. There are basically three broad categories of tools, based on the focus and nature of the framework: Mapping, Reporting, and Aligning tools. Organizations such as the Global Reporting Initiative (GRI) and United Nations (UN) related institutions lead the research and development of these tools and frameworks. Grainger-Brown & Malekpour (2019) suggests that, to support organizations in engaging with and acting upon the SDGs, a suite of tools and frameworks have been developed by scholarly and practice communities over the past years. As an example, the new version of the ‘Global Reporting Initiative’ includes the SDGs, the ‘SDG compass’, and the ‘SDG industry matrix’.

One of the latest tools launched in January 2020, is the SDG Action Manager, a web-based impact management solution. Developed by UN Global Compact in collaboration with B Lab, this tool aims to provide all types of companies and operations an opportunity to learn, manage, and directly improve their sustainability performance, enabling businesses to address the SDGs by 2030.

3. Materials and Methods

For the purpose of this study, it is important to establish the difference among the processes of addressing the SDGs. Most of the current academic studies had the objective of presenting different tools to report on the SDGs (Linser & Lier, 2020; Miola & Schiltz, 2019). They analyzed and proposed ways to better report SDGs and their trade-offs (Kroll et al, 2019). On the other hand, this work took a step back and aimed to offer an overview of a tool to access the SDGs, and interpret and implement measures to track them. In order to successfully report and implement sustainable initiatives along its operations, a company needs to understand and address SDGs that are applicable to its business (Muff et al, 2017).

3.1. Company Description

This study was carried out in collaboration with a forest company located in Romania. In different countries, this company owns total forestland of over 700,000 ha. Their core activities are framed around sustainable forestry, forestland purchasing, and silvicultural services. Its main business focuses on wood production and the sale of cutting rights; in addition, they sell high-quality waterfront plots and soil resources and lease rights of access to their land. For the purpose of this research, the idea was to offer the company a tool to justify and support their sustainability reporting and bring more scientific-based orientation in identifying and tracking the contributions towards the SDGs, helping them to better understand, prioritize and set goals. The SDG Action Manager was applied to manage the SDGs tracking in the Romanian Forest Operations.

3.2 The SDG Action Manager

The SDG Action Manager tool was tested jointly by the researcher, the Romanian Country Manager, and the administrative manager, through online assessments during May 2020. The SDG Action Manager is structured as a series of distinct modules, beginning with a “Baseline Module”, designed to be comprehensive and rooted in the Ten Principles of the UN Global Compact as well as the Sustainable Development Goals. At the end of the process, the company will be able to get a clear view of its operations, supply chain, and business model and what prioritized measures are necessary to successfully implement actions that meet the SDG's targets. This tool works as a voluntary process. The results might be used as parameters to develop action plans or either complement possible future

measures or existing frameworks and tools, improving the companies' activities in reporting sustainable operations progress.

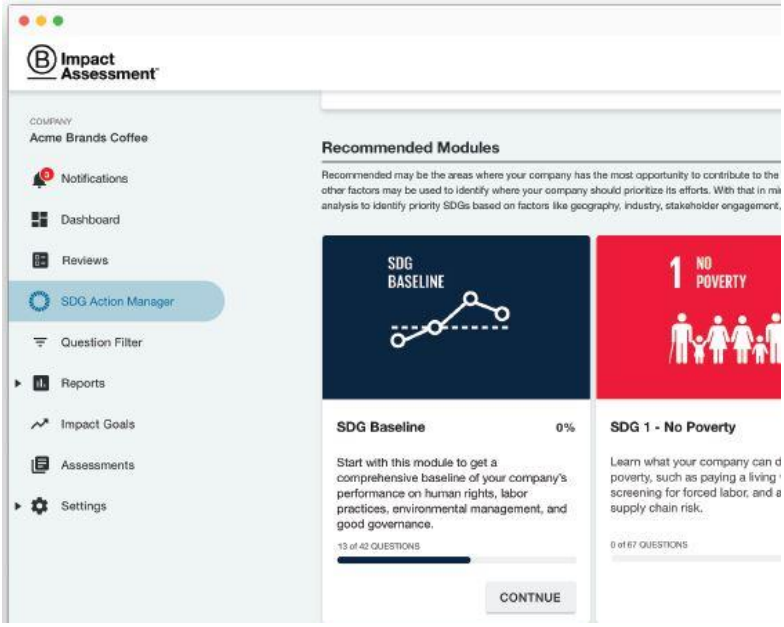

Figure 1: SDG Action Manager Dashboard.
Source: © Copyright 2020 B Lab

3.3 Data collection

To start using the tool, a user profile was created on the platform where the company details such as the Company Workforce, Corporate Structure, and Primary Operating Address were filled. The first step was, of answering the 35 questions of the Baseline Module, which included cross-sector issues applied to all SDGs, focusing on topics such as human rights, labor practices, environmental management systems, and good governance. According to the SDG Action Manager Technical Guide, the users will receive guidance on which modules to select, facilitate the prioritization of SDGs and better identify opportunities for improvement, given their particular context. As a result, the "Recommended SDGs" section, with questions designed to go deeper into the business processes (UNGC, 2020). Within the recommended SDGs, the company can undertake the SDGs that are of most interest to their business, based on their activities, geography, industry, etc. The recommended module questions are structured to cover different aspects of businesses that can contribute positively to the Global Goals. The main subtopics are Business Model, Internal Operations, Supply Chain, Collective Action, and Risk Level.

3.4 Data analysis

After completing the selected modules, there is a Report Section where the company has access to its SDG performance. Here, one can check the performance for the baseline and for each recommended SDG module, and also for the subtopics within each module. The SDG performance objective is to support companies to keep tracking their improvements towards the implementation of SDGs targets. The scoring for each module is presented as a percentage (0-100%), with the underlying subtopics given based on a scoring (0-25) procedure, in order to provide an easily understandable overall score for a given SDG module, while also allowing the users to more clearly track and quantify detailed performance and improvements on a deeper level. Each subtopic per module is equally weighted in the overall performance rating for that module (UNGC, 2020).

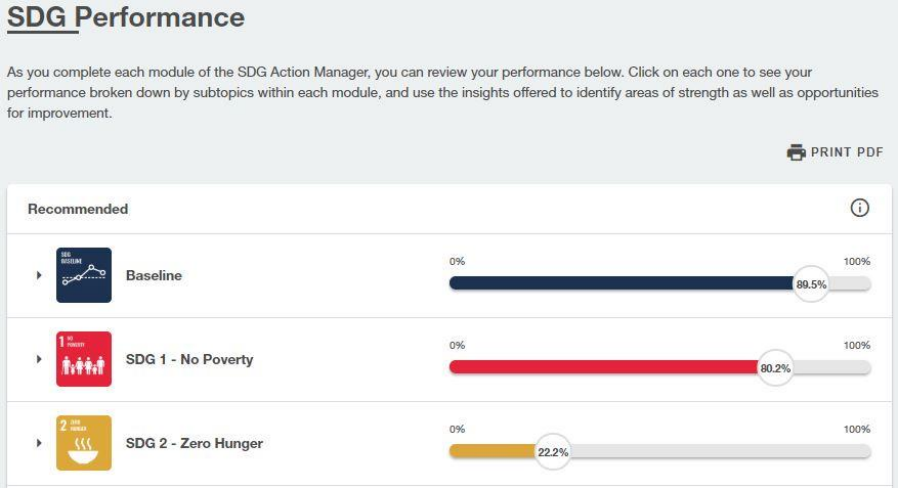

Figure 2: SDG Performance Rating.
Source: © Copyright 2020 B Lab

In addition to the individual scoring, a Risk Level assessment is available on the platform. The objective of this assessment is to raise awareness of potential important priority areas for a company to consider when acting; however, it does not consider the negative or hindering practices within the company. In contrast to the scoring methodology, the risk level is measured as "flag ratings" (UNGC, 2020). For the SDG Action Manager system, positive practices cannot exceed potentially negative practices in the process, and that being so, it is important to measure and acknowledge them separately.

4. Results

After the first Baseline Module assessment, the SDG Action Manager recommended 11 SDGs out of 16, considering the most relevant SDGs for the company activities. The remaining SDG 4, SDG 7, SDG 9, SDG 10, and SDG 11 were considered non-relevant to the business. After the assessment, the company chose to focus on 6 SDGs from the 11 recommended ones: SDG 1, SDG 6, SDG 8, SDG 13, SDG 15, and SDG 16.

Figure 3: Selected SDGs for the Forest Company.
Source: Copyright © United Nations

The six selected SDGs were chosen based on the company's core activities and future planned actions to improve and optimize sustainable positive impacts. According to a survey conducted as part of the development of the SDG Action Manager, 50% of companies aim to prioritize between 1-5 SDGs (UNGC, 2020). Although there are 17 SDGs, they are interconnected and holistic.

Each SDG module has a different total number of questions. The questions were based on a balance between depth and breadth of coverage for each SDG target, but also with an emphasis on targets of universal relevance and materiality across businesses (UNGC, 2020). The baseline module questions covered common topics from specific SDGs modules, through its 35 questions. Furthermore, only the companies' selected SDGs specific modules (SDG 1, SDG 6, SDG 8, SDG 13, SDG 15, and SDG 16) were answered completely, which resulted in a response of 100% of these specific modules, different from the response percentage of the remaining SDGs that were not completely answered (FIGURE 4):

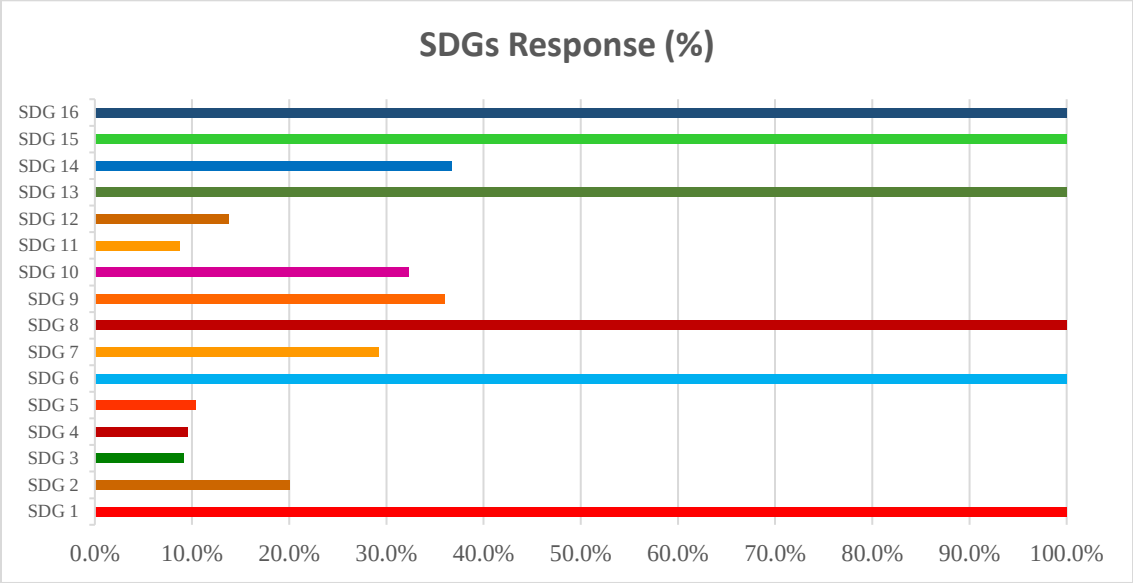

Figure 4: SGDs Specific Module Response (%).
Source: The author.

The SDG Action Manager online dashboard brings the Report Section, where it is possible to find the SDG overall performance for each specific SDG module.

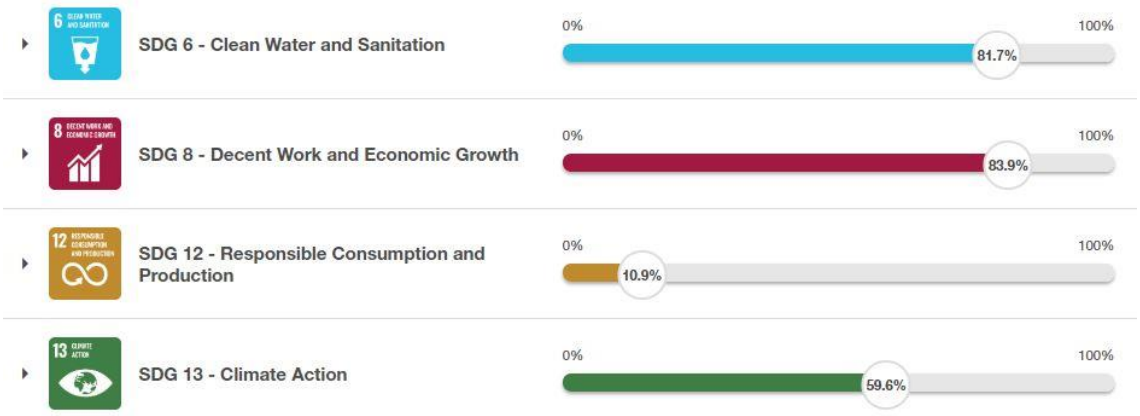

Figure 5: SDG Specific Module Overall Performance.
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As expected, the higher performances were found in the selected SDGs, in which the module questions were completely answered. Among the total 16 SDGs, the performance ranged from 2,90 % to a maximum of 96,30%, as can be seen in Figure 6.

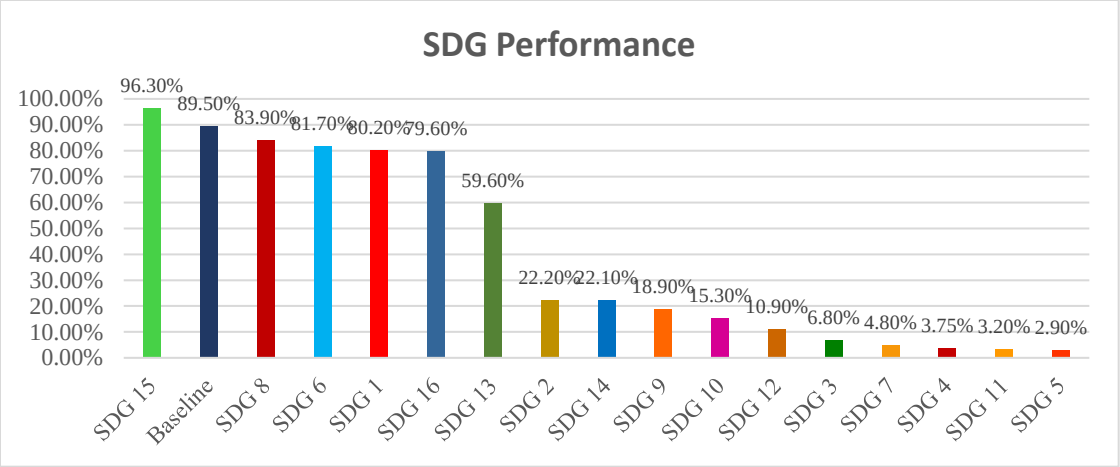

Figure 6: SGDs Performance (%).
Source: The author.

Of the six selected SDGs, SDG 15 "Life on Land" presented the best performance (96,30%), followed by SDG 8 "Decent Work and Economic Growth" (83,90%), SDG 6 "Clean Water and Sanitation" (81,70%), SDG 1 "No Poverty" (80,20%), SDG 16 "Peace, Justice and Strong Institutions" (79,60%) and SDG 13 "Climate Change" (59,60%). The Baseline Module presented the second-best score (89,5%). Besides the overall SDG performance score, there is a score breakdown by each subtopic within the SDG-specific module, which aims to assist companies in understanding their respective strengths and potential areas for improvement (FIGURE 7).

Figure 7: SDG 15 Performance subtopics scoring.
Source: © Copyright 2020 B Lab

The four subtopics (Business Model, Internal Operations, Supply Chain, and Collective Action) are presented on a points basis (0-25), in order to provide an easily understandable overall score. For SDG 15, for example, it is possible to clearly track and quantify positive performance and improvements towards the accomplishment of life on land targets that meets the company's practices.

Finally, the risk assessment for the selected SDGs (1, 6, 8, 13, 15, 16) varied from Low to High Risk (TABLE 1). The risk assessment covers potential issues that may affect the SDGs. The main objective of this section is to indicate risks and potential areas to mitigate.

TABLE 1: Risk Assessment Level on Selected SDGs.

SDGs	**Risk Level**	**Risk Assessment**
SDG 1	Low	***Risk to Achieving No Poverty:*** NONE

SDG 6	High	***Risk of undermining the progress on Clean Water and Sanitation:*** - We do not consider special needs related to gender and physical ability while planning water, sanitation and hygiene services in our company's facilities and communities - Our suppliers do not consider special needs related to gender and physical ability while planning water, sanitation and hygiene services in their facilities and communities - Our facilities are located in or close to sensitive water related ecosystems ***Exposure to Risks Identified to Achieving Clear Water and Sanitation:*** - 5% or more of our revenues come from an industry identified above as having risk to contribute to SDG 6 - Clean Water and Sanitation
SDG 8	Low	***Risk of undermining the progress on Decent Work and Economic Growth:*** - We have had operational or on-the-job fatalities ***Exposure to Risks Identified to Achieving Decent Work and Economic Growth:*** NONE
SDG 13	Low	***Risk of undermining the progress on Climate Change:*** NONE
SDG 15	High	***Risk of undermining the progress on Life on Land:*** - We or our supplies operate in an industry with a large potential impact on terrestrial biodiversity (*e.g.* Agriculture, Logging, Pulp and Paper, etc.) - We engage in lobbying activity, including involvement in industry organizations and trade associations that engage in lobbying activity, that have the risk of inhibiting progress on SDG 15 - Life on Land - Our facilities or operations are located adjacent to or in sensitive terrestrial or freshwater ecosystems
SDG 16	Low	***Risk of undermining the progress on Progress on Peace, Justice and Strong Institutions:*** NONE

5. Discussions

After using the SDG Action Manager, some interpretations were possible. The app is an important tool for companies that want to start tracking the SDGs along with their operations and have no clue about how to start the process and which tools and frameworks to use. According to a PwC SDG Engagement Survey in 2015, which generated 986 business responses, only 13% of businesses surveyed stated that they had appropriate tools to measure and manage their impacts in the context of the SDGs (PwC, 2015). In addition, the World Business Council for Sustainable Development (WBCSD) reported that 79% of its members acknowledge the SDGs, but only 6% measure their contribution to their achievement (WBCSD, 2017).

This study enabled the company, which has been already reporting sustainability initiatives, to strengthen and justify its choices regarding SDGs tracking and monitoring. Through the use of the SDG Action Manager, the company was able to analyze specific details and practices regarding human and labor rights, environmental issues, and anti-corrupt measures, that may be neglected in the previous sustainability assessments. In addition, the SDG Action Manager highlighted specific issues which demand more attention from the company's strategic planning, for example, measures towards SDG 13 "Climate Change", which had an unexpected low performance (59,60%), and its carbon emissions reductions targets. According to Jacob (2017), establishing a reliable performance measurement system for the SDGs is important to ensure effective evidence-based policymaking.

The fundamental advantage of using the SDG Action Manager is the possibility of any company, independently of its size, location, and funds available for reporting on sustainable practices, to start addressing the SDGs in their operations. The majority of frameworks for engagement of enterprises in the SDGs, most conceptual developments, and the frameworks for reporting, are designed for large enterprises (Mousiolis et al. 2015). Another advantage reported by the company is the integration of different SDGs along with the modules and the possibility of understanding the focus and targets of each SDG. For example, the tool presents aspects of risk assessments for natural disasters and labor activity, that may be unknown to many decision-makers. This inconsistency between commitment

and action can be in part explained by the lack of appropriate impact measurement and management systems that enable businesses to demonstrate their contribution (Mori et al. 2017).

In recent years, tools for impact measurement and management of sustainable initiatives have multiplied. Still, managers face issues and questions that need to be addressed to obtain reliable and actionable knowledge towards sustainable development. These critical questions include choosing tools that fit specific objectives and meet data requirements; making results actionable through transparent evaluation criteria; integrating more comprehensive impact measurement, without exhausting organizational capacity to handle complex sustainability issues (Martinuzzi & Schönherr, 2019).

Besides proving to be an excellent alternative for companies to start addressing the SDGs along with their activities, the studied company pointed out some topics that need special attention:

- *The generalization of questions in the assessment:* the tool seems to cover a broad range of industries, having no specific inquiries for the forest sector;
- *The tool seems to be a starting point:* the assessment shows which SDGs to focus and work on, but other tools and frameworks will be necessary to track progress and to meet indicators;
- *The risk assessment management should be reviewed:* the risk level results do not comply with the SDG performance, considering that it uses another scale of measurement, which may cause confusion and affect the strategic planning;
- *The tool's interface and support system need to be improved:* for implementing the SDG Action Manager in a company's system, updates and interface modifications are needed.

Therefore, after completing the assessment and testing the web-based tool, the company expressed its satisfaction in using the tool. Further studies and investigations will be developed in the company and presented to the direction board, and the SDG Action Manager may be suggested for further developments of sustainability strategies. Despite plenty of studies regarding SDGs and their applications, the overview of the SDG Action Manager as a tool to track and monitor SDGs in forest companies is a recent study. Up to date, no similar study analyzing this tool and its applications has been done, not allowing the findings of this study to be compared and discussed.

6. Recommendations

Based on the test assessment conducted and its results, this study proposes some recommendations for the improvement of the SDG Action Manager and its applicability in forest operations. Despite understanding the main features of this tool, which is inserting and initializing companies in the SDGs tracking and reporting, the main recommendation of this study is that, the tool's developers should review its broad coverage and the necessity of also considering different sectors in its modules assessments, designing more specific topics for different industries. This study also reinforces previous research that suggested measures to strengthen sustainability reporting and accelerate actions towards SDGs. These measures include:

- To increase the awareness and education regarding environmental issues and sustainable development among the population, mainly in the business sector; this way, more companies could support and train their teams to better report on sustainability-related questions;
- To promote corporate transparency as a means to learn, and to improve positive sustainability impact across different industries. It is important to encourage businesses to report both improvement actions that need to be done along with their operations, and also to report initiatives that already have positive impacts and are present in the companies' daily processes;
- To improve the reporting of SDGs in different types of business, in small, medium, or multinational companies. As many companies report their progress toward the SDGs accomplishment, much more sustainable development and sustainability concepts will spread over the business sector, strengthening this practice over companies' culture;
- To spread the idea that identifying and tracking actions toward the SDGs is not a difficult and expensive initiative, but instead, an initiative that aggregates value to the process, and that there are free and easy tools and frameworks that could assist organizations in starting reporting on the SDGs. Strong reporting on sustainable development goals can play a role in stimulating new partnerships, scaling sustainable business models, and enabling new financial investments. Enterprises that aim to keep competitive in the future

economy and have sustainability concerns ought to consider starting using tools that can assist them in addressing the Sustainable Development Goals.

7. Conclusion

This study aimed to analyze the applicability of the SDG Action Manager to track and report on the SDGs in a forest company along its forest operations. In a conclusion, the adoption of this tool in monitoring and reporting on sustainability progress and the SDGs is an initiative that supports long-term planning and decision-making, by providing substantial information to stakeholders and to the general community. In the next years, the Sustainable Development Goals will guarantee that companies follow sustainable standards in their business, ensuring that the environment and society do not pay an elevated price for this development. Sustainability Reporting should not be faced and understood as a new fashion trend only, yet as a manner to guarantee a serious commitment of a company towards sustainable development. Tools and frameworks that assist companies in addressing the SDGs should be considered, as they will help sustainable business models towards the SDG achievements. The SDG Action Manager proved that free tools and frameworks are available to assist companies in starting the process of reporting on sustainable development goals, allowing the improvement and increase of corporative activism and SDGs' visibility and adherence. Undoubtedly, the forest sector stands out as an important player in tackling climate change and strengthening sustainable initiatives. Different forest operations can contribute to SDGs goals and targets, and the whole forest supply chain can increase and accelerate sustainable development through its processes.

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Annual Available Amount of Forest Biomass Resources from Profitable Aggregated Forests in the Kanuma Area of Tochigi Prefecture, Japan

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Abstract: This study estimated the annual available amount of forest biomass resources from profitable aggregated forests merging sub-compartments in the watershed of the Kanuma Area, Tochigi Prefecture, Japan, by considering the regeneration expenses incurred by the sustainability of forest management and by discounting the future revenues and costs to the present net values. In addition to the economic balances, this study estimated the GHG emissions including CO_2, CH_4, and N_2O. 32,264 sub-compartments (26,552 ha in total and 0.82 ha in average) of 41,062 sub-compartments (33,059 ha in total and 0.81 ha in average) were aggregated to 1,241 aggregated forests (26,552 ha in total and 21.40 ha in average) although 8,798 sub-compartments (6,507 ha in total and 0.74 ha in average) were not aggregated. Under the Feed-in-Tariff program, the economic balances of both, direct combustion and small-scale gasification facilities would be positive. For log prices of 10,000 JPY/m^3 and forest biomass resources prices of 3,000 JPY/tDM, the annual available amount of forest biomass resources with subsidies and regeneration costs was increased to 18,216 tDM/year from 12,044 tDM/year before aggregation because the harvesting cost including the indirect cost such as the machine moving cost in addition to the variable cost was decreased to JPY3,074/tDM from JPY6,571/tDM. Since subsidies play important roles on economic balances of regeneration and thinning operations in Japan, the annual available amount of forest biomass resources without subsidies was reduced to 6,058 tDM/year. In relation to log price increments, the annual available amounts of forest biomass resources were increased. The GHG emission of the direct combustion plants having a capacity of 6.0 MW was decreased to 72 gCO_2eq/kWh from 81 gCO_2eq/kWh before aggregation. That of a small-scale gasification power plants having a capacity of 2.4 MW was also decreased to 58 gCO_2eq/kWh from 63 gCO_2eq/kWh before aggregation. Thus, aggregation is crucial for economically viable and environmentally friendly forest biomass supply in Japan.

Keywords: aggregated operation, economic balance, forest biomass resource, GHG emission, supply potential

1. Introduction

Following the Great East Japan Earthquake, the supply capacity of electricity has been reduced, because the operation of many nuclear power plants has been suspended. In this context, the Japanese Government proposed to promote the introduction in use of renewable energy sources including biomass. In August 2011, the "Act on Purchase of Renewable Energy Sourced Electricity by Electric Utilities" was adopted in the Diet for the introduction of the "Feed-in Tariff Scheme for Renewable Energy" starting from July 2012. In the Feed-in Tariff (FIT), the purchase price (without tax) of electricity sourced by unused materials such as thinned wood and logging residues was of 32 JPY/kWh, that sourced by general materials such as sawmill residues was of 24 JPY/kWh, and that sourced by recycled material such as construction waste wood was of 13 JPY/kWh. Furthermore, a price of 40 JPY/kWh for unused materials having a generation capacity less than 2 MW was set in order to promote the use of wood coming from thinning operations and logging residues from a large number of small, fragmented, and scattered forests, starting with April of 2015. Incentives have promoted the use of power generated from unused materials, and they are expected

to increase the use of wood sourced by thinning operations and logging residues from 2 million m^3 in 2014 to 8 million m^3 in 2025 based on the forest and forestry basic plan of Japan established in May 2016. This study estimated the annual available amount of forest biomass resources from profitable aggregated forests in Kanuma Area of Tochigi Prefecture, Japan while considering the regeneration expenses for the sustainability of forest management and by discounting the future revenues and costs to the present net values using the long-term relationship between the supply potential and the procurement cost of forest biomass resources established in a previous study (Aruga et al., 2011). In addition to the economic balances, this study estimated the greenhouse gas (GHG) emissions including CO_2, CH_4, and N_2O while the studies of Yoshioka et al. (2005b) and Aruga et al. (2011) estimated only CO_2 emissions.

2. Materials and Methods

2.1 The General Approach

Forest biomass resources can be categorized into several categories including logging residues, wood sourced by thinning operations, and broadleaved trees (Yoshioka et al., 2005a). GIS layers of forest resource, slope, public and forest roads were obtained from Tochigi Prefectural Government in order to estimate the supply potential and the procurement costs of timber and forest biomass resources. In order to analyze the long-term relationship between the supply potential and the procurement cost of timber and forest biomass resources, in this study, future forest resources on each stand were predicted using the system yield table, Local Yield Table Construction System (LYCS, Shiraishi, 1985). Then, the stand harvesting schedules were planned by balancing the supply potential of forest biomass resources using random search while minimizing the procurement costs. Annual available amounts of forest biomass resources were estimated as the supply potential from profitable sub-compartments.

2.2 Study Site

The site chosen for this study is located in Kanuma area, consisting of Kanuma city and Nishikata town (Aruga et al., 2011). This area encompasses 52,000 hectares, of which about 65% are covered by forests. Most of forests are man-made (79%) of which tree species are conifers; Japanese cedar (Sugi) and Japanese cypress (Hinoki) account for 54% and 23% of the trees, respectively. Most of conifers are within 45-50 years old. As for the site slope, most of forests are relatively steep, 30 degrees or more. The density of the road network in the Kanuma area is of 18 m/ha.

2.3 Procurement Costs

Harvesting and transporting systems for forest biomass resources were classified into two types depending on the parts of a tree used to recover energy wood (logging residues or the whole tree sourced by thinning operations and broadleaved trees). Logging residues are considered as a byproduct of conventional forestry while the wood coming from thinning operations and broadleaved trees are assumed to be felled for energy utilization. Therefore, the system boundary of logging residues starts with comminuting logging residues at the landing by a mobile chipper while the system boundary of thinning operations and broadleaved trees starts with felling operations in the forests (Aruga et al., 2011). In this study, cable skidders, swing yarders, tower yarders, and conventional yarders are assumed to be used for the skidding/yarding operations. Cable skidders could be used for slopes below 11 degrees for uphill skidding and for slopes below 19 degrees for downhill skidding. In this study, one machine from the described types is assumed to be selected for each stand so that the skidding/yarding costs are minimized within the topographic condition of each stand (Aruga *et al*. 2011). The harvesting and transporting costs of timber and forest biomass resources were estimated in relation to slope θ (degree), average stem volume V_n (m^3/stem), harvesting volumes per ha V (m^3/ha), the number of trees harvested per ha N_F (stem/ha), skidding/yarding distance L_Y (m), and transporting distance L_T (m). In addition to the direct costs of labor, machine, and fuel, the indirect costs of labor (55% of the direct cost of labor), machine moving cost (50,000 JPY/each), overhead costs (14% of the total direct cost), piling costs in the log market (700 JPY/m^3), handling fees associated with the logging contractor (5% of timber and forest biomass prices) and the log market (5% of timber prices), and consumption tax (5% of the direct cost) are considered herein. Thinning operations are subsidized in Japan. In this study, subsidies were estimated using the standard unit costs, areas, assessment coefficients, and the subsidy rate. Standard unit costs were determined by age and thinning rates (Table 1).

Table 1. Standard unit costs (JPY/ha) for thinning operations

Age (year)	Thinning rate

	Less than 30%	More than 30%
26-35	400,792	600,612
36-45	381,288	571,935
46-59	386,176	579,261

The assessment coefficient and the subsidy rate were assumed to be 1.7 and 4/10, respectively. In addition to subsidies given to conduct thinning operations, subsidies to develop strip roads for thinning operations are also received in Japan. These subsidies were also estimated using standard unit costs, areas, assessment coefficients, and the subsidy rate. Standard unit costs for construction of strip roads were determined on slope categories (Table 2).

Table 2. Standard unit costs for construction of strip roads

Slope	Standard unit costs
< 5 degrees	159
6 to 10 degrees	191
11 to 15 degrees	230
16 to 20 degrees	276
21 to 25 degrees	477
26 to 30 degrees	850

In addition to these timber extraction costs, regeneration expenses including site preparation, planting, weeding, vine cutting, pruning, and forest inventory were estimated by labor expenses and the number of people necessary in each operation, non-personnel expenses, and insurance expenses (Okawbata 2003). Regeneration expenses were estimated as 2,512,376 JPY/ha for Japanese cedar and 2,892,365 JPY/ha for Japanese cypress, respectively. This study considered the subsidy for regeneration. Similar to the thinning operations, subsidies were estimated using the standard unit costs, areas, assessment coefficients, and the subsidy rate of Tochigi Prefectural Government. Subsidies were estimated as 1,227,400 JPY/ha for Japanese cedar and 1,219,240 JPY/ ha for Japanese cypress, respectively. Therefore, the net regeneration expenses were estimated as 1,284,976 JPY/ha for Japanese cedar and 1,673,125 JPY/ ha for Japanese cypress, respectively.

2.4 Revenues

The current supply potential of timber and forest biomass resources can be estimated from the stem volume recorded in the forest register and the coefficients such as the thinning ratio, ratio of the top and branches' volume to stem volume, and tree density (Aruga et al., 2011). To estimate the future available amounts of timber and forest biomass resources, the yield system table, LYCS (Shiraishi, 1985) was applied to the forest register. Time interval was set to five years. In order to ensure a steady yet continuous work of the energy conversion plants, forest biomass resources should be steadily and continuously supplied. In this study, the stand harvesting schedules were planned for sixty years by balancing the supply potential of timber and forest biomass resources using the random search approach set to minimize the procurement costs (Aruga et al., 2011). Revenues were estimated using the supply potential and log prices which were set to 10,000 JPY/m^3 and forest biomass resources prices which were set to 3,000 JPY/ton of dry matter (tDM). After the estimation of revenues, the available amounts of forest biomass resources from profitable sub-compartments were also estimated. In addition to these figures, sensitivity analyses were conducted with various log prices such as 8,000 and 12,000 JPY/m^3, and forest biomass resources prices such as 6,000 and 10,000 JPY/tDM, respectively. Forest biomass resources prices (6,000 JPY/tDM) were estimated with the additional subsidy and an amount of 10,000 JPY/tDM was estimated according to the FIT introduced in Japan.

2.5 Economic Balances

Two types of energy-conversion technology were considered in this study. One was the direct combustion and the other was the small-scale gasification (Aruga et al., 2011). Under the FIT program, the price of electricity was set to 40 JPY/kWh for less than 2 MW produced and 32 JPY/kWh for more than 2 MW produced. Furthermore, this study assumed that the steam could be sold to houses at a price of 0.5 JPY/kg. Then, the economic balances of direct combustion and small-scale gasification were estimated.

2.6 GHG Emissions

GHG emissions coming from all the processes of the system were examined using the method described by Yoshioka et al. (2005b), Aruga et al. (2011), and Ministry of the Environment (2005). In addition to those described in Yoshioka et al. (2005b) and Aruga et al. (2011), dismantlement of a power generation plant was estimated as 5% of the construction costs.

3. Results

3.1 Economic Balances

The maximum supply potential of forest biomass resources was estimated to 28,872 tDM/year, which was enough to meet the fuel requirement of a 5 MW direct combustion power plant (Aruga et al., 2011). According to the procurement costs (9,562 JPY/tDM) of forest biomass resources including the subsidies and regeneration costs, thinned trees were the cheapest (6,960 JPY/tDM), followed by logging residues (9,330 JPY/tDM); broadleaved forests incurred the greatest costs with 13,143 JPY/tDM (Aruga, 2017). This study aggregated 32,264 sub-compartments (26,552 ha in total and 0.82 ha in average) of 41,062 sub-compartments (33,059 ha in total and 0.81 ha in average) to 1,241 aggregated forests (26,552 ha in total and 21.40 ha in average) in the watershed although 8,798 sub-compartments (6,507 ha in total and 0.74 ha in average) were not aggregated. As a result, procurement cost of the average, thinned trees, logging residues, and broadleaved forests were reduced to 3,682, 358, 6,700, and 12,566 JPY/tDM, respectively (Figure 1).

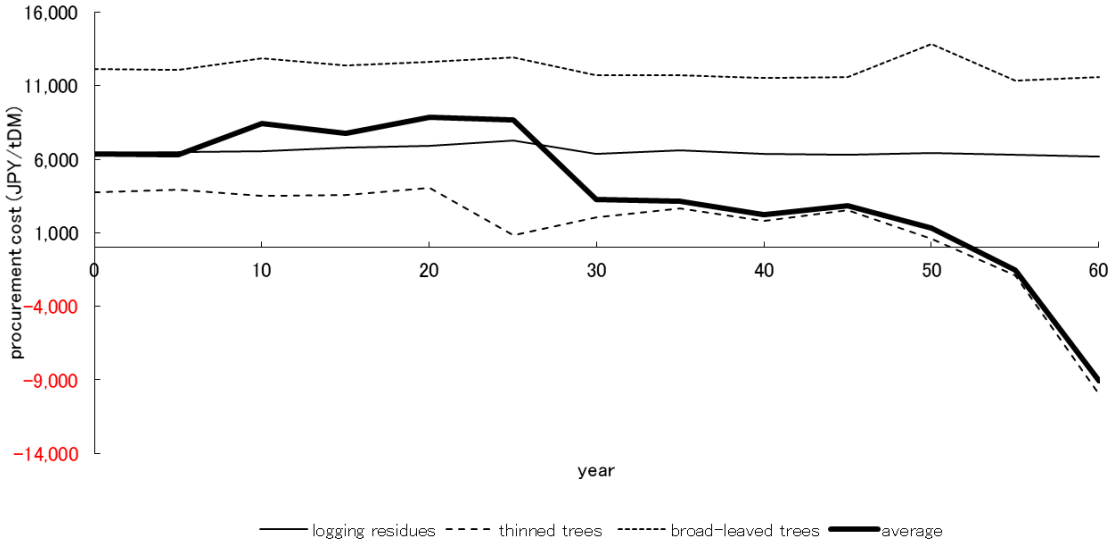

Figure. 1. Procurement cost including the subsidies

According to the supply potential of forest biomass resources including subsidies and regeneration costs, logging residues were assumed to be harvested based on the harvesting schedule while the broadleaved forests and wood sourced by thinning operations were assumed to be harvested to meet sufficient volumes if the forest biomass resources were not sufficient (Figure 2). The trend shown in Figure 2 was similar to the results of a previous study (Aruga, 2017). For timber, the maximum supply potential and the procurement cost were of 82,729 m^3/year and 5,565 JPY/m^3 without aggregation, while the same figures were of 85,929 m^3/year and 5,173 JPY/m^3 with subsidies and regeneration costs.

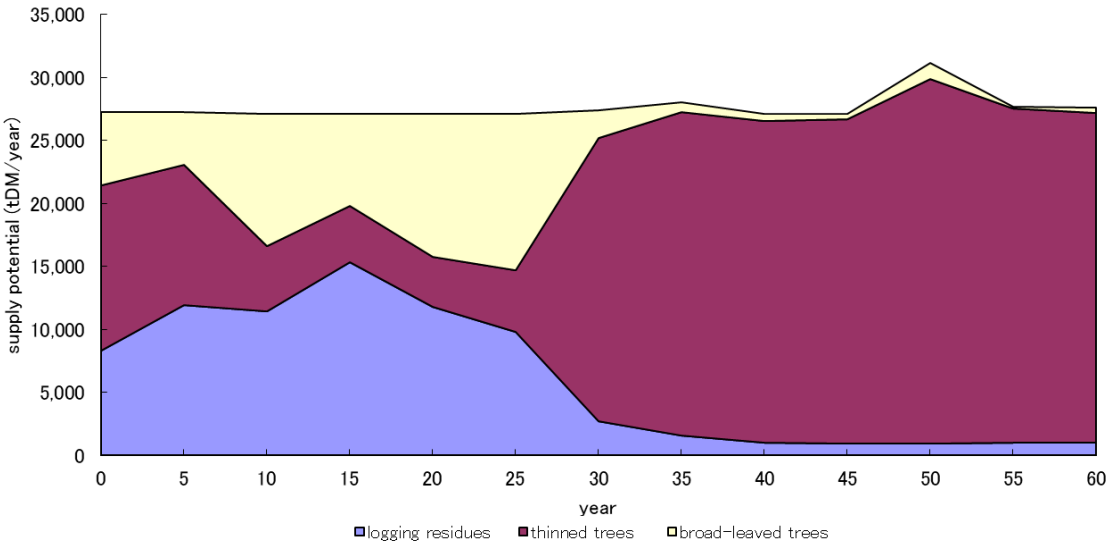

Figure 2. Supply potential with subsidy

In a previous study (Aruga et al., 2011), the average price of electricity sold to power grids in Japan was assumed to be 8 JPY/kWh. Since the generation costs specific to direct combustion and small-scale gasification were more than 24 and 13 JPY/kWh, the economic balances of electricity generation were in deficit. If the steam could be sold to houses at a price of 0.5 JPY/kg, the economic balance of small-scale gasification would be positive whereas the economic balance of direct combustion would remain negative (Aruga et al., 2011). Under the FIT program, the price of electricity was set on 40 JPY/kWh for those plants producing less than 2 MW and to 32 JPY/kWh for those producing more than 2 MW. Therefore, if the steam could be sold to houses at a price of 0.5 JPY/kg, then the economic balances of both direct combustion and small-scale gasification would be positive (Figure 3). The economic balances would be improved by the subsidies, especially for direct combustion in which the procurement costs contributed significantly.

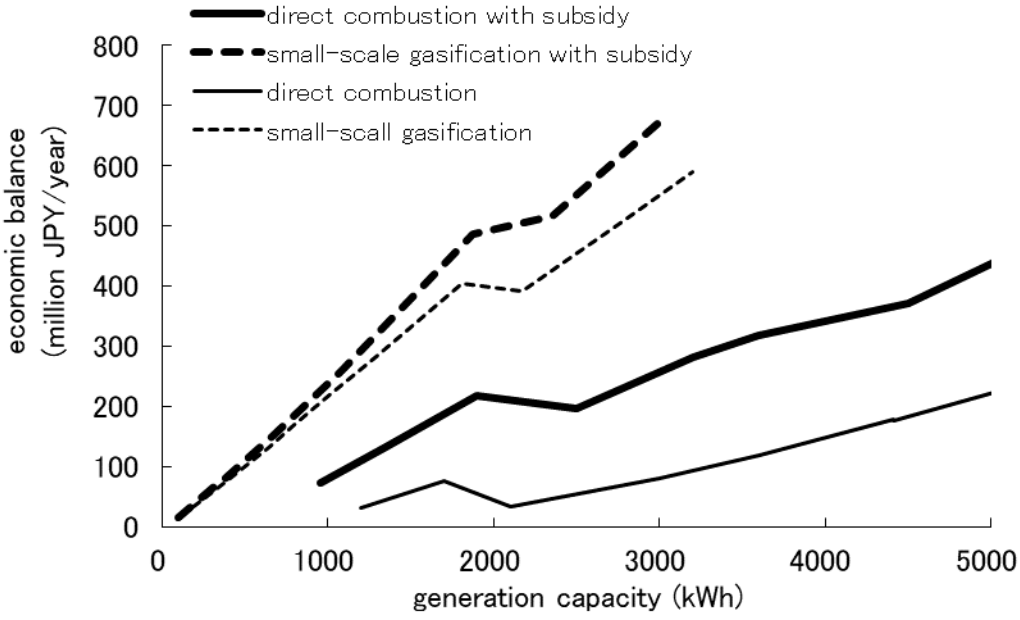

Figure 3. Generation capacity and economic balance

3.2 Annual Availability of Timber and Forest Biomass Resources

With log prices set to 10,000 JPY/m^3 and forest biomass resources prices set to 3,000 JPY/tDM, Aruga (2017) estimated the annual available amount of forest biomass resources from profitable sub-compartments including subsidies and regeneration costs at 12,044 tDM/year. It consisted of logging residues (3,999 tDM/year) and thinned trees (8,045 tDM/year). After aggregation, the annual available amount of forest biomass resources with subsidies and regeneration costs was increased to 18,216 tDM/year because the harvesting cost including the indirect cost such as the machine moving cost in addition to the variable cost was decreased to JPY3,074/tDM (Table 3).

Table 3. Availability of forest biomass resources and timber and the procurement costs with and without subsidies and regeneration costs for log prices of 10,000 JPY/m^3 and forest biomass resources prices of 3,000 JPY/tDM

Source	Subsidy		No Subsidy	
	Regeneration	**No Regeneration**	**Regeneration**	**No Regeneration**
Total	18,216 tDM/year 3,074 JPY/tDM	21,252 tDM/year 1,028 JPY/tDM	6,058 tDM/year 8,654 JPY/tDM	18,078 tDM/year 8,601 JPY/tDM
Logging residues	5,521 tDM/year 6,580 JPY/tDM	6,263 tDM/year 6,601 JPY/tDM	2,132 tDM/year 6,537 JPY/tDM	6,973 tDM/year 6,580 JPY/tDM
Thinned Trees	12,692 tDM/year 1,547 JPY/tDM	14,986 tDM/year -1,302 JPY/tDM	3,923 tDM/year 9,806 JPY/tDM	11,103 tDM/year 9,870 JPY/tDM
Broadleaved Trees	3 tDM/year 7,596 JPY/tDM	3 tDM/year 7,657 JPY/tDM	3 tDM/year 7,614 JPY/tDM	3 tDM/year 7,671 JPY/tDM
Timber	78,946 m^3/year 5,010 JPY/m^3	89,703 m^3/year 5,164 JPY/m^3	30,406 m^3/year 4,852 JPY/m^3	99,840 m^3/year 5,188 JPY/m^3

With these prices, only 63% of maximum supply potential of forest biomass resources was available and a few broadleaved forests were assumed to be harvested. Also, due to the limited prices, the procurement cost of forest biomass resources was reduced from 3,682 JPY/tDM (see Figure 1) to 3,074 JPY/tDM (see Table 3) because the procurement cost of logging residues was reduced from 6,700 JPY/tDM to 6,580 JPY/tDM and that of broadleaved forests was reduced from 12,556 JPY/tDM to 7,596 JPY/tDM although that of thinned trees was increased from 358 JPY/tDM to 1,547 JPY/tDM. For timber, the annual available amount and the procurement cost were of 78,946 m^3/year and 5,010 JPY/m^3 respectively, accounting for 92% and 97% of the maximum supply potential and procurement costs of timber. Subsidies play important roles on economic balances of regeneration and thinning operations in Japan. However, subsidies would be reduced due to limited budget of the Japanese government. Since the revenues from clear cutting operations cannot cover the regeneration costs in the current conditions, forest owners would not conduct planting operations even on unsuitable natural regeneration sites after clear cutting. Therefore, sensitivity analyses were conducted to discuss the effects of subsidies and regeneration operations on the annual available amounts and procurement costs of forest biomass resources.

Without subsidies and with regeneration costs, the annual available amount of forest biomass resources from profitable sub-compartments was estimated at only 6,058 tDM/year. It consisted of logging residues (2,132 tDM/year), the wood sourced by thinning operations (3,923 tDM/year), and broadleaved forests (3 tDM/year) as shown in Table 3. Only 21% of the maximum supply potential of forest biomass resources was available. With these limited prices, the procurement cost of forest biomass resources (8,654 JPY/tDM) was higher than that with subsidies because the procurement cost of wood coming from thinning operations increased from 1,547 JPY/tDM to 9,806 JPY/tDM while the costs of logging residues and broadleaved forests without subsidies were similar to those with subsidies. For timber, the annual available amount and the procurement cost were also reduced to 30,406 m^3/year and 4,852 JPY/m^3 due to no subsidies for regeneration costs. Without regeneration costs, the annual available amount and the procurement cost of timber were significantly higher, especially without subsidies. Subsequently, the annual available amount of logging residues was higher. However, the increment was small with subsidies. The annual available amount of wood coming from thinning operations with subsidies was increased whereas that without subsidies was decreased significantly. Therefore, it was confirmed that subsidies play an important role in thinning operations. If subsidies would be reduced due to the limited budget of Japanese government, regeneration and procurement costs should be reduced by developing new harvesting systems and by enhancing the forest road network in order to ease the extraction of timber and forest biomass resources.

According to the increment of log price, the annual available amounts of forest biomass resources from profitable sub-compartments were increased because the profitable sub-compartments were increased (Table 4). However, a few

broad-leaved forests were still harvested in this scenario. Then, the forest biomass resources prices were increased (Table 5). As a result, the annual available amounts of broadleaved trees from profitable sub-compartments were increased in direct relation to increment of forest biomass resources price.

Table 4. Availability of forest biomass resources and timber and the procurement costs with subsidy and regeneration according to different log prices and for 3,000 JPY/tDM forest biomass resources prices

Source	8,000 JPY/m^3	10,000 JPY/m^3	12,000 JPY/m^3
Total	12,090 tDM/year 3,410 JPY/tDM	18,216 tDM/year 3,074 JPY/tDM	21,182 tDM/year 2,776 JPY/tDM
Logging	3,133 tDM/year	5,521 tDM/year	6,449 tDM/year
residues	6,511 JPY/tDM	6,580 JPY/tDM	6,608 JPY/tDM
Thinned	8,953 tDM/year	12,692 tDM/year	14,730 tDM/year
Trees	2,323 JPY/tDM	1,547 JPY/tDM	1,097 JPY/tDM
Broadleaved	3 tDM/year	3 tDM/year	3 tDM/year
Trees	7,631 JPY/tDM	7,596 JPY/tDM	7,611 JPY/tDM
Timber	44,732 m^3/year 4,554 JPY/m^3	78,946 m^3/year 5,010 JPY/m^3	92,313 m^3/year 5,323 JPY/m^3

Table 5. Availability of forest biomass resources and timber, and procurement costs with subsidy and regeneration according to 10,000 JPY/m^3 log prices and different forest biomass resources prices

Source	3,000 JPY/tDM	6,000 JPY/tDM	10,000 JPY/tDM
Total	18,216 tDM/year 3,074 JPY/tDM	33,176 tDM/year 4,769 JPY/tDM	33,163 tDM/year 5,081 JPY/tDM
Logging	5,521 tDM/year	5,924 tDM/year	5,872 tDM/year
residues	6,580 JPY/tDM	6,712 JPY/tDM	6,663 JPY/tDM
Thinned	12,692 tDM/year	20,651 tDM/year	20,261 tDM/year
Trees	1,547 JPY/tDM	1,875 JPY/tDM	2,010 JPY/tDM
Broadleaved	3 tDM/year	6,601 tDM/year	7,030 tDM/year
Trees	7,596 JPY/tDM	12,077 JPY/tDM	12,611 JPY/tDM
Timber	78,946 m^3/year 5,010 JPY/m^3	84,754 m^3/year 5,022 JPY/m^3	83,998 m^3/year 5,023 JPY/m^3

3.3 GHG Emissions

The GHG emission of the direct combustion plants having a capacity of 6.0 MW was decreased to 72 gCO_2eq/kWh (Figure 4) from 81 gCO_2eq/kWh before aggregation. That of a small-scale gasification power plants having a capacity of 2.4 MW was also decreased to 58 gCO_2eq/kWh from 63 gCO_2eq/kWh before aggregation. Thus, aggregation is crucial for economically viable and environmentally friendly forest biomass supply in Japan. Furthermore, these values were higher than the CO_2 emission namely 44 gCO_2/kWh for the direct combustion and 41 gCO_2/kWh for a small-scale gasification. Komata et al. (2017) estimated the GHG emissions to be about 80 gCO_2eq/kWh for direct combustion power generation facilities having a capacity of 5.7 MW. Ministry of Environment (2013) estimated GHG emissions as 195 gCO_2eq/kWh for a small-scale gasification facility. The results of Komata et al. (2017) were similar to those from this study. Ministry of Environment (2013) estimated the GHG emissions from more detailed processes compared to the approach of Yoshioka et al. (2005b) and Aruga et al. (2011) whose methods were used in this study.

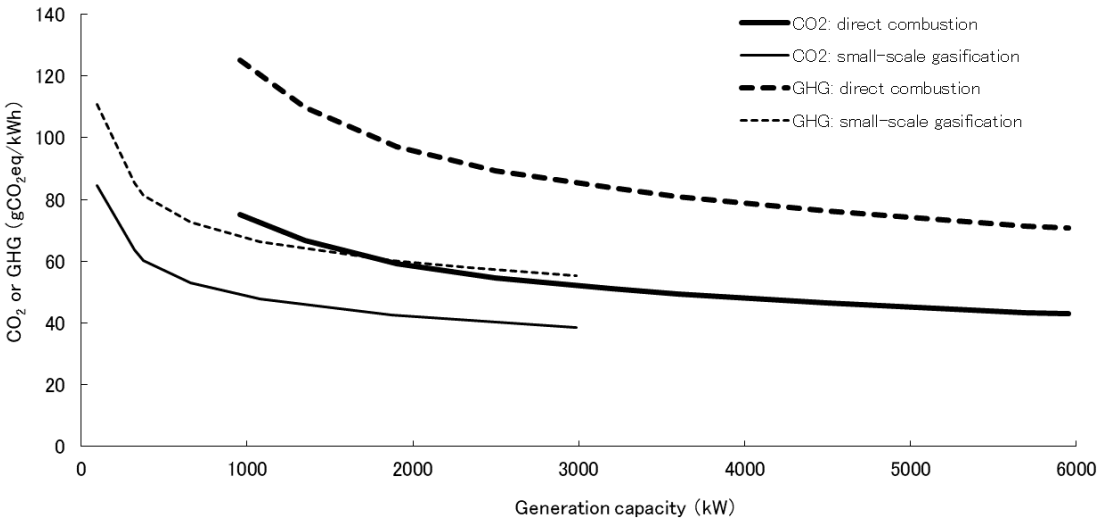

Figure 4. GHG and CO_2 emissions related to the production capacity

4. Acknowledgement

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Sieving and Covering of Wood Chips Improves Storability

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ABSTRACT

Minimising dry matter losses during storage of comminuted forest fuels is desirable from both an economic and a sustainability perspective. This study examined fuel quality and amount of recovered energy during the storage of forest wood chips stored at full industrial scale at three locations, and the effect of sieving and covering piles with a water-resistant, vapour-permeable fabric. Sieving wood chips before storage, that is, reducing the number of fines smaller than 8 mm, reduced the cumulative dry matter losses to <2%, while cumulative dry matter losses after storage for 4-6 months using current practices, that is, unsieved and uncovered, reached 10.6%. The combined effect of storage management led to a value loss of 11.5%, while both covering and sieving led to lower losses, with the combination of sieving and covering giving a 1.3% value increase, and thus, increased storability.

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Analysis of Wheel Loader Work Efficiency at Biofuel Yards and Terminals

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ABSTRACT

Wheel loaders are commonly used in the handling of comminuted biofuels at terminals/fuel yards, but thus, is not well studied. To be able to analyze operational cost for different designs of terminals/fuel yards, wheel loader productivity and utilization time is of importance. The objective was to develop models for loading, unloading, and transporting wood chips within the terminal area and piling and covering of wood chips for storage.

Time studies of wheel loaders handling wood chips were done at three sites in Sweden. Work cycles for transportation of chips and for building storage piles were performed. Additionally, the work for covering of piles using manual work in combination with wheel loaders were also done. Division into work elements in combination with accurate and frequent time and motion data collection and analysis made it possible to model wheel loader loading and unloading work, driving speed for straight or curved distances as well as acceleration and deaccelerating distances, and stacking and covering work.

This study presents models that can be used to analyze different work patterns for wheel loaders were details of path geometry, driving distances, pile sizes and wheel loader properties, such as bucket size, bucket fill degree and driving speed etc. can be adjusted. From such analysis, work cycle productivity can be defined and used for analysis of operational cost for various terminal/fuel yards design.

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State-of-the-art Boom-corridor Thinning

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ABSTRACT

The interest of finding new ways to effectively and sustainable utilize small-diameter tree biomass from European forest to replace fossil use increases. Boom-corridor thinning in combination with mechanized felling and bunching technology show promise to promote such expansion.

The aim is to present 17 years of R&D on methods and technology for boom-corridor thinning dedicated for implementation in dense (< ca 3000-4500 stems/ha) small-diameter (<10-12 cm dbh) tree stands and to conclude the-state-of-the-art and discuss next R&D steps.

The presentation is based on <30 scientific peer-reviewed subject-related international publications on the development of methods and technology for boom-corridor thinning and evaluation of its effects on ecosystems services, economy over forest rotations, biodiversity and the environment.

This work is part of the conclusions of the Smallwood project, executed under the Forest Value program, in which boom-corridor thinning was studied under Swedish, Finnish, Slovenian and Spanish conditions.

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Logging Features in Different Landforms in the Southeast US

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ABSTRACT

Over time logging businesses adapt to recessions and then the recovery of forest products demand by changing business size and configuration. Logging mechanization has been a primary tool for controlling costs and maintaining profitability while satisfying demand for forest products. Current methods to enhance productivity using larger and more reliable machines are easily adopted in areas with significant scale of operations or harvest volume and access to markets. When those conditions are less than optimal, lower system utilization may affect the adoption and affordability of systems that minimize cost. For a variety of reasons including urbanization, loss of markets, and reduced forestry investment, there may be detectable differences in harvesting efficiency in Piedmont and Upland areas of the US South compared to the Coastal Plain. Changes in logging businesses have been tracked by surveys of logging businesses, conducted by research universities and trade associations. We used logger data collected from onsite surveys from 2011 to 2018 by FIA foresters in six southeastern states (AL, GA, FL, NC, SC, and VA). The surveyed loggers were a representative sample accounting for about a 10% sample of both logging firms and total harvest. We used the data to describe the differences in firm productivity, size, harvest attributes and estimated costs within geographic and harvest size classes. The differences in these categories may be important in determining the stress on the logging system and the locally appropriate approaches to system organization, cost control and mechanization.

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Multi-Objective Optimization of Cross-Section Completion Rate and Sawing Power in Sawing Caragana Korshinskii Kom Branches

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ABSTRACT

To reduce the sawing power of the Caragana. Korshinskii Kom. (C.K.) stubble device and improve the cross-section's quality, this paper conducted branch sawing tests on a self-designed sawing experiment rig. Using the central composite design test method, the operating parameters of the sawing experiment rig were studied experimentally, with moving speed, sawing speed and bevel cutting angle as the influencing factors and sawing power and cross-section completion rate as the objective functions, to establish a multiple mathematical regression model between them. The test results show that sawing power is influenced in order of significance by sawing speed, moving speed and bevel cutting angle, and the cross-section completion rate is in the order of moving speed, sawing speed, and bevel cutting angle. The optimal combination of working parameters is sawing speed of 42m/s, moving speed of 0.3m/s and bevel cutting angle of 10deg, which corresponds to sawing power and cross-section completion rate of 279.73W and 82.6% respectively, and the relative error between each performance index and the theoretical optimized value is less than 5%. The test results provide a reference in the search for high efficiency and low consumption designs of the C.K. stubble equipment.

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Unmanned Aerial Vehicle Monitoring of Forestry Best Management Practices: Feasibility, Potentiality, and Framework

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ABSTRACT

Forests in the southern US have intensive silvicultural activities and as a result of these activities, it is important that soils and aquatic resources are protected. Nearly 62% of timber harvests take place in the southern US, where mechanized equipment is typically used to harvest timber. Harvesting activities can result in nonpoint-source (NPS) pollution by altering the natural phenomenon that regulates water quality. Timber harvest activities such as the construction of roads, skid trails, and stream crossings have the greatest potential for erosion and sedimentation issues. Implementation of forestry best management practices (BMPs) during and following timber harvesting is important for water quality protection. The Clean Water Act recognizes the implementation of BMPs as the most effective tool to address NPS pollution from silvicultural activities. BMP implementation status is commonly used to show that water quality has been protected during and after timber harvesting. Conventional on-the-ground surveys are typical for assessing BMP implementation; however, these surveys can be time-consuming. These days unmanned aerial vehicles (UAVs) have been progressively used in various fields to monitor and manage resources. However, their use in monitoring forestry BMPs still needs to be evaluated. This research will assess the effectiveness of UAVs for assessing forestry BMPs, and we will develop protocols for monitoring BMP implementation with UAVs. During the study, data will be collected from recently completed timber harvests in Alabama, Georgia, and Florida. The expected outcome of this study is to assess the efficacy, pros, and cons and document the framework and protocols for using UAVs to monitor BMPs. Preliminary results will be presented in the meeting.

Keywords: harvesting, BMPs, sedimentation, soil erosion, UAV

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Wood-based Hydrogel to Support Planting under Dry Conditions

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Keywords: hydrogel, wood fibre, gelatin, xanthan gum

EXTENDED ABSTRACT

1. Introduction

Wide areas of Europe, and also in other parts of the world, are faced with very dry weather conditions with low precipitation during the growing season and soil conditions being unfavorable for water storage, which challenges the planting of young trees. In consequence, there is a need to support tree growth during the first weeks after planting and to overcome dry periods without rain. There are various soil conditioners available at the market, which try to close this gap. One of these are hydrogels, basically, a water storing material, mainly a granulate, that works like a sponge. It fills up when there is a surplus of water or when it rains and releases the stored water in dry periods to the soils and thus to the root system of the trees. Unfortunately, most of these hydrogels consist of superabsorbent polymers based on polyacrylates, which are not fully degradable because of its micro-plastic ingredients.
Within the EU-project "ONEforest" (funding ID 101000406), a hydrogel based on wood fibers and thickening agents, in particular gelatin or xanthan gum, both are commonly used in the food industry, is developed. Two applications are foreseen for the wood-based hydrogel: (i) as soil conditioner to improve the water storing capacity of the soil and (ii) as top soil cover to reduce the evaporation from the soil and competition with weed circular around the young tree.
Initial studies were performed to better understand the dosage and a possible application/spreading of these two kinds of hydrogels.

1.1 Formulations of Wood-based Hydrogels

With Gelatin

1 l Water
150 g Gelatin
80 g Wood Fibers

Mix water with gelatin and let it soak for 30 min.
Heat the gelatin up to 55°C to melt it.
Add fibers and mix it again.

With Xanthan gum

1 l Water
40 g Xanthan
20 g Wood-Fibers

Mix all together.

2. Experimental Designs

2.1 Soil Moisture Measurements with a Wood Fiber – Gelatin Mixture

An initial experiment with four variations (both, formulation and dosage) of the wood-based hydrogel in standard planting pots was conducted, to study a water storing effect of the hydrogel. Five pots (each 9 l) with 5.0- 5.5 kg of commercial planting soil were used for each variation. Measurements of soil moisture and weight were done ones per day over three months from December 09, 2021 to February 28, 2022.

(i) Reference (brown line)
(ii) with 125 g wood fiber-gelatin mixture (green line)
(iii) with 250 g wood fiber-gelatin mixture (dark green line)
(iv) with 250 g commercial hydrogel (BeGrow – Boost M; blue line)

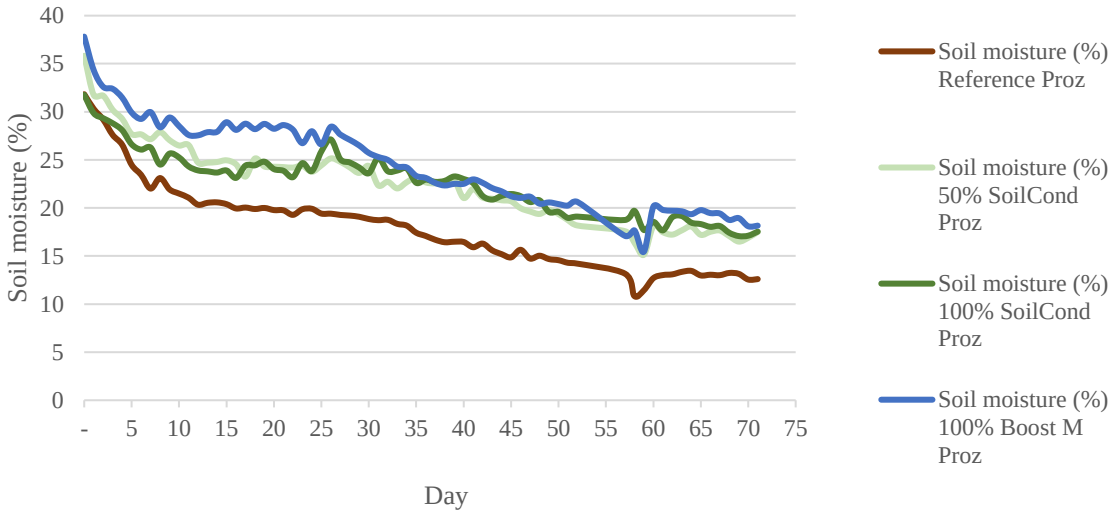

Figure1. Results of soil moisture measurements with a wood fiber-gelatin mixture

The wood-based hydrogel performed about equally well in the moisture measurement compared to the conventional product. All dosages of hydrogel considered better results than the variant without any hydrogel.

2.2 Planting Trail in Saxony-Anhalt, Germany with Wood-based Hydrogel

A first planting trial was setup in Saxony-Anhalt, Germany, to better understand the work process of applying the wood-based hydrogel parallel to a conventional planting of trees, here Red Oak (Quercus rubra). Thereby an analysis of survival rates and growth performance was conducted.
Eight variants were tested, in particular:

(i) Reference
(ii) 1 l of wood fiber-gelatin mixture added into the planting hole (soil conditioner)
(iii) 2 l of wood fiber-gelatin mixture added into the planting hole (soil conditioner)
(iv) 2 l of wood fiber-gelatin mixture added on the top of the soil in a +/- 10 cm radius around the tree (top soil cover)
(v) a combination of (ii) and (iii);
(vi) 1 l of wood fiber-xanthan gum mixture added into the planting hole (soil conditioner)
(vii) 2 l of wood fiber-xanthan gum mixture added into the planting hole (soil conditioner)
(viii) 2 l of a commercial hydrogel based on polyacrylates.

The tree height and basal diameter were measured directly after planting on March 29, 2022 and after four months of tree growing on July 20, 2022.

Table 1. Preliminary Results

Variation	Mean Growth [cm]	Standard deviation	Mortality rate

		[cm]	[%]
i	5,33	10,62	12
ii	0,43	2,70	47
iii	2,07	8,13	80
iv	6.27	7,26	13
v	2,03	4,28	100
vi	2,97	5,28	3
vii	3,73	12,36	27
viii	5,87	13,37	20

The lowest mortality rate was recorded in the variant with a 1 l wood fiber-xanthan gum mixture added into the planting hole. This is especially remarkable, as the work process to prepare the hydrogel with xanthan as thickener requires much less effort than the hydrogel with gelatin as thickener. The main reason is the heating of gelatin up to 55 °C to activate its binding characteristics.
All variants with an application of 2 l hydrogel performed worse. Here, the mortality rate was unexpected high.
By now it is difficult to determine what was the reason for the poor deposition. It could be due to poor plant quality, a reduction of air circulation rate caused by changes in the oxygen household within the soil or generally reduced root growth. However, soil physical and chemical analyses were not performed at this stage.
Based on the promising results of the experiment, we will continue developing the wood-based hydrogels.

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Simplify Bucking Optimisation to Handy Mobile Application: EVO (Eucalyptus Valuechain Optimization)

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ABSTRACT

Eucalyptus plantations are a notable source of income for smallholders in Thailand. The problem can be presented in a question form “What is the best possible way to cut tree stems into logs? For this reason, we have developed eucalyptus bucking optimization research based on a dynamic programming approach to seek for the best solution. The bucking optimization requires two different types of dataset consisting of tree stem profile and feasible length-diameter combination of each assortment. However, this sort of solution is somehow complicated for farmers to understand the theory. Thus, the aim of this mobile application is to simplify the study results into handy software for everyone. The mobile application called: EVO: Eucalyptus Valuechain Optimization, is available for Andriod mobile phones.

The compulsory inputs include average DBH, spacing, and area. If users know sort of end users i.e. veneer, pulp, sawnlog, wood chips, MDF, etc about the location and purchase price, that would be beneficial in order to get accurate estimation. Otherwise, the program just computes based on the default value. Then, the program will automatically compute and present the result in terms of visualization, i.e. graph, current stock, revenue, and profit. Results also indicated to which industries farmers shall sell the timber for and which proportion according to assortment in order to obtain the most profit from harvesting. Furthermore, benefits of this program, users can retry to input different scenarios and see what is different if they cut the trees now or extend the rotation a bit longer. This program somewhat helps in prediction future value for the forest. At this point, the program is not only to tell the profit from selling wood, but also to benefit forest management planning. So far, the mobile application has been downloaded more than 1000 times.

However, the limitations of the software are valid only for eucalyptus clones in Thailand, did not include the defects of the wood for calculation, and applicable to the tree with the DBH less than 12 inches. Currently, software is not available on the Apple store yet, but there is a plan to develop web-based applications for iPhone users in the future.

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Improving Supply Chain Efficiency by Evaluating Forest Transportation Obstacles and Innovative Solutions in the Southeastern US

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ABSTRACT

Currently the wood supply chain is experiencing significant logistical and operational challenges in truck transportation. Obstacles related to driver shortages and retainment, increases in insurance premiums and diesel fuel costs, insufficient training, and truck/part shortages are especially pronounced. The goal of this project is to evaluate the inefficiency in the transportation link of the Southeastern US wood supply chain and to determine the primary obstacles leading to a disconnect between logging business owners and truck drivers. We will conduct 5 case studies across the Southeastern US, to evaluate innovative strategies that established businesses have enacted to combat transportation issues. In addition, a group of online surveys will target logging business owners, log truck drivers, and contract hauling business owners/drivers to evaluate opinions regarding transportation challenges and obstacles in forest transportation. Surveys will be analyzed to determine linkages and opportunities between the three groups within the Southeastern US. Major disconnects of secondary transportation will be identified with realistic alternatives to combat current inefficiencies.

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Harvesting Options for Medium-Rotation Poplar Plantations Established on Ex-farmland

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ABSTRACT

Tree farms have been a common solution for the temporary medium-term exploitation of marginal farmland for many decades. Among the many different farm models proposed over the years, the one that is currently most popular is a medium rotation (5-8 years) tree plantation established with poplar, eucalypt or acacia, depending on the ecological regions. The plantation is often manage as a coppice and kept on site for 3 to 4 rotations (app. 20 years) before the eventual return to farming. These plantations have attracted the interest of conventional wood industries which are leading the resurgence of short rotation forestry on ex-arable land. In Europe, much new planting is occurring East, in countries such as Poland, Romania or Slovakia, which offer an ideal combination of good soil conditions, moderate land price and a rapidly developing economy. So far, low labor cost in Eastern Europe has allowed the widespread use of manual or semi-mechanized work techniques for establishment and harvesting: however, the rapid development of these regions generates a growing concern about the future availability of cheap labor, which determines a strong interest for mechanization. Furthermore, mechanized harvesting offers distinct advantages in terms of simplified logistics and enhanced work safety. The main challenge with harvesting these plantations is presented by the small individual tree size. Even the smallest tree harvesting machines are designed for trees with an optimum size around 0.2 m^3, and productivity declines very quickly when stem size is smaller than that. In such instance, the most common solution lays with mass handling, whereby more trees are harvested in one cycle in order to compensate for their small size. This presentation reports about the results of full-size controlled field experiments conducted by CNR for IKEA over four harvesting seasons, from 2018 to 2022. These trials allowed testing a full range of techniques and technologies, including cut-to-length harvesting, whole-tree harvesting, all implemented with different machines and models for side-to-side performance comparison. The goal was to find the system that resulted in the highest productivity, lowest cost and maximum value recovery for any given conditions.

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GreenLane Norway - A Supply Chain Laboratory Experiment for Challenging Coastal Climates

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Keywords: logging, hauling, lead-times, value loss, coastal weather

EXTENDED ABSTRACT

Forest industries depend on a stable year-round supply of even log quality. The EU Era-Net GreenLane project (2019-2021) focused on developing managerial responses for high value and resilient supply in the face of challenging climate scenarios. The collaboration spanned the climatic conditions of northern Europe from oceanic Norway (NIBIO, coordinator) to sub-artic Sweden (Skogforsk) and continental montane Austria (BOKU). This presentation reports the results of the Norwegian study case.

The goal of the collaboration was to develop virtual supply chain laboratory environments which enabled log value-tracking and interactive testing of harvesting and transport responses. The focus was on implementing weather-driven models for both wood quality (Kanzian et al. 2022) and trafficability (Fjeld et al. 2022). The Norwegian case (oceanic) focused on value-tracking via transport lead-time limits. In this context managers typically rely on experience-based classification of seasonal terrain and road trafficability. However, in this study high resolution maps for quaternary surface deposit types together with matched logging truck messaging (PapiNet standards) and weather data enabled a five-class approximation of relative bearing capacity (RBC), as a digital alternative to local experience.

The case was based on two supply regions of the Allskog forest owners association (FOA) covering three climate zones from outer to inner coast (Figure 1). The supply chain laboratory exercise involved coordination of weekly decisions for purchase, harvesting and hauling by two-person teams. The exercise was done in an excel-based supply chain model and had an eight-hour duration. After purchase to the FOA contract bank, contracts were scheduled with six CTL harvesting teams and hauled with six trucks to two pulp mills and three sawmills. Weekly decisions were entered manually via the user interfaces with map and dashboard graphics as the only decision support.

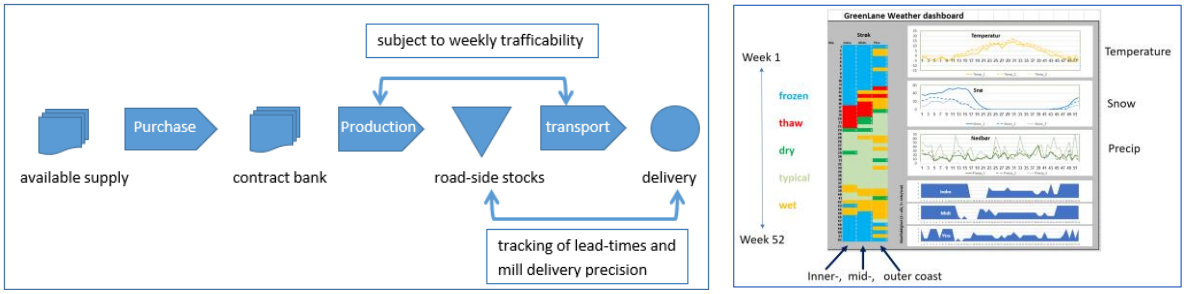

Figure 1. General map of manager functions (left) with 52-week weather and trafficability scenarios (right).

Two different workshops provided different backgrounds for the testing; NMBU masters students (wood supply) and Allskog production and transport managers. The workshops focused on coordination between production and transport where the score KPI used was net value; calculated simply as bonus for high delivery precision minus value losses for degrades. The highest value score was achieved by student teams 3 and 6 (Table 1). While team 3 achieved the highest delivery bonus (1 106 200 NOK), team 6 had the highest net value (1 019 355) because of lower value losses in road-side stocks (81 645 NOK).

Table 1. Student workshop results showing both operational KPIs (relocation and transport distances, truck capacity utilization) and value KPIs (delivery bonus, value loss and net value; NOK=Norwegian crowns).

Team	Relocation distance (km)	Average transport distance (km)	Variation in truck capacity utilization (%)	Delivery bonus (NOK)	Value loss (NOK)	*Net value (NOK)*
1	1251	63	16	1 031 000	229 152	*801 848*
2	910	84	10	775 000	552 803	*222 197*
3	823	67	3	**1 106 200**	**219 972**	***886 228***
5	793	85	2	781000	89 835	*691 165*
6	354	80	1	**1 101 000**	**81 645**	***1 019 355***

The winning team (team 6) was most successful in exploiting the variation in the harvesting contract bank to adjust harvesting production rates. This capability enabled them to better manage road-side stocks so that they could both meet mill demand and minimize lead times/value loss when necessary. This approach outperformed other high performing teams who strictly balanced production and delivery pace to match mill demand. Student teams were more proficient at finding good solutions, while managers more quickly identified the organizational development necessary to improve performance.

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A Prototype Hybrid-electric Self-propelled Carriage

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ABSTRACT

Cable logging works in such a manner that the potential benefits of electrification and energy recovery are highest among all forest harvesting technologies. As loads are moved between places with different potential energy, the possibility for energy recovery is high - which is greatly simplified with electrification. That would also favour easy energy transfer between running components, desirable when mooring. Equipment manufacturers started to hybridize and electrify cable logging equipment within the last decade. This trend started with electrified slack pullers, now being available from most of the leading manufacturers. A number of electric dropline carriages are also under development, and a first model of a hybrid tower yarder is already on the market. This poster presents the first hybrid-electric self-propelled dropline carriage, developed by the Italian start-up Leitalpin Ltd., with the scientific support of the Free University of Bolzano and CNR IBE. The new machine is powerful, green and aptly named: the HULK. HULK's patented concept relies on a powerful traction drive in capstan configuration, a fully independent dropline winch and a high-power energy storage system, fed by a lightweight combustion engine. HULK achieves travelling speeds beyond 10m/s and its pulling force is large enough to fit a 5-ton tower yarder. On average, a fuel saving of at least 50% can be expected when compared to existing Diesel-hydraulic models. Energy neutral operation is possible when transporting downhill on sufficiently long and steep lines. The first prototype has already been tested in 2021, and the second prototype was presented at Interforst in Munich in July 2022. After the planned extensive field trials, this new product is expected to achieve its market launch within 2023.