Proceedings of the

Precision Forestry Symposium 2014:

The anchor of your value chain

Stellenbosch,
South Africa

March 3-5, 2014

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Precision Forestry Symposium 2014: The anchor of your value chain

Official Proceedings (Extended Abstracts) of the
6th Precision Forestry Symposium
Held in Stellenbosch, South Africa
March 3 – 5, 2014

Edited by: Pierre Ackerman, Elizabeth (Lise) Gleasure & Hannél Ham

Preface

Pierre Ackerman

I am indeed honoured to provide the introduction to this volume of proceedings on behalf of the Precision Forestry Symposium of 2014 (PF 2014) technical review and organising committee. These proceedings represent scientific contributions to the PF 2014 symposium titled “The Anchor of your Value Chain” presented in Stellenbosch, South Africa, from the 3th to the 5th of March 2014. The Conference is jointly hosted by Stellenbosch University’s Department of Forest and Wood Science and the International Union of Forest Research Organizations (IUFRO).

The PF 2014 symposium, an international event held every four years, is a forum for forest scientists and practitioners from around the world to share their research, knowledge, experience, and emerging ideas with the wider forestry community. The stewardship of the PF 2014 lies with the international precision forestry community, and this conference is third of its kind to be presented by Stellenbosch University. This meeting follows previous successful symposia held in 2006 and 2010. The high quality of material presented and the large number of delegates attending PF 2014 attest to current and continued interest in promoting the all-important facet of precision forestry to the international forest industry.

I would like to thank all those who were involved in the organisation of this symposium for their significant contributions to the success of this event. In particular I would like to thank the organising committee for taking time to establish the title and sub-themes of the symposium. They also conveyed considerable effort to the review of the large number of extended abstracts for oral presentation originally submitted. I would also like to thank Hannél Ham, Lise Gleasure and Poppie Gordon for their hard work in the background which has most certainly contributed to the success of this conference.

PF 2014 is indebted to the authors of the extended abstracts included in this volume as well as attending delegates who have travelled from far and wide to share this event with us. I would also like to thank our sponsors; Tigercat, Signumat, Alternative Structures, Cape Pine, Haglöf Sweden, Bell, the South African Department of Agriculture, Forestry & Fisheries, Stihl, Optron, Trimble Forestry, Hans Merensky, Husqvarna, Southern Mapping, Olofsfors, Eco-tracks, PG Bison, SA Forestry Magazine and Wood Southern Africa & Timber Times for their generous contributions.

These proceedings are reproductions of extended abstracts submitted to the symposium with editing to achieve consistent format. No attempt was made to review or verify results, although the abstracts were reviewed for suitability by members of the symposium scientific review committee as set out below. The following experts served as extended abstract reviewers for the 2014 Precision Forestry Symposium in South Africa:

Pierre Ackerman	South Africa
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Walter Warkotsch	Germany
Martin Ziesak	Germany

March 2014 Pierre Ackerman

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Precision Forestry

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As presented at the 6th Precision Forestry Symposium

Keynote 2

Precision Forestry: a journey not a leap

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Industry experts will often dwell on the gap between current operations and those that are possible based on the theory of precision forestry. It must be acknowledged, as an industry, we have a long ways to go to fully realise the theory of precision forestry - perfectly placing the right tree in the right place at the right time, carefully managing its growth and health to meet key quality and value objectives and then harvesting that tree based on a real market demand at the right time and delivering it in the right form to the right customer; all while minimising costs and maximising value. Even to match the standard of our cousins in agriculture and manufacturing, the forest industry has work to do, but it is also important to acknowledge that real progress has been made in the face of real challenges; as an industry we are on the right path.

As the research and development in forest operations advances, undoubtedly will be the case with many of the presentation at this conference, we are continually presented with the potential and opportunity these advances represent but less frequently are we given the full picture on the challenges that must be met. First and foremost change is hard, even if the rare cases where technical challenges are easily met there remains the shift of business arrangements and often the hardest of all is to change the way people work and behave. If we think about current operations, where ever we come from in the world, and compare that to a perfected theory of precision forestry there are many technical challenges, primarily in reliably obtaining and managing the information on the natural systems we manage before you get to the hard work of changing business arrangements and the people within the various stakeholders involved in forestry.

A real experience we have recently had in Australia with the application of optimised transportation planning and management speaks directly to these issues. The research and development, followed by desktop modelling against real operations clearly showed opportunity for up to 20% improvement in transport operations. As the work progressed to real operational application, the real challenges to reach the opportunity identified revealed themselves. There remain a number of technical changes in how operational data (in-supply-chain inventory, location of operations, routing to customers, etc.) is captured and managed such that the transport can be optimised. Equally important is how the relationship and business arrangements between forest owners, contractors and processors need to be adjusted to reach the identified potential. Last and certainly not least is changing how all the people involved view and manage the transport operations. While I would love to say we have achieved a full application, I am still proud to say we are working hard and making progress with industry.

Considering these real challenges come with every change, as an industry we need to take pride in and celebrate the real progress that is being made on the path to true precision forestry. The application of LiDAR has seen great improvements in what we know about the trees and landscape we manage and with clever understanding of real industry problems has led to detailed site quality mapping for better growth predictions and planning of management activities like fertiliser application. The application of satellite imagery has spawned better detection of pest attack and thus better placing industry for rapid response. Later in the supply chain we are seeing ground based LiDAR allowing for standing tree measurements allowing effective connection to what products in the market demand that the tree can meet. This links in with, the now common, value optimisation in STANFOR-D to look at different value potentials even before the tree is cut. And of course the earlier mentioned transport and logistics optimisation, which is in different states of application in forestry around the world. These and the many other advances over the last ten or so years are all key sign posts along the road to precision forestry and I have no doubt that many new sign posts for the road ahead with be presented at this conference.

As you are intrigued and attracted by the potential that can be unlocked by the ideas and development presented at this year's Precision Forestry Conference, I also challenge you to consider efforts and change that will be required to convert that potential to reality and how that advancement fits in the broader development of precision forestry. If we approach these new opportunities fully aware of the challenges they represent, I have no doubt we will succeed on our journey to precision forestry.

Theme 1: Enhanced forest stand and individual tree attribute information

Session Chairs: Bo Dahlin & Martin Ziesak

Tree crown-fibre attribute relationships for adding wood quality information to forest inventories in Canada

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Introduction

The tree crown has long been considered to have a strong effect on a number of wood properties that affect the value of timber (Larson, 1969). Stem taper, branchiness, the width and distribution of the annual ring area increment and a number of wood fibre attributes are influenced by the size and structure of the tree crown.

Current forest inventories in Canada provide information about the quantity of forest resources (e.g., height and volume) but not about quality. If wood quality information could be incorporated into forest inventory, it would support more effective preparation and implementation of tactical and operational plans related to road networks, timber harvesting, timber transportation and allocation to mills.

Advances in remote sensing technologies such as high resolution digital imagery and LiDAR are creating the prospect that the resolution and mapping of individual tree crowns will soon become operationally feasible. If relationships between fibre attributes and crown features can be developed, remotely sensed tree crown information could be used to predict tree and fibre attributes and to add this information to forest inventories.

The Crown-Fibre Attribute Relationship (CFAR) was initiated by the Canadian Wood Fibre Centre in 2009 to examine whether relationships between fibre attributes and crown features were a potential approach for adding wood quality information to forest inventories.

Materials and methods

Data for a number of species from existing sample plots and silvicultural experiments across Canada were used to develop and test relationships between crown characteristics and a number of tree and fibre attributes. As the focus was to assess the potential of such relationships, crown characteristics such as crown height, width, area, and base were obtained from ground measurements. The tree and fibre attributes considered included: tree diameter, maximum branch diameter, ring area increment distribution, sapwood area distribution, and wood density.

Results

Tree DBH and maximum branch diameter can be predicted with a RMSE of about 10% (Groot & Schneider 2011, Cortini et al. 2011, Filipescu et al. 2012). The magnitude and distribution of ring area and sapwood area can be effectively modelled using crown information (Cortini et al. 2013, Cruickshank et al., in preparation). Internal fibre attributes such as wood density show predictable patterns, but it may be challenging to relate these patterns to crown features (Cortini et al., in review).

Conclusions

It is feasible to predict tree DBH, maximum branch diameter and the distribution of sapwood and ring area mainly from crown characteristics such as tree height and crown width or area. There is strong potential to incorporate these attributes into forest inventory as remote sensing of tree crown characteristics progresses.

Initial attempts to predict wood density from tree crown information have been less successful. Recent advances in the functional ecology of wood formation may lead to model forms that are better suited for relating internal fibre attributes to crown characteristics.

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Improving the accuracy of diameter distribution predictions by using stand table projection

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Introduction

A forest planning system plays a valuable role in forest management for activities, like creation of the Annual Plan of Operations and the 3-year tactical plan, which are important for both silvicultural and harvest planning operations. A growth and yield simulator is a critical part of the forest planning system and is used to project stand growth into the future. A terrestrial forest enumeration in a stand of trees (compartment) usually provides the best description of that compartment at that point in time. The enumeration provides stand-level descriptive statistics, such as stems per hectare, stand diameter at breast height (Dbh), height and basal area per hectare. It also provides a stand table, consisting of a Dbh-class frequency distribution with an associated average height by Dbh-class. The Dbh distribution provides management information on the size and frequency of the trees in a stand which are important for estimating product mix and harvesting productivity. Each stand of trees has a unique Dbh distribution associated with it. A bucking simulation is typically applied to the stand table to estimate different log product volumes. The accuracy of growth and yield predictions will improve when we calibrate the growth models with the actual stand-level inventory data.

The objective of this project is to demonstrate how the accuracy of predicted Dbh distributions can be improved further by using the 'Stand Table Projection' method. More accurately simulated Dbh distributions will provide more accurate tree size and log product estimates. Although complex to program, this methodology has already been incorporated in some of the growth and yield simulators in South Africa.

Materials and Methods

In South Africa, stand-level based models are largely used for growth and yield prediction and projection. The different model components and methodologies for linking them have been summarized by Kotze et al. (2012). Within this framework all Dbh distributions are predicted with the Weibull frequency distribution model for which the parameters are recovered with the 'method of moments' approach of Garcia (1981), as presented by Gadow and Bredenkamp (1992). This method is commonly referred to as the 'Weibull method'. Although fairly accurate in some cases, the theoretically predicted Dbh distributions do not recognize and project the unique shape of the observed diameter distribution.

The implementation of a generalized method for Stand Table Projection, as presented by Nepal and Somers (1992), has been described in detail by Corral-Rivas et al. (2009) based on a sample of South African data. The advantage of this methodology is that it uses the unique shape of the observed diameter distribution and projects it into the future, while maintaining consistency with the stand-level growth model.

Results

To illustrate the stand table projection method, consider a pine compartment with inventory at age 19 years, as shown in Table 1. The stand has a reasonably normal stand structure, but with high variability, as shown in Figure 1. The inventory data is used to calibrate the growth model and the growth is then projected to age 25 years. The estimated stand-level parameters at age 25 years are also shown in Table 1. To illustrate the comparative difference between the two methods, the Dbh distribution is predicted with the Weibull and Stand Table Projection methods at both calibration and final age of 25 years. The result from the Weibull method is shown in Figure 1 and the result from the

Stand Table Projection method is shown in Figure 2. The Weibull method typically presents a smoothed distribution, while the Stand Table Projection method takes the observed distribution and projects it forward in time. Although the stand-level parameters are the same, the product estimates from these two distributions will be very different.

Table 1: Inventory data.

Observation	Age (Years)	Trees /ha	Basal Area (m^2/ha)	Dominant Height (m)	Dbh		
					Quadratic mean (cm)	Standard Deviation (cm)	Minimum (cm)
Calibration	19	296	27.0	21.9	34.1	11.1	3
Projected with the Weibull method	25	274	29.6	25.3	37.1	13.3	4
Projected Stand Table Projection method	25	274	29.6	25.3	37.1	13.3	12

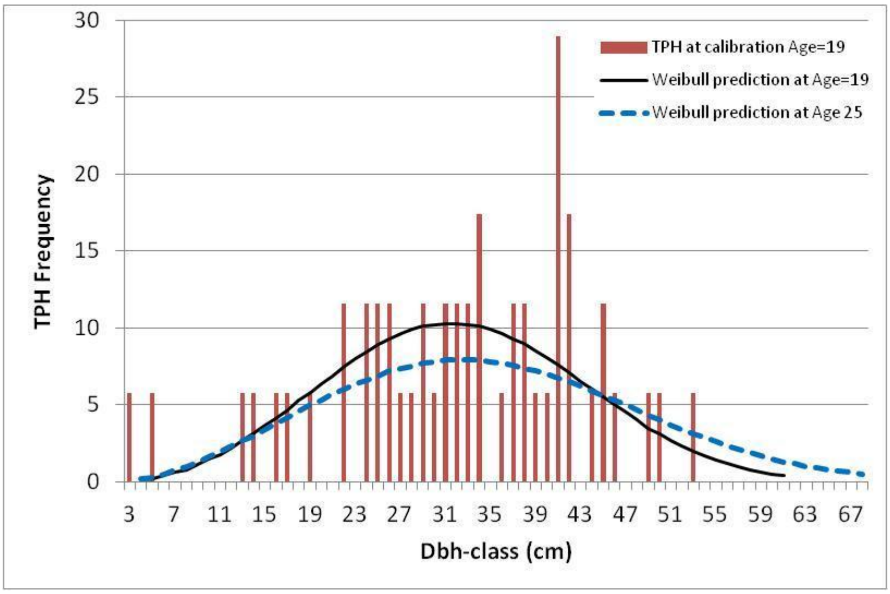

Figure 1: Dbh distributions predicted with the Weibull method at calibration age (solid line) and at final age of 25 years (dotted line), compared to the observed Dbh distribution (bar).

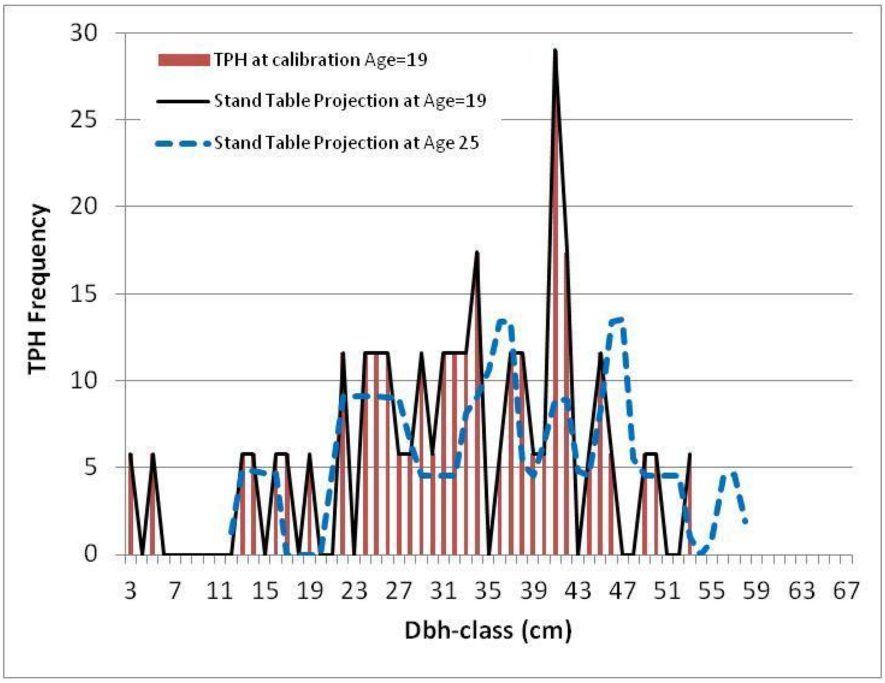

Figure 2: Dbh distributions predicted with the Stand Table Projection method at calibration age (solid line) and at final age of 25 years (dotted line), compared to the observed Dbh distribution (bar).

Conclusions

The utility and performance of the Stand Table Projection method is highlighted when forest stands have more complex stand structures. Calibration of growth and yield simulation systems with actual tree size distributions from inventory data improves accuracy of projections. The addition of the Stand Table Projection method further improves the accuracy of projected Dbh distributions and consequently should improve the accuracy of the resulting log product estimates.

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A spatial approach to edge effect modelling

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Forest edge effect

One of the major objectives in plantation forestry is a high level of homogeneity in distribution and dimension of trees within the stand. Precise planting geometries, intensive silviculture and genetic selection are used to achieve this homogeneity. However, natural variability is still introduced by micro-site conditions and disturbances. A substantial source of variation is caused by edge effects of neighbouring stands or other land use forms. The edge effect causes trees at the stand edge to develop differently from trees in the interior of the stand.

Quantifying edge effect

The aim of the presented study was to simulate the edge effect based on average stand interior variables as typically received from an enumeration and spatial information on the current and historic stand neighbourhood. By re-introducing this natural variance as well as its spatial pattern, we expect to derive improved planning information.

A major objective is thus isolating the effect of the edge interaction from the other factors contributing to stand variance and quantifying the result in terms of stand output. A methodology is introduced for quantifying interaction at stand edges between a given stand and its neighbouring stands over the lifetime of the stand. Transferring the edge interaction value from the edges to all the trees within the stand is then done by applying inverse distance weighting interpolation from the edges to the tree position. Once an edge interaction value has been calculated for each point, the extent of the edge effect is quantified. The spatial extent of the edge effect was derived empirically from an existing fully spatially mapped stand by means of breakpoint regression. The expected variance as a result of edge influence is then quantified by producing a set of models, which can reproduce the effect of the edge interaction on tree height, diameter and volume.

Edge effect over time

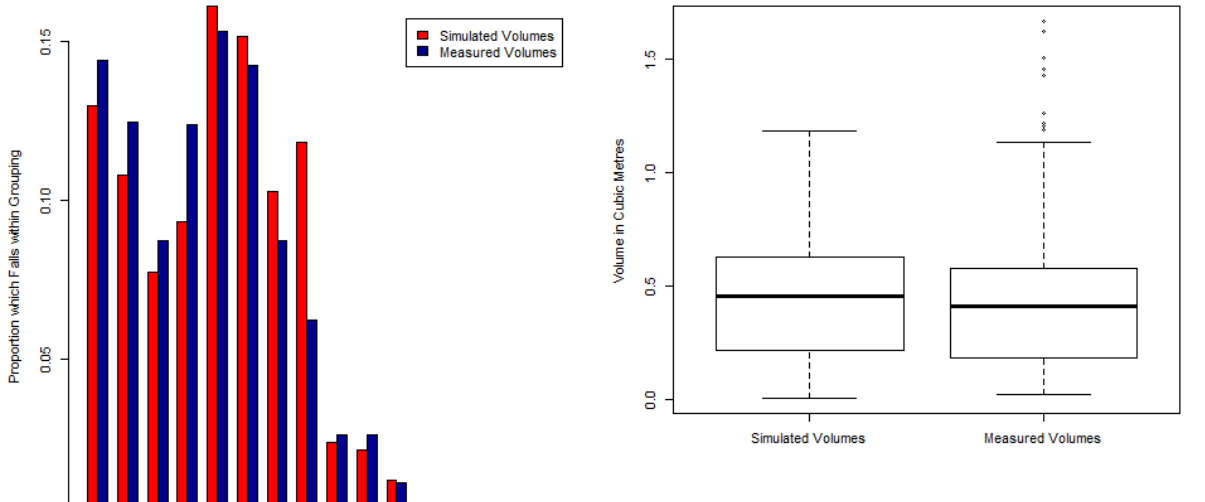
The edge effect is treated as a dynamic interaction for which the temporal aspect needs to be considered, because the current spatial structure of a stand is influenced by its current neighbourhood but also by the historic development of the neighbourhood in relation to the stand in question. Each stand therefore undergoes an edge effect which is completely unique to that stand, within a given time period. For this reason the presented methodology is a spatial-temporal one, aimed at providing a way in which growth and yield forest modelling could be augmented by the inclusion of the edge effect in a practical way.

Simulating edge effect

To explicitly quantify edge effects, the natural variance had to be separated into a component explained by edge effect and into a second component introduced by other factors, such as micro site conditions and disturbance. The second component is treated as an unexplained residual variance. In order to provide a realistic simulation of a stand output at a finer, tree level, this second stand variance nonetheless needs to be quantified. The variance attributable to factors other than the edge effect is mimicked by generating a random number by means of a parameterised stochastic process based on the variance of the inner stand region, which is beyond the reach of the edge effect. In this way, a realistic spatial pattern of a plantation forest stand, taking into account the edge effect and combining it with the natural stand variance is achieved.

Spatial modelling for precision forestry

With this proposed spatial modelling approach, the accuracy of the stand structural description is improved and provides a better base for further planning. Improved information as to the composition, as shown in Figure 1, of a stand in terms of tree variables is obtained as well as an indication of the spatial arrangement of this composition within the stand. The study makes use of open source software resources namely the R framework and QGIS and explores aerial stereophotogrammetry as an option for data collection.



	Mean	Standard Deviation	Median	Kurtosis
Simulated Volumes	0.44	0.252	0.454	-0.77
Measured Volumes	0.416	0.267	0.412	0.561

Figure 1. A comparison between the distributions predicted volumes for all the trees within the complete stand (red bars) and the stand volumes from data extracted from stereophotogrammetric data.

Adaptation and parameterisation of a single tree, hybrid growth model to South African conditions for *Pinus elliottii*

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Abstract

Single tree forest growth models have often been shown to introduce an increased flexibility as opposed to stand models in particular if stands have experienced disturbances. This study, founded by the EU Marie Curie Project Climate Fit Forests and the NRF/DST project Green Landscapes aims to use and adapt the SILVA framework, a European based forest growth simulator, to South African conditions for *Pinus elliottii,* a pilot species in South African plantations. However, major differences in the mode of competition exist due to predominantly edaphic limitations to growth in South Africa when compared to more light-limiting circumstances in Europe. Adjustments to the growth and competition sub-models are necessary to cater for local climate conditions.

The data used in the study is based on spacing trials and permanent sample plots over a wide range of site conditions in South Africa. The simulation model is constructed by using a potential modifier approach, whereby a potential growth for a given site class is estimated, which is then modified by competition to the estimated growth. The potential height model initialises the simulation with a potential height-age relationship using nonlinear quantile regression in R, parameterised from a South African spacing trial series. Potential diameter increment was obtained using nonlinear quantile regression from an increment-diameter relationship. The shifting importance of edaphic vs. light conditions under different rainfall and water availability was tested by applying multiple competition indices which differ in their focus on local crowding and overtopping. These are then compared to each other and finally combined in a model with differing weighting factors based on a simple aridity-index to explain water availability. Due to inherent collinearity arising from using multiple indices as variables, Principle Components analysis was used for testing performance of the different indices under different climatic conditions, variable selection and finally model construction from the selected variables. The competition indices will then be incorporated into the modifier function to reduce potential growth increments to realised values.

It is thought that the novel approaches used in the study for forestry applications, i.e. nonlinear quantile regression combined with principal components analysis will contribute to the development of novel methods in the South African forest industry. Furthermore, the modelling approach and initial modelling framework will outline the major issues for introducing single tree models to South Africa in order to facilitate precision forestry in the country.

From points to products – practical LiDAR applications for plantation forest management

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Abstract

Mondi Ltd, an international pulp and paper company, recently acquired its first LiDAR data set over a portion of its plantation forest area in South Africa. Due in part to the significant investment required to perform the LiDAR acquisition, maximum value needed to be extracted to justify the expense and quickly demonstrate to management the value of this form of remote sensing. After performing some basic quality control (QC) on the LiDAR data, procedures and workflows were designed and documented for the creation of bare ground Digital Elevation Models (DEMs); first return Digital Surface Models (DSMs); Canopy Height Models (CHMs) and similar products that would be of value to forest managers. Results from these products improved silviculture and harvest planning operational data; road and stand delineation, slope class determination; and provided stand tree heights.

Lidar Data Acquisition and Processing

Lidar technology was chosen due to its ability to supply very detailed 3D spatial data that is relevant to forest managers who need to work at the precision forestry level. Airborne Lidar data, at a minimum point density of 6 points/m, was supplied as LAS-formatted tiles, together with 10 cm false colour infrared imagery. Quality control (QC) was done to confirm the data met specification requirements.

Derivative Products Created from the Lidar and the Associated Benefits

Lidar data in a LAS format is simply a point cloud of limited use. It therefore needs to be processed into useful products, which is done by using specific data classes from the point cloud. These derived products were applied in the following manner:

Terrain Visualisation and Ground Roughness

Accurate terrain data is critical to successful forest management planning, especially at the precision forestry level. Lidar is able to accurately capture micro-terrain features, slopes and rough ground features (boulders etc) even where canopy covers the terrain (Figure 1).

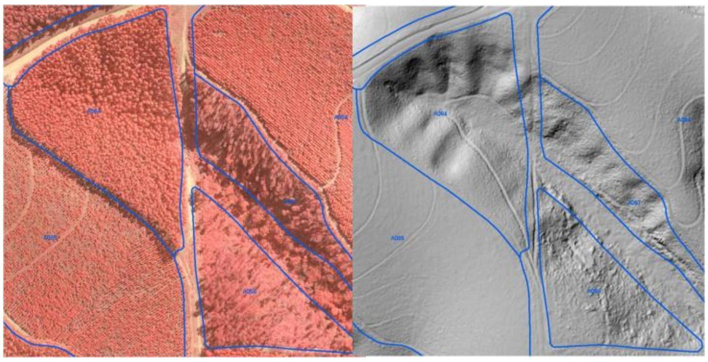

Figure 1: Hillshade DEM derived from Lidar data with orthophoto on left

Slopes and Slope Classes

Slope plays a major role in many forest planning and operational activities, influencing such factors as safety, productivity, machine selection, site sustainability, and accessibility. Therefore, the ability to derive detailed slope and slope class information is important and can have a significant impact on the forest plan, e.g. slopes between 45 and 60 percent require leveling harvesters that have a cost premium over conventional harvesters. Thus, the ability to accurately map where these slopes are can have a major impact on both costs and safety. Mondi originally derived slope classes using 20m Digital Elevation datasets. These proved to be too coarse in steep terrain, but the Lidar derived DEMs were of a much higher level of detail, to the point where accurate machine/terrain matching is possible (Figure 2).

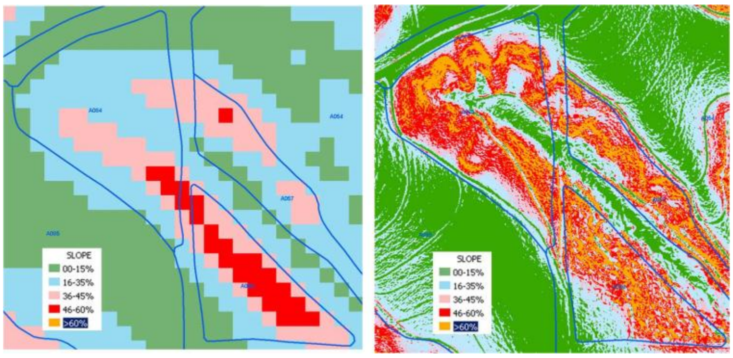

Figure 2: Twenty Meter Slope Classes on left Compared to LiDAR-Derived One Meter Slope Classes on right

Machine access and Timber Extraction:

High road banks in steep terrain can hinder access into forest stands. Stacking of extracted timber can also be problematic in these cases. Being able to identify where these conditions exist can greatly improve harvest planning. Road banks are visible on lidar-derived slope data.

Additional Terrain Datasets:

Other useful terrain–based datasets that can be extracted include very detailed aspect data, contour data (even to 0.5m contours if required).

Improved Forest Road and Stand Delineation:

It is often very difficult to map roads when these are under canopy. Because Lidar can penetrate through very small gaps in the canopy road delineation is clearly identifiable (Figure 3), enabling accurate mapping of roads. Lidar data can also be used to map forest stand boundaries (Figure 4), thus improving the quality of a forest database.

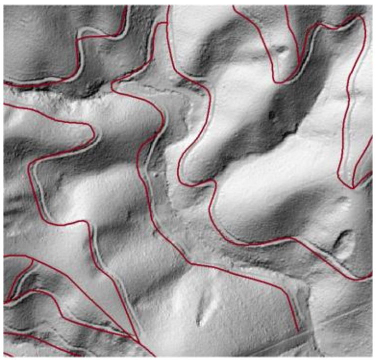

Figure 3: Road misalignment

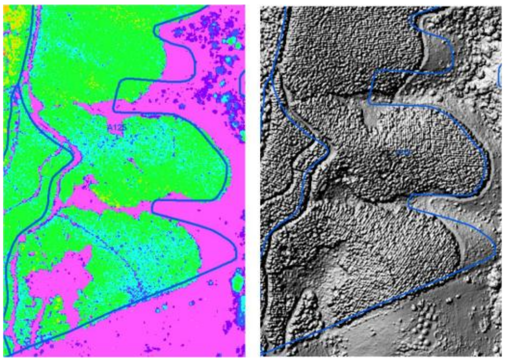

Figure 4: Stand boundary misalignment

Stand Tree Heights

A critical measure for foresters is stand tree height, and a core function of lidar is the ability to record height data accurately. In addition to providing tree height data, a Canopy Height Model (CHM) also provides a very good indication of variability within a stand (Figure 5). Summary height statistics, such as the mean height and range at a stand level, can be derived. Where additional statistical relationships, such as height/DBH curves are available, further analyses can be done to derive stand tree size and volume estimates.

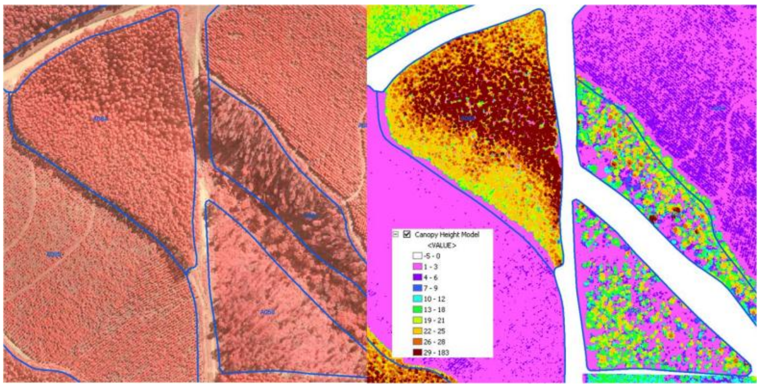

Figure 5: Canopy Height Model (CHM), showing different height classes

Conclusion

Often, an initial reaction to acquiring a lidar collection is concern regarding the cost of obtaining such data, frequently followed by concerns with working with such large volumes of data. However, the detail and accuracy of information produced from lidar are such that the cost-benefit is positive and very real. In the case study described in this report, the improvement in slope class definition and its impact on Mondi's ability to improve harvest planning justified the cost of obtaining the data. These harvest plans were no longer based on estimated areas but on actual calculated areas. In addition, there was a very significant reduction in accident risk due to incorrect machine/terrain matching. Areas requiring the use of leveling harvesters were now clearly defined, and the risk of a non-leveling harvester being used in terrain too steep was greatly reduced.

Together with the ability to minimize the impact of road banks affecting access to stands and problems stacking timber on roadside, this has enabled forest planners to produce more cost-effective harvesting plans. The added benefits of improved road and forest stand boundary data, the ability of the DEM hillshade products to enable users to clearly visualize the terrain they needed to work in, the provision of stand tree height data, as well as better understanding of variations within stands all resulted in improved management focus and better management decisions.

Assessing one year pine growth at stand level with single tree detection based on ALS data

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Introduction

Airborne laser scanning (ALS) is a modern, efficient and accurate method of obtaining information about forests. The utilisation of ALS allows collecting accurate and detailed data in a very short period of time, thus the interest in this technology among foresters is still increasing. The data acquired using LiDAR are used by scientists to determine and characterize the enormous number of forest features and quantities, which are relevant for large-scale forest inventory, determination of biomass, forest planning and management.

There is a limited number of papers dealing with forest changing detection evaluated with multi-temporal Airborne Laser scanner data (Yu et al. 2004, Yu et al. 2006; Woodget et al. 2007). All these studies present, among others, tree height growth using different methods and parameters acquired from Crown Height Model (CHM), Digital Surface Model (DSM) or point cloud statistics such as percentiles. Best results were received for “maxZ” value, which was obtained for each tree at two different dates (Yu et al. 2006). All of the presented works were evaluated using changes in a period of minimum two seasons. Some of the previously done measurements state that it is possible to capture even one-season tree growth (single tree measurement level) using ALS data (Mielcarek 2012).

This study was performed in order to evaluate possibilities of determining a pine stand’s one-year growth using the ALS data (based on single tree detection). The results were then compared with the yield table growth. The mentioned “maxZ” values were used to capture the tree growth.

Study area

The measurements were conducted in the Głuchów Forest Stands (51°45'19"N, 20°6'28"E) located in Rogów Forest District (central part of Poland). This forest complex belongs to the experimental facilities of Warsaw University of Life Sciences (SGGW). There were set five sample plots covered by Scots pine (*Pinus silvestris*) of various age grouped in five age classes:

1: 1 - 20 years
2: 21- 40 years
3: 41-60 years
4: 61-80 years
5: 81-100 years

Materials

The ALS data were acquired using Falcon II airborne laser scanner system from TopoSys GmbH (Biberach Germany) installed on the plane board. The flight height was about 700 m. In order to have the possibility to detect a tree’s growth the area of investigation was scanned twice- in May and August 2007. The main difference between data acquired in May and August is the point density. The level of the average density of points expected to be 5 pts/m2 for data acquired in August and 11 pts/m^2 for May.

The collected data were used to generate a Digital Surface Model of the Głuchów Forest Complex. The expected accuracy of generated DSM was 0.5 m in location and below 0.15 m in height. These two DSMs (generated for May and August) were used for further analysis.

Methodology

Firstly, single tree detection was performed (Stereńczak and Miścicki 2012). The generated Crown Height Model from August was filtered with median filter. Firstly the initial segmentation was performed. During this process primary segments were secreted and height layers were determined. Segments that did not possess the shape of trees (diameter ratio extends beyond the range 0.3 – 3) were merged with neighbouring regions based on the longest common border. Primary segments were assigned to the corresponding altitude class and such regions were combined. If there were more than one high–altitude region, each was split and separate spatial objects were created (groups of the primary segments – stands of similar height). Altitude regions were re-filtered using Gaussian filter (various values), according to the following principle - higher layers with larger values and lower with smaller. The next step of segmentation was the determination of the average crown area in each plot. If the crown surface was greater than the mean + 2 x standard deviation, it was again filtered with Gaussian filter of 2 pixels less than the first attempt. After the establishment of final segments, the crowns' radii were determined. In each segment, the maximum height was defined. Pixels with values below 0.7 * Hmax were removed. The next task was the calculation of the maximum pixel value within the previously obtained (in segmentation process) crown contours. This procedure was performed for each DSM (May and August).

Afterwards the maximum pixel values (within the corresponding crown contours) obtained for May and August DSMs were subtracted. The obtained value was considered as the tree growth. Finally the mean value of tree growth for each stands age class were calculated and compared to the growth table acquired from yield tables (Szymkiewicz 1986).

Results and conclusions

Acquired results present height correlation (Figure 1) between age and height growth for stands based on single tree detection methods. The trend is well visible: the height growth decreases with the age of the stand. Variations seen on Figure 2 are mostly related to stand density and site quality.

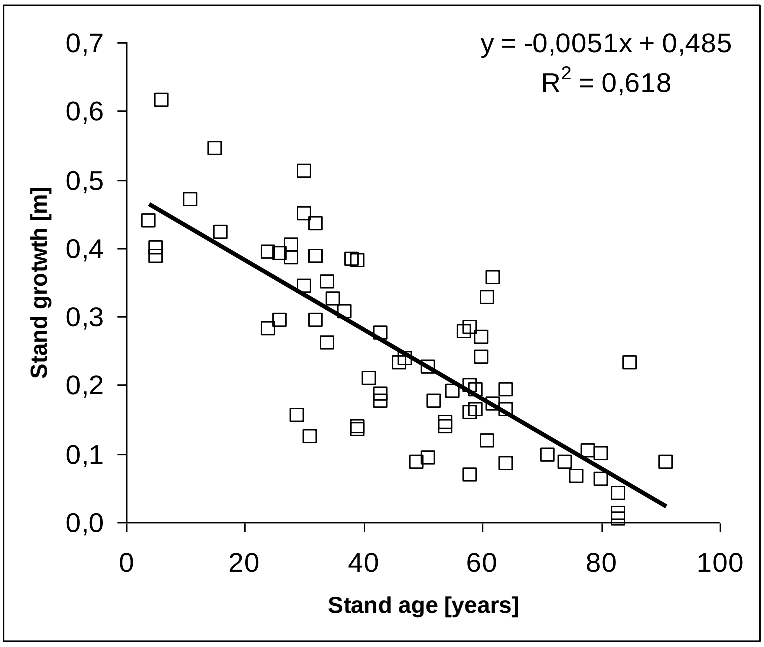

Figure 1: Single stand height growth in respect to stand age

The results clearly show that the mean growth value depends on the stand age and its value is close to yield table mean growth for specified age class (fig. 2).

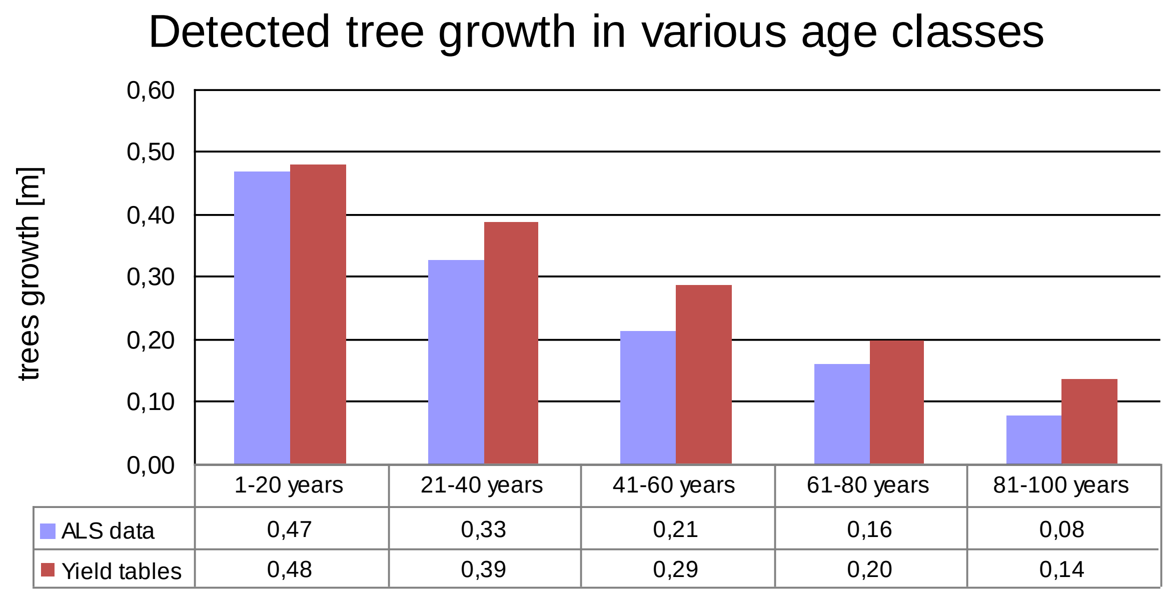

Figure 2: Comparison of mean one-year tree height growth obtained from ALS data and yield tables for age classes.

According to presented results we can conclude that:

1. It is possible to capture one year pine growth at the stand level based on DSM generated from ALS data.
2. Correlation between stand age and acquired growing is highly correlated R^2=0.62.

Acknowledgement:

We are thankful to Krzysztof Będkowski for providing the data from the Polish Ministry of Science and Higher Education project: 2 P06L 02229: "Using airborne and terrestrial LIDAR scanning for analyzing forest spatial structure and forest function in landscape".

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The use of near infra-red analysis (NIRA) to determine fibre productivity in a eucalyptus pulp wood stand

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Introduction

Near infra-red analytical spectroscopy (NIRA) has been used in the last decade in a variety of applications. The technology proved to be suitable for determining the chemical composition of agricultural biomass more rapidly than traditional wet chemistry methods. NIRA is used extensively in the forest research environment to speed up tree breeding programs and to predict wood chemistry with processability to name a few. Applications of near infrared analysis in association with multivariate statistical analysis (MVA) is highly effective to determine chemical wood properties e.g. cellulose, lignin and extractives. In Kraft processing NIRA has successfully been used to determine the concentrations of NaOH, Na_2S and Na_2CO_3 in white and green liquors and to determine process parameters e.g. kappa number and residual active alkaline.

Objective

The objective of this study was to establish fibre productivity of series of clones across site quality and age classes, making use of key growth and yield parameters of and wood properties. Simultaneously, age – age correlation is done to assist tree breeders in ranking of clones from one age class to another. The outcome of early and accurate predictions will result in shorter tree breeding cycles with numerous benefits such as earlier deployment and consequently earlier harvesting of advanced genotypes for processing purposes.

Materials & Methods

A series of productivity blocks of eucalyptus clones, established as genetic gain trials in Zululand and planted on a site gradient, were selected for this study; one from a good (CT091) and one from a poor site (CT092). Clones were grouped in blocks of five year periods of commercialisation, from pre 1990 to 2005 (four clonal groupings).

Breast height diameter (DBH) at 1.3m and tree height (m) were recorded annually for every tree. To determine wood quality, five trees each of 20 eucalyptus clones (in their four groups) were sampled per site. Petrol driven drills fitted with a 12 mm hollow corer drill bit were used to extract two wood cores per tree from bark to bark through the centre of the trees at DBH. One core was sealed and used to determine basic wood density, while the second core was used to prepare saw dust for NIRA scanning. These cores were reduced manually to wafer size discs and then ground in 3 stages through 10mm, 5mm and 1mm sieves. Each sample was decanted into a glass vial and scanned in Near Infra-red wavelength range with a Bruker Multi Purpose Analyser. This extraction procedure was repeated at ages 4, and years on the same trees.

NIRA models

NIRA models were developed prior to the prediction of results for samples used in this study. The near infra-red spectra of samples were combined with data points from analytical chemistry (e.g. Seifert cellulose, or Klason lignin) in a single prediction model making use of Bruker OPUS Quant 2 package. The model calibration is based on partial least squares regression with cross validation.

In contrast with the prediction of wood chemistry with NIRA, which is an indirect method of measurement, the basic wood density was measured from the cores that were kept intact as the quotient of oven dry weight over maximum saturated green volume in $g.cm^{-3}$.

Results

The two sites with similar rainfall (c. 1250 mm an^{-1}) differed only in dominant soil types, but exhibited vastly different growth. The different genotypes (GU, GC and GT) and the individual clones when analysis of variance was conducted showed significantly different diameter growth. The good site (CT091) on Fernwood sands had an average MAI for all genotypes (GU, GC, GT and *E. grandis*) at eight years of 32.4 m^3 ha^{-1} an^{-1}, while the poor site on Longlands soil form had a MAI6 of 15.1 m^3 ha^{-1} an^{-1}.

Basic wood density differed significantly for different clones in each trial. The good site had a slightly lower basic wood density for the trial means of 0.431 g.cm^{-3} versus 0.457 g.cm^{-3} of the poorer site.

The NIRA calibration models worked well for predicting the wood chemistry. The multi species models for % cellulose and % lignin returned respectively: coefficient of determinations of 94.69% and 95.02%; root mean error of estimations of 0.426 and 0.371; and residual prediction deviations of 4.34 and 4.48. These figures are suitable for screening genotypes for wood chemistry without having to apply analytical methods.

Fibre gain factor is a measure of the increase in pulp fibre per hectare that can be expected from genetically improved planting stock relative to that available as a benchmark. It consists of improvement in one or all components of the yield of pulp fibre per hectare: namely wood volume (Vol), basic wood density (BWD) and cellulose content per unit mass of wood (CEL).

$$Fibre\ productivity\left(\frac{kg}{ha}\right) = Vol\left(\frac{m^3}{ha}\right) \cdot BWD\left(\frac{kg}{m^3}\right) \cdot CEL(\%)$$

Hence Fibre Gain Factor was calculated as:

$$Fibre\ Gain(\%) = \frac{(CEL_{improved} - CEL_{benchmark})}{CEL_{benchmark}} \cdot \frac{100}{1}$$

In this study, all the material planted commercially from 1988 – 1990 were used as the benchmark. When gains on the good site are considered in Figure 1, it is construed that the gain in volume of the 2001-2005 clones over the benchmark was 30% and that of available fibre to the market with 17%.

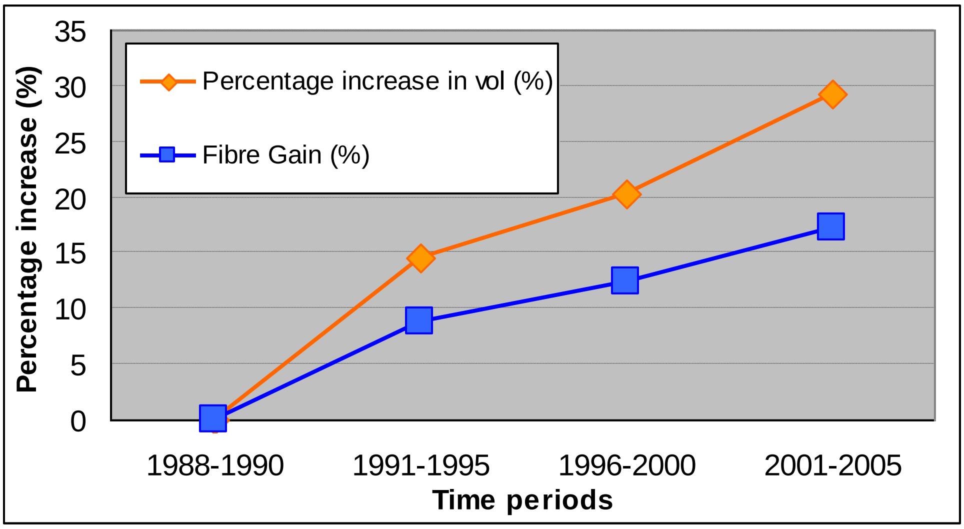

Figure 1: Gains made in Volume ha^{-1} and Fibre gains from 1988-2005 at CT091.

Conclusion

From the study presented in this abstract, it is clear that NIRA is a sufficiently accurate technology to replace analytical chemistry to calculate real fibre gain from one period to another with the inclusion of volume and basic wood density as variables of measurement.

Evaluation of forest growing stock accessibility for harvesting systems using LiDAR data

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Introduction

The research on possible applications of Light Detection and Ranging (LiDAR), and especially the use of data acquired by Airborne Laser Scanner (ALS) sensors, for forestry and environmental applications has provided significant results in recent years. As a consequence the use of accurate and high spatial resolution Digital Terrain Models (DTMs) from LiDAR data has highlighted an increasing demand for a growing number of mapping and GIS tasks related to forest applications also in the field of forest engineering (Pirotti et al, 2012).

Most of these studies in the forestry field focus on the extraction of structural parameters and on forest biomass estimation (Montaghi et al. 2012, Wulder et al. 2012), while the applications in the field of forest operations are still limited. Recently White et al. (2010) proved that high resolution DTMs derived from LiDAR survey can be effectively used to identify forest roads even under dense forest canopy. Contreras et al. (2012) has also proposed to estimate the earthwork volume in forest road construction using a LiDAR derived high resolution DTM. Heinimann and Breschan (2012) use a single-tree approach based on LiDAR data to make a pre-harvest assessment on areas where a cable-crane will be installed.

The terrain slope, together with the structural characteristics of the forest and the roughness of the terrain, are the determining factors in the choice of the system of extraction. Moreover the various systems of extraction are also limited by distance to roads.

The potential of ALS to derive detailed information both on ground micro morphology and on forest characteristics (eg. growing stock) make now possible to develop more precise and dependable forest accessibility maps.

This work will present a DSS-GIS tool that uses ALS data for the evaluation of forest growing stock accessibility through a categorization of the terrain in accordance with the limitations of different harvesting systems.

Material and methods

The first step of the analysis is the investigation of the forest road network, where LiDAR data plays a key role in the pre-identification of the roads even under dense forest canopy (White et al, 2010). Forest roads are then classified in terms of construction standards by identifying the main constraints (i.e. roads widths and curve radius) for the machine access by a field survey.

All GIS processes for the definition of the harvesting systems applicability have been integrated within a model in ArcGIS 10.2 using ModelBuilder interface. Technical limits have been defined considering terrain slope, distance from the closest road with adequate standards, roughness of the terrain and terrain orography (presence of ridges). To evaluate terrain roughness, an index has been derived from a DTM (directly generated from ALS data) that notes the presence of rocks or understory vegetation detectable from LiDAR pulses. A surface model is thus generated which includes the LiDAR points that are not normally classified as ground in the normal routine (Pellegrini et al. 2013).

At the last stage, a local maximum detection algorithm (Koch et al. 2006) is used to identify single trees from the CHM (Canopy Height Model). Growing stock maps are then derived after the calculation of the expected volume of each tree by using local allometric function.

Both the maps (extraction system feasibility and forest growing stock) have been validated; the first comparing the result with the historical database of harvesting operations which occurred in the last 10 years, and the second through the collection of 28 ground-truth plot (20 m radius) in the field where growing stock has been measured.

The join between the two maps gives an idea about the possible level of use of different types of machinery providing indications for the optimal equipment of forest enterprises at a local level.

This methodology has been tested in an area of 35 square kilometres located in north-eastern Italy where LiDAR data have been acquired in July 2012. The test site area is completely covered by a mixed Norway spruce, silver fir and beech forest and with a high variability in morphologic conditions. The study area is designated as a test-site within the Alpine Space Project named NEWFOR (www.newfor.net).

Results

System of extraction evaluation

Figure 1 shows an example of how the terrain classification according with the different extraction systems feasibility looks like with a map resolution of 1m.

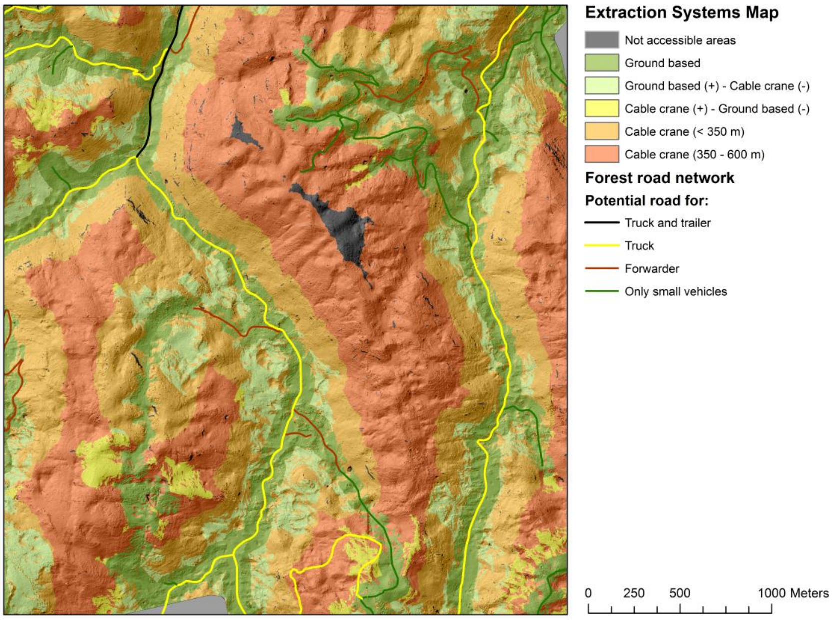

Figure 1: Example of system of extraction map

The comparison of the indication of map with 59 harvesting operation that took place in the area shows quite a good reliability (Table 1) with a right classification of the area in the 85% of the cases (50 harvesting sites).

Table 1: Validation matrix of the extraction systems maps compared with real extraction sites

Extraction system	N real harvesting site	Model result	
		Ground based	Cable crane
Ground based	34	26	8
Cable crane	25	1	24

In almost all the cases, (one exception) the error is due to the fact that ground based systems have been used in areas indicated as suitable for cable crane extraction.

Growing stock estimation

Figure 2 shows an example of the single tree map (a) and the derived growing stock distribution map (b).

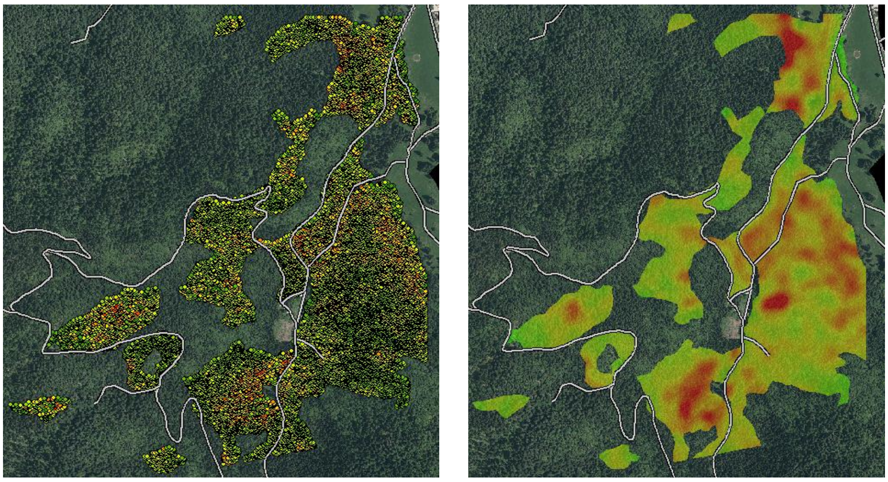

Figure 2: Example of single tree extraction map (a) and derived growing stock distribution map (b) for Norway spruce stands

Table 2 presents the expected error for the two different forest types in terms of volume underestimation (%). This error is due to the fact that using a single-tree approach, it is possible to detect only the trees in the dominant layer. Furthermore, in mixed irregular stands (i.e. Norway spruce, silver fir and beech) single tree detection is more difficult due to the more complex structure; consequently the error result higher.

Table 2: expected error for the two different forest types of the areas in term of volume underestimation (%)

Forest type	N plots	Error % (mean)	Error % (min)	Error % (max)
Mixed irregular stands	12	-12.41	-4.59	-23.52
Even aged conifers stands	16	-19.57	-5.18	-40.22

Finally, by linking the two previous maps it becomes possible to estimate the number of trees and the relative volume (m^3) that potentially can be harvested using each system (Table 3).

Extraction system	Trees Number	Volume (m^3)	%
Ground based	289 072	363 696	26.8
Ground based (+) - Cable crane (-)	189 014	261 608	19.3
Cable crane (+) - Ground based (-)	45 334	50 032	3.7
Cable crane (<350)	345 383	368 900	27.2
Cable crane (350 - 600)	252 926	280 635	20.7
Not accessible	30 446	30 289	2.2
	1 152 175	1 355 160	

Table 3: Number of trees and the relative volume that potentially can be harvested using each system

Conclusion

This preliminary analysis has shown that ALS data can provide useful information in order to evaluate the forest growing stock accessibility considering the different types of harvesting systems.

The use of terrain variables (slope, roughness) derived from a high resolution DTM seems to be effective in predicting the feasible harvesting systems, as the model result corresponds with reality in the 85% of the cases. Errors in systems classification are due to the fact that most of the forest enterprises are equipped only with forwarders and tractors and few have cable systems. For these reasons there is a use of ground based systems even in situations where the use of cable system would likely be better both in terms of safety and productivity.

The use of ALS for the calculation of the growing stock is actually a hot topic and nowadays methodology is developing very fast. The single tree approach seems to be more effective for the evaluation of the harvestable volume (that is mostly in the dominant layer).

The analysis of the growing stock sharing into the different harvesting systems shows that 47% of the volume is in areas more suitable for cable crane systems. This information could be an advice for forest enterprise for the orientation of future investments.

Going forward with this project, the focus will be on both the improvement of the model, especially for determination of the roughness index, and improvement of the volume estimation using different approaches.

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Theme 2: Development of site-specific precision forest management strategies

Session Chair: Dirk Jaegar

Using non-destructive evaluation as a means of predicting inherent wood properties: eastern larch grown in Northwestern Ontario as a case study.

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Abstract

The forest sector needs to be more responsive to global demands. This requires a research-based understanding of the useful characteristics and limitations of the harvestable wood. Resource attributes or wood characteristic mapping of the Northwestern Ontario (NWO) species eastern larch was considered with respect to developing tools to assist foresters and wood products manufacturers to increase this species utilisation. The research aimed to utilize inherent wood properties in order to maximise product potential. The study area included the 6 EcoRegions of NWO where samples and data were collected from a resource of 22 destructive and 20 non-destructive plots in natural stands plus 22 destructive and 120 survival plots from plantations. We developed wood characteristic maps for eastern larch to display radial and axial variability of inherent wood properties within the study area. Following completion of these maps non-destructive evaluation using acoustic wood velocity and increment cores to predict inherent wood properties at a stand level was completed. Through all the testing that was carried out it was found that the greatest variability in the selected wood properties displayed by this species was between sites. Longitudinal or axial variability was significant between the butt log, the main stem, and the crown log for all the selected wood properties tested. Radial variability between the juvenile core and sapwood (mature wood) for all the selected wood properties tested was significant. On a regional scale this research approach allows us to include inherent wood property attributes in the Forest Resource Inventory. This provides managers with a tool to better utilize the resource and optimise the value of the resource.

Soil damage avoidance while maintaining efficient logistic operations

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Background

During one year about 120,000 areas are harvested in Sweden with a volume of 75 million cubic meters. Each of these harvest areas requires planning by a forest manager in order to design a harvest plan. Such a plan includes which parts of the area should not be harvested due to ancient heritage, vulnerable areas and special habitats. Also included is the proposed location of primary trails used by the harvester and forwarder. This planning work, if it is done at all, requires considerable time and is done manually. Moreover, once the forwarding is done, there often is soil damage, see figure 1 below for two examples. These damages cause increased fuel consumption of the harvester, decreased production of future forest, release of mercury to the ground water at worst, increased maintenance cost and more importantly a great deal of criticism from the public as it affects people's recreation, hunting and the value of nearby homes. In recent times forest companies have agreed to return to these areas in order to repair any damages found, but this has considerable cost and reduces the capacity for other operations. Hence, in a few projects, there is the objective to develop planning tools that can establish and propose better trail networks for the forwarder in order to minimize soil damage.

Figure 1: Examples of damages done by forwarders at one harvest area.

Harvest and forwarding operations

The standard harvest approach in Sweden is to use cut-to-length operations. This is typically done in teams of one harvester and one forwarder. A typical area for clear cutting is 1 - 40 hectares. Besides the roundwood (sawlogs and pulplogs), there is also an increasing use of the forest residues, such as tops and branches, fuel logs and stubs. The harvest areas have, in general, moderate or no slopes but quite rough structures. There are also large lake systems throughout Sweden and there is often heavy rainfall in particular during autumn. This period together with the spring period when thawing (melting of the ice in the ground) occurs is the time when most soil damage occurs. In the winter season when soil is frozen, there is essentially no problem. During the summer there may be problems during periods with lots of rain. In the annual planning, there is the objective of avoiding harvesting sensitive areas during these difficult periods. However, there is no possibility to stop harvesting and hence there is an increasing need for planning tools specific to the operation of each individual area. When the trails are planned, there are a number of objectives to consider. Some of these are the following:

- Avoid ditches, peatland, water, steep slopes (>19 degrees), conservation areas, historical sites
- Minimum turning radius for trails and minimum distance between side trails
- Complex cost structures depending on the number of times a forwarder passes (including the weight) a trail, soil type, side angles due to slopes

Today there are an increasing number of information sources available. Many companies are using LIDAR to obtain information on single trees. This can then be used to simulate bucking and very precise volume output predictions can be done on the assortment level. From LIDAR data it is possible to get very precise geographical information in three dimensions. From other sources it is possible to get soil and water maps. Most harvesters and forwarders in Sweden today have on-board computers to follow up production and location.

Planning approach

To design a full trail network (primary and secondary trails), we use the following process:

1. Discretise the area in squares of 3 m x 3 m.
2. Determine landing points (piles of logs) depending on the reach of the harvest arm
3. Network design
   a. Construct primary trails (many runs with forwarder)
   b. Construct secondary trails (few runs with forwarder)
4. Determine forwarder routing

The discretisation is done based on the width of the forwarder. From each node there are eight arcs going out to adjacent nodes with a 45 degree angle between. This network of nodes and arcs becomes the base. For each node there is information on its three dimensional coordinates and slopes for each arc. Furthermore, as we know the soil type and any presence of water and trees, we can compute a function map which relates to a "cost" or penalty to use each arc. This is the basis of the design problem and we want to minimise the overall penalty. Given the locations of the trees and the size of the arm of a harvester, we can decide landing points where all logs will be placed. To find a network, we formulate a network design problem. This optimisation model includes flows on arcs and binary decisions to indicate whether the arc is used or not. This model can be very large and it cannot be solved directly. Instead, we apply a Lagrangian relaxation technique which decomposes the problem into two subproblems. The first subproblem is given in the flow variables and is in fact a shortest path tree problem. This establishes the minimum cost route from each landing points to the nearest pickup point where the logs are stored close to forest road. This problem can be efficiently solved by e.g. Dijkstras method. The second subproblem separated into one for each arc (or binary variable) and the reduced cost determines if the arc is used or not. These subproblems need to be coordinated and we use a subgradient method to update the Lagrangian multipliers. As the problem is very large, there is a need to first construct the main trails and then the secondary trails. The definition of a trail is when the forwarder passes it a fixed number of times (in our case 40). In the final step, we solve a vehicle routing problem to find the routes used by the forwarder. This information can be used also on a tactical level to estimate the actual forwarding times in a tactical planning.

Case study

We have tested the proposed approach on a harvest area of about 35 hectares. The harvesting produced 77,138 logs with a total volume of 12,499 cubic meters. There are 14 different log assortments. The first step of the method gave a base network with 50,202 nodes and 329,568 arcs. The resulting model has 25,666 variables and 14,965 constraints in a set covering problem. The solution gave 1267 landing points. We only use a heuristic and the solution time was only one second. The network design problem has 1.6 million variables and 1.2 million constraints. With the subgradient method, we needed 3 minutes to find the main trails and 20 minutes for the secondary trails. In our approach we cannot guarantee an optimal solution as it is a heuristic approach. For the main trails there are 1,810 arcs (0.5%) generated and for the secondary trails 30,020 arcs (9.1%). Given the network, the forwarder routing problem has 15,241 piles at 1,808 loading points. For this problem, we make use of the solution method in Flisberg and Rönnqvist (2007). This takes 2 minutes and provides 678 routes. The total length driven by the forwarder is 709 km and it will take the forwarder 16,422 minutes (11.5 days with 24 hour of working per day). Figure 2 provide the resulting landing points (left) and the network (right).

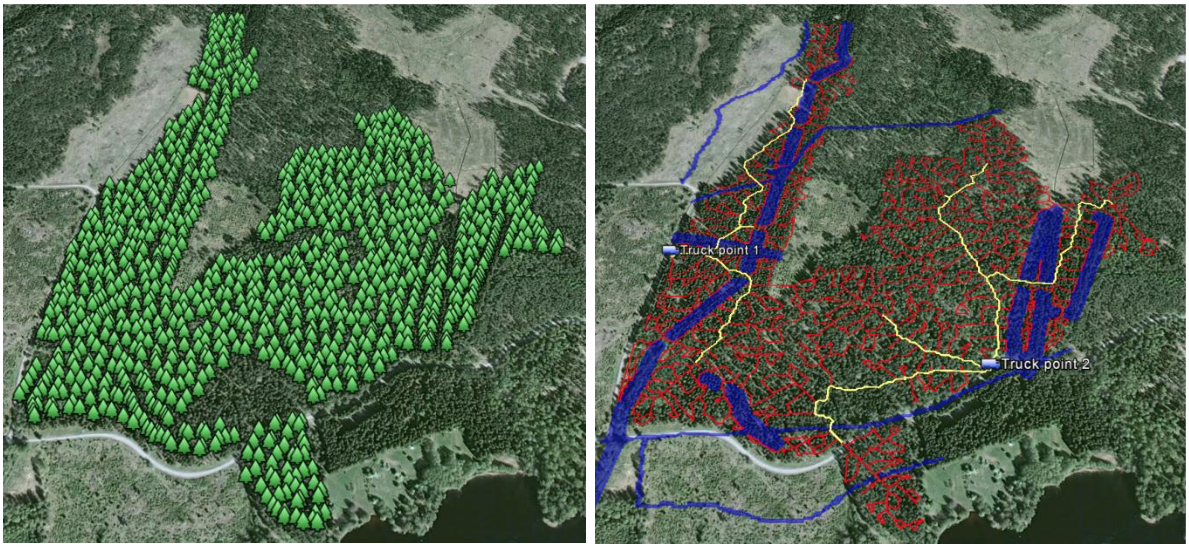

Figure 2: Landing points (left) and designed network (right). The blue areas are water ditches or creeks, yellow lines the main trails, the red lines the secondary trails, and "Truck point x" are two points for the storage close to forest roads.

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Save fuel by planning and good tracks

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Abstract

Let us use all the tools, proper equipment and knowledge we have and start planning before we start logging! The whole range of people who are involved in the chain from the forest to the industry should be included and together set up guidelines for different machine systems. It is also important to have control systems which are easy to follow during the harvest process. We need more communication through the organizations, giving a greater understanding of each issue in the pursuit of sustainable forestry.

Introduction

Many companies have realised that fuel prices are quite high and form a considerable part of the cost for an operation. Furthermore, increased awareness of soil damage forces both the operator and forest manager to make the operation more environmentally friendly. This is interesting because both things may point in the same direction – saving fuel.

An experiment on soft soils showed that a forwarder could use 2-4 litres h^{-1} more of fuel on soft ground when the wheels are sinking down (Wästerlund, Andersson & Bygdén, 2010) and on top of that reduce speed (Bygdén & Wästerlund, 2010), meaning lower production per hour. Instead, it would be better to build roads or put major temporary roads on hard ground to increase both the speed of the forwarder and reduce soil damage. This would both increase production, save the soil and decrease the use of fuel (Wålberg von Knorring (2012)).

Soil and tree root damage after an operation - e.g. a thinning operation - may reduce forest growth considerably (Wästerlund, 1989) and damage may reduce the growth of trees nearest the damage by up to 50 % (Figure 1). The problem is that most people do not see this kind of damage on the outside of the tree until the year of final cutting; often 30-50 years later when the year rings are visible. Thus, it is difficult to convince foresters of the real problem.

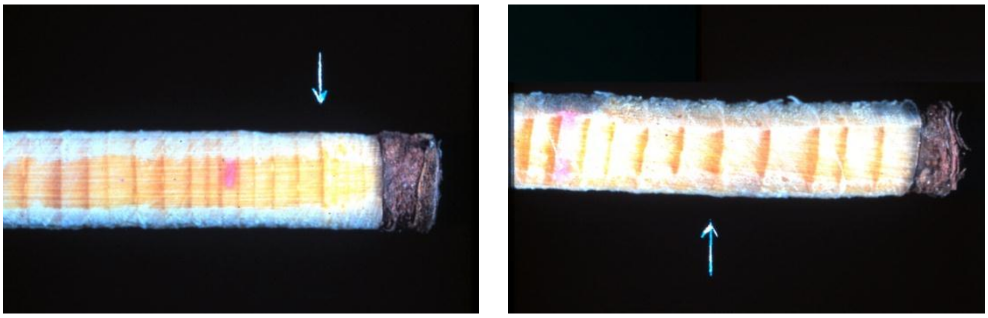

Figure 1: Increment cores from a tree standing near deep wheel ruts (left) and a tree standing 3 m from a wheel rut (right). Arrow marks time for thinning and red dot 5 years before. Photos: I. Wästerlund.

The conclusions from these studies can be summarized as:

- Good soil on major roads increases production and reduces fuel costs
- Tracks increase productivity on soft places and decrease fuel consumption.
- Money is saved in the long term with good planning and good tracks – also saving the ground and forest productivity!

- Wet soil and heavy machines create deep ruts in the soil and that combination must be avoided
- The guidelines presented here follow a simple relationship between ground pressure and soil strength with the purpose of getting less than 10 cm wheel ruts
- More studies are needed to make more precise and better guidelines, but present models can serve as a general principle and start the discussion.

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Estimating potential stump harvest from multiple data sources - an example from a county in southern Sweden

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Abstract

Stumps have become a potential resource for bioenergy. In Finland more than a million m^3 is harvested annually. In Sweden this resource is still not utilised to any significant degree. As stump utilisation requires some major investments at the power-plant and for the supply chain, it is desirable to estimate what volumes could be procured at different costs and for different restrictions. The study was conducted in the county of Kronoberg in southern Sweden. The county has 646 000 ha of productive forest.

Figure 1: Finnish stump-lifting device.

The conditions of Swedish forests have been assessed by SLU at a 25x25 m pixel resolution. The assessment is made by combining satellite data with NFI-plots. Standing volume, age and species composition are some of the variables that are estimated. The pixels may be combined into stands by automatic segmentation. All stump harvesting starts with a regular final felling. In order to create plausible harvest areas, a number of stands were chosen randomly from among stands that were eligible for final felling (above a certain age). The area was chosen so as to correspond to the approximate area of final harvest during the last five years. In order to study the influence of probability in harvest allocation, five five-year harvest areas were generated.

Figure 2: Map of southern Sweden with the county of Kronoberg indicated (© Lantmäteriet).

From the generated harvest areas, stands that were considered suitable for stump harvesting were chosen. For Nordic conditions, stump harvesting is more or less restricted to Norway spruce (*Picea abies*). The volume of the stumps can be estimated from the stem volumes. Different restrictions can be applied to the stump harvesting, e.g. buffer zones to water and conservation areas. Economic restrictions must also be considered such as minimum volume per ha and extraction distance. The digital land-use map as well as the digital road map were utilised to construct buffer zones close to lakes and streams and to estimate the extraction distance to the closest road. In this study all stumps were presumed to be utilised by a power-plant in the largest city of the county (Växjö) which is also located relatively centrally. The hauling distances for the stumps were estimated. Thus, it is possible to give fair estimates of potential stump harvesting volumes and the cost structures for those volumes.

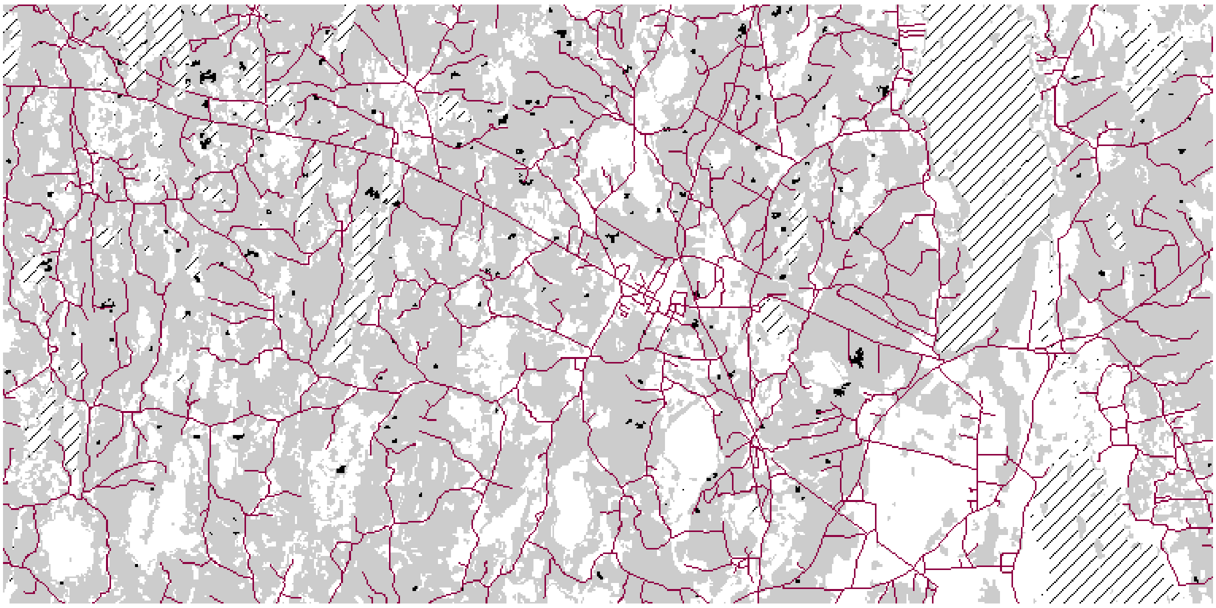

Figure 3: Map (detail) with potential harvesting sites indicated in black. Grey colour represents forest and the hatched areas are waterbodies.

The major proportion (80%) of the forest in Kronoberg county is owned by non-industrial private forest (NIPF) owners, the average size of an estate being ca. 40 ha. If the owners are interested to let anyone utilise their stumps (and at what price) is another question which this study does not address.

Cypress (*Cupressus lusitanica* Mill) plantation management based upon a stand density index concept

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Introduction

This research was conducted in the Antioquia province of Colombia (South America), where cypress (*Cupressus lusitanica* Mill) is not a native species, due to the interest of some enterprises for planning purposes.

The main objective has been to acquire knowledge on growth and yield and density as a tool for management, as well as to develop a quantitative approach for the most productive and profitable management.

The basic concept for management was a fully stocked range of stands, measured as stand density index – SDI; a variable independent from site class. Cypress growth and yield knowledge in Colombia is lacking, both from old planted forests and from forest management tradition.

Material and methods

A field survey of 20 permanent plots, close to 1 000 m^2 in size and square in shape were measured once a year during the dry season for 2-6 years. A total of 87 measurements were taken in this time. Stand ages ranged from 4-39 years. The plot altitude ranged from 1800 – 2500 m above sea level; these plantations are in the Holdridge life zone (humid-perhumid)-Lower montane and (bh-bmh) Montane classification. Individual tree volumes were calculated based on the author's volume equations for the same plantations (Forestales Fve Ltda., 1991).

Simulation modelling software developed by the author has been used for a case study management application.

Results

A summary of the plot data is shown in Table 1 below.

Table 1: Average plot measurement results

t (yr)	**hdom (m)**	**S (m/15yr)**	**N (trees/ha)**	**dg (cm)**	**cca-dg (cm/age)**	**G (m2/ha)**	**cca-G (m2/ha-yr)**	**Stand density index (trees/ha)**	**Vsc (m3/ha)**	**cca-Vsc (m3/ha-yr)**	**cma-Vsc (m3/ha-yr)**
15,2	16,7	22,11	1.984	15,2	0,7	33,11	2,53	774	232,6	20,2	18,0

An equation for site index at the 25 years reference age was developed (equation 1). Volume growth minus bark growth was also modelled (equation 2). Both equations are shown against the scatterplot of data in Figure 1 below.

$$S_{di} = h_{dom} + 0.81t_{25} - 0.0078t^2 \quad (1)$$

$$cca - Vsc = 0.0011t^{-0.40}S^{1.58}Sdi^{0.88} \quad (2)$$

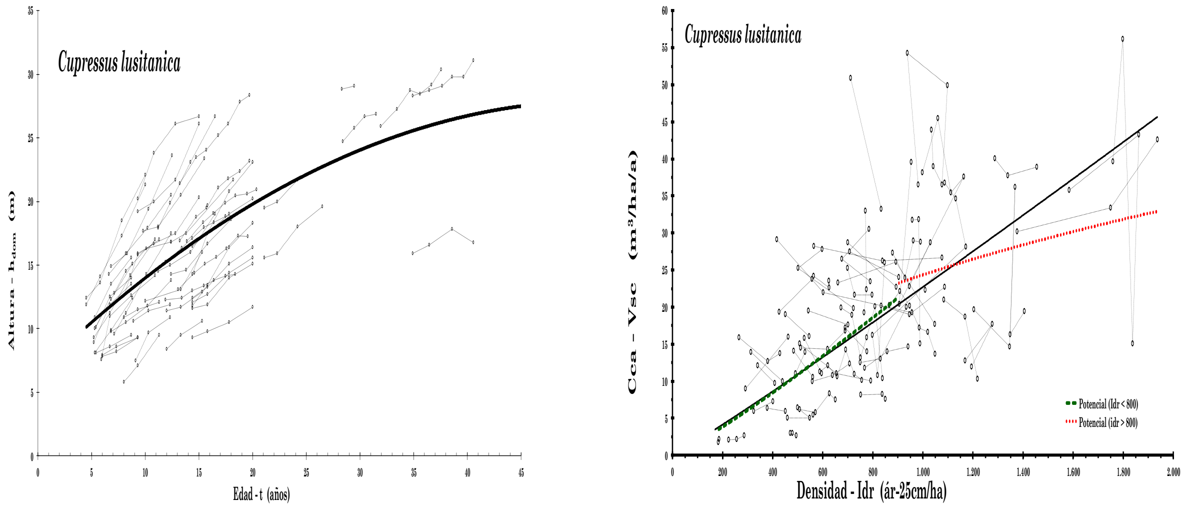

Figure 1: Height with respect to age on the left (a) and volume growth versus the stand density index on the right (b).

Conclusions

At a stand density index greater than 600 trees at 25 cm ha^{-1}, there is not a significant difference in volume growth. This density level is typically reached after 10 years of age, and field surveys confirm this stand density index as preferred. This stand density index is therefore recommended as the minimum managed stand density. The range of stand density depends on logging operational costs and has been defined with a minimum logging volume of 75 m^3 ha^{-1}.

Application

Productivity under management using principles and equations developed.

The results and equations developed in this study have been applied to a plantation forestry project for the company Reforestadora Madetec S.A.'s cypress stands. Equations for four levels (growth, yield, remaining stand and log size classification) were used as the input for a simulation model using software developed by the author to estimate future management results and forest productivity.

Three stands with different management strategies were simulated and ranged in areas from 4.25 ha to 32.8 ha (Table 2). The field survey inventory data for these stands was also compiled (Table 3).

Table 2: Description of simulated stands

Stand Code	Species	Area (ha)	Plantation Date	Management Strategy
Cl-A	*Cupressus lusitanica*	32,80	Sp/01/74	Thinning
Cl-B1	*Cupressus lusitanica*	51,63	Sp/01/74	Felling
Cl-B2	*Cupressus lusitanica*	4,25	Sp/01/74	To be defined
Total: planted 285,94 ha; standing 285,94 ha				

Table 3: Summary of field survey inventory data for simulated stands

Stand	Inventory date	Age (years)	h (m)	N (trees/ha)	dg (cm)	Stand density index (t/ha)	V (m^3/ha)	Vr (m^3)
Cl-A	Jan/25/95	20,4	24,9	936	25,1	942	410,2	13.455
Cl-B1	Jan/16/95	20,4	23,3	962	24,3	919	342,2	17.668
Cl-B2	Jan/18/95	20,4	24,2	1.187	25,4	1.218	521,0	2.214
Total	281,59 ha							77.443
Average		**18,1**		**1.078**		**813**	**275,0**	**14836,9**

The simulation model produced an estimated forest inventory (Table 4).

Table 4: Simulated estimated forest inventory for each stand

Stand	Inventory date	Age (yr)	h (m)	S (m/ 25yr)	N (t/ha)	dg (cm)	G (m^2/ha)	Stand density index (t/ha)	V (m^3/ha)
Cl-A	St/25/95	21,1	25,4	28,08	936	25,4	47,61	963	445,9
Cl-B1	St/25/95	21,1	23,8	26,30	962	24,6	45,90	940	404,3
Cl-B2	St/25/95	21,1	24,7	27,31	1.187	25,7	61,60	1.241	556,2
Cl-B3	St/25/95	20,4	23,9	26,93	821	25,2	40,95	832	363,9
Average		**20,1**		**25,23**	**1.100**			**881**	**345,7**

Stand	Vr (m3)	Vr1 (m3)	Vr2 (m3)	Vr3 (m3)	Vr4 (m3)	Vr5 (m3)
Cl-A	14.625	4.959	7.661	1.110	624	270
Cl-B1	20.874	3.401	12.850	2.607	1.457	559
Cl-B2	2.364	187	1.495	362	233	87
Cl-B3	6.005	1.981	3.246	408	265	104
Total	**98.849**	**20.042**	**45.935**	**14.884**	**12.099**	**5.889**

This simulation method and type of results has also been used for other forest plantation projects, including *Pinus* species as well as broadleaf species (*e.g.* teak, *Gmelina arborea*, *Eucalyptus*, *bombacopsis* ssp.*quinata*) and also a mangrove project.

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Mechanised pine thinning harvesting simulation: productivity and cost improvements as a result of changes in planting geometry

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Abstract

Mechanised harvesting for thinning has traditionally involved the use of row thinning to provide access into the compartment by heavy machinery and the inter-row area subsequently receiving a selective thinning. These row thinnings have, in most cases, been applied on the 7th row to a standard 2.7m x 2.7m planting geometry. This allows a machine trail width of 5.4m on the thinned row and the distance to the furthest tree (8.1m) being within the limits of the harvester boom reach. In the current state, these widths and spacing's are sufficient to allow machine movement through the stand and minimal damage residual trees.

A simulation study, based on changing the planting geometry in order to investigate the effect on harvesting in terms of stand impact, simulated harvesting productivity and harvesting system costs was done. This involved creating sample compartments of different planting geometries, from the standard 2.7m x 2.7m to 2.5m x 2.9m, 2.3m x 3.1m and 2.4m x 3m at thinning reference ages for South Africa. These compartments were 'virtually' thinned and harvested by means of a simulator.

The proposed planting geometry changes maximised the reach of the harvester by increasing the row removed from 7th to 9th and in turn reducing the machine trail length ha^{-1} by 20%. This reduces stand impact from harvesting activities and increases the proportion of selectively harvested trees per hectare. The resultant increase in the distance between thinned rows increased the volume harvested per meter of trail ($m^3.m^{-1}$) in turn leading to increased harvesting productivity by 10% to 20% when changing the geometry from the standard 2.7m x 2.7m to 2.3m x 3.1m and 2.4m x 3m for first and second thinning respectively. Based on this there was a reduction of overall thinning harvesting cost by up to 11% from the standard to the proposed planting geometries.

The study links the fields of silviculture, growth and yield management and timber harvesting. It also highlights the applicability of simulation methods for testing harvesting scenarios to developing economically viable alternatives and illustrates how the different segments of the forestry supply chain interact and potentially complement each other.

Theme 3: New transportation logistics technologies for fibre deliveries

Session Chair: Walter Warkotsch

Deriving cooperative biomass resource transport supply strategies in meeting co-firing energy regulations: a case for peat and wood fibre in Ireland.

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Introduction

Ireland, like all EU 27 countries, has a legal binding to the EU Directive 2009/28 EC which sets a target of 20% of all energy consumption to come from renewables by 2020 [1]. Ireland's contribution to this target is set out in the National Renewable Energy Action Plan (NREAP) which ensures that 16% of all national energy consumed by transport, electricity and heat will come from renewable sources by 2020 [2]. This will be achieved in the form of 40% electricity generation from renewable energy sources (RES), 12% for the consumption of heat and 10% for the transport sector. One main aspect of the NREAP (2010) is that the target of 30% co-firing for Ireland's 3 peat power stations that was set in the Energy White Paper (2007) [3] must still be achieved. To complete this initially, implies the offsetting of 0.9 Mt of peat with biomass. This paper looks at using a Linear Programming approach to analyse and provide the transport supply strategies necessary for optimal woody biomass allocation from the resources currently available in Ireland in order to meet the co-firing targets for two time horizons, 2015 and 2030.

Materials and Methods - Geographic Distribution of Supply and Demand Points

The three peat power plants are located quite centrally in Ireland within a triangular area of approximately 1,414 square kilometres (sq km). The maximum buffer distance of 73 km is between P1 and P3. The shortest distance of 44km is between P2 and P3. Figure 1 shows a GIS map of geo-referenced locations compiled to include; 3 peat power stations, 3 WBP mills, Sawmills, Peatlands, County Boundaries and Country Coastline.

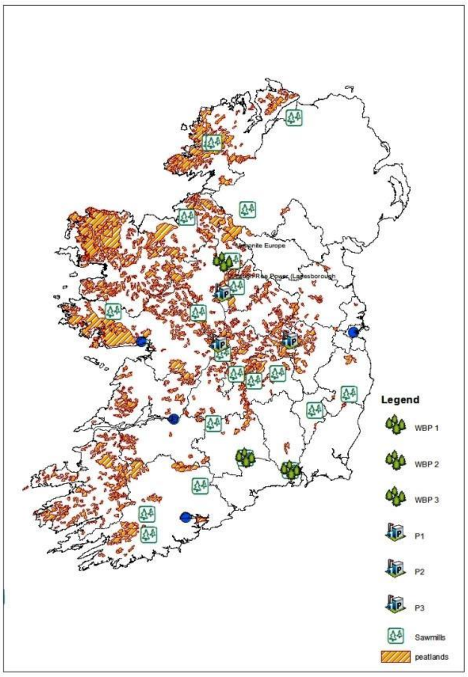

Figure 1: GIS Peat Power station map of Ireland. Also includes Peatlands, Wood Based Panel mills and Sawmills.

In total, 18 sawmills producing wood chips were identified as possible sources of mill residues for both electricity co-firing and the wood based panel (WBP) sector. Annual statistics on woodflow for the Republic of Ireland were obtained from Knaggs and O' Driscoll, 2011 [4]. A WBP plant is also regarded as a potential market for these chips. The energy and board sectors are considered here. The energy sector includes 3 peat fired plants with staggered goals for co-firing with renewable biomass. The total demand volumes in solid cubic metres are detailed in table 4 with an assumed moisture content of 40% and an energy content of 7.3 GJ / m^3 or 10.4 GJ / tonne [5]

P1 has a planned intake of biomass of 420,000 m^3 (300kt) in 2015, which equates to 30% of its intake of peat. This percentage value has been set by Irish legislation. This is planned to increase to 700,000 m^3 in 2020 when a 50% co-firing target is reached and when approximately 500 000 t of peat needs to be replaced with an alternative fuel. It is anticipated that this figure will remain consistent for the 2030 analysis. For P2 and P3, there is no intake of biomass in 2015. The planned intake for P2 and P3 in 2030 is assumed to be 30% of its current peat consumption and is equivalent to 504,000 and 378,000 m^3 respectively. P2 and P3 plan to co-fire from 2019 onwards. Given that it will take P1 eight years to reach a 30% co-firing rate, the year 2030 is seen as a logical time horizon for this analysis.

The board sector includes 3 WBP mills. Two of the board plants source only chips directly from the available resource, while the other mill can include both woodchips and pulp. Sawdust is neglected in the analysis here as a mill residue for bioenergy, as it is primarily re-used by the sawmills as boiler fuel and the increasing wood pellet manufacture in Ireland.

Results

The three scenarios run for each time horizon (2015, 2030) solved feasibly due to the inclusion of an unlimited pulpwood supply at € 5000 TJ^{-1}. For Scenario2015, the focus on a Global solution allocates the sawmill residues relatively equally between sectors with 268.9 km^3 to the Energy sector and 248.9 k m^3 to the Board sector (table 1). When the emphasis is placed on minimising the delivered cost to the Board sector, all available sawmill residues are allocated to them (517.8 k m^3 to the Board and 0.0 k m^3 to Energy). The Energy sector sources only from the alternative biomass pool at a value of 420 k m^3. Finally, when the optimisation was run for the benefit of the Energy sector, approximately 410 k m^3 of sawmill residues are allocated to them, while the board plants collectively receive 107.5 k m^3.

For Scenario2030, the total demand is increased from 1 587 500 m^3 to 2 749 500 m^3 – an increase of 58% in a constrained market. This is in line with the predicted forecast of roundwood production in Ireland to 2028 where the net realizable volume of thinnings alone from the private sector and Coillte (public forest estate) will be 738 000 m^3 and 1166 000 m^3 respectively, giving a total of 1904 k m^3 potential 'other' biomass direct from the forest sector [6]. Focusing on a Global optimum resulted in 47.8% of Energy demand being met from sawmill residues while only 9% of the Board sector's demand comes from there. When the optimisation's focus is on minimising delivered costs to the Board sector, all the sawmill residues are allocated to them as in Scenario2015, although this now makes up only 18.8% of the total demand, and 42.5% of the Board plant's requirements. When optimising for the Energy sector in 2030, the distribution of allocation in absolute quantities is equivalent to that from Scenario2015; however, their relative importance was diminished to 14.9% and 3.9% respectively.

Table 1: Volumes allocated under various scenarios in volumes (000 m^3 (%)).

Scenario	**To Sector**	**Biomass**	**MAIN FOCUS IN OPTIMISATION RUN**		
			GLOBAL	BOARD	ENERGY
Scenario2015	Energy	Residue	268.9 (16.9)	0 (0)	410.3 (25.8)
		Other	151.0 (9.5)	420.0 (26.5)	9.7 (0.6)
	Board	Residue	248.9 (15.7)	517.8 (32.6)	107.5 (6.8)
		Other	918.6 (57.9)	649.7 (40.9)	1 060.0 (66.8)
	Total 2015		1 587 500	1 587 500	1 587 500
Scenario2030	Energy	Residue	1 313.0 (47.8)	0 (0)	410.3 (14.9)
		Other	269.0 (9.8)	1582 (57.5)	1 171.7 (42.6)
	Board	Residue	248.9 (9.0)	517.8 (18.8)	107.5 (3.9)
		Other	918.6 (33.4)	649.7 (23.7)	1 060.0 (38.6)
	Total 2030		2 749 500	2 749 500	2 749 500

Conclusion

This paper considers how the adoption of sweeping policies impacts other actors presently supplying or utilising woody biomass resources. The SAWMILL sector (18 sawmills), BOARD sector, 3 board plants, and ENERGY sector (3 peat fired power stations) were included in a linear programming (LP) based transportation study. Specific transport costs between each residue producing sawmill and each board and energy plant were modelled and used in finding the minimum delivered cost for a number of scenarios. Results showed how overall supply costs increase with increasing alternative energy cost, but also how the dynamics between sectors' focus worked. The cost of transport to the Energy sector ranged from € 306 043 to € 996 842 in Scenario2015, while the increased demand in 2030 led to a range of between € 1 132 831 and € 4 926 040, depending on the alternative cost selected. For the Board sector, whose absolute demand remained constant, the total transport cost ranged between €868 506 and €3 454 916 in Scenario2015. The unchanged demand showed that the transport costs also remained the same for the 2030 Scenario; however, the optimisation focusing on the Energy sector, increased the delivery cost to the Board sector by up to € 693 730 per year by 2015 and € 842 271 per year by 2030, indicating intervention would be necessary if political ambitions of a 30% co-firing should happen without detriment to other important wood based industries.

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A simulated annealing algorithm to solve the log-truck scheduling problem

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Introduction

In this paper, we present a simulated annealing (SA) approach for solving the log-truck scheduling problem, which is an extension of the timber transport vehicle routing problem with time windows (TTVRPTW). The problem is characterised by a heterogeneous fleet of trucks that depart from their corresponding depots and must perform a number of daily transport tasks to move log products between wood pickup (harvest areas) locations and industrial customers, such as pulpmills and sawmills. Commencing at their depots, each truck must perform a number of successive transport tasks, each one charaterised by a trip between a designated harvest area and an industrial customer, until the number of daily working hours is completed (Karanta 2000, Audy et al. 2012). The objective of the model is to minimise total empty travel time for the whole fleet as well as waiting times at wood pickup locations. In addition, time windows and accessibility to harvest areas and customers, must be taken into account.

Material and Methods

In order to provide the inputs to solve the truck scheduling mathematical model, the daily transport tasks must be predefined. A task corresponds to a truck load or transport order that must be performed to obtain a feasible solution. The problem structure with tasks occurring at depots and customers reduces the number of constraints and variables considerably, as opposed to vehicle routing problems without predefined transport tasks.

The mathematical model corresponds to an adaptation of the formulation presented by Gronalt and Hirsch (2007) and Oberscheider et al. (2013), and it is formulated as a standard multiple depot vehicle routing problem with pickup and delivery (MDVRPPDTW). The model optimally allocates a fleet of logging trucks to transport tasks assuming a centralised transport system is in place to provide schedules for trucks and ensure that their utilisation is maximised.

Our solution approach to solve the truck scheduling problem is based on a standard SA procedure, and it was implemented and programmed in Visual C++ using an object-oriented design. It includes the SA heuristics as an optimisation engine in combination with a deterministic discrete event simulation to emulate the movement of trucks throughout the day. In addition the simulation model keeps track of all the performance metrics associated with the daily tasks performed by the trucks, and provides general metrics for the whole fleet.

Our solution approach consists of the following steps:

1. Determination of the SA cooling schedule, including parameter testing
2. Construction of an initial feasible solution with a greedy heuristic
3. Solution improvement by applying four different search improvement methods

The cooling schedule of the SA algorithm implemented is fully defined by the following components: Initial temperature (T0), final temperature (FT), temperature reduction factor (α), and iterations at each temperature (niter). Four SA search improvement methods were implemented: single task insertions, single task swaps, task insertions for a set of n-trials, task swaps for a set of n-trials. A small set of problem instances generated from real-life data was used to test and validate our algorithmic approach. The instance consisted of a sub-set of 30 transport tasks and 10 trucks, taken from an original data set comprising more than 150 transport tasks, 60 trucks, 25 wood pickup locations, and eight customers. Our SA algorithmic approach was implemented and programmed with Visual C++, while the mathematical model formulation was implemented and solved with the software GAMS® v. 24.1.3 and the solver CPLEX®.

Results

Table 1 shows the per cent deviation between the average solution (five runs) in each cooling scheme and the best single SA solution obtained for a total of 180 runs. The best single SA solution was obtained with an initial temperature of 20000, a temperature reduction factor of 0.999, and 1000 iterations per temperature. The maximum deviation between the average solution and the best single SA solution was 3.6%.

Table 1: Per cent deviation between the average solution in each cooling scheme and the best single SA solution

	Temperature reduction factor											
	0.8			0.95			0.99			0.999		
	Initial temperature			**Initial temperature**			**Initial temperature**			**Initial temperature**		
Iterations per temperature	20000	40000	100000	20000	40000	100000	20000	40000	100000	20000	40000	100000
500	3.0	3.5	3.6	2.7	2.9	2.6	2.2	2.1	2.0	1.1	1.3	1.3
1000	3.2	2.8	3.0	2.7	2.0	2.4	1.6	2.1	1.7	0.9	1.2	1.1
1500	2.7	3.6	2.8	2.4	2.2	2.1	1.6	1.6	1.5	1.3	1.0	1.1

In order to compare the efficiency of our SA heuristics, we also compared the best SA solution obtained in each temperature adjustment factor group with the optimal solution obtained with the optimisation software GAMS® and the solver CPLEX®. The mathematical formulation of the problem solved with an optimisation solver consisted of more than 16,000 integer variables and 17,000 constraints.

Table 2 shows the results for the problem instance evaluated. A neighbourhood structure with 60% probability of insertions and 20% of swaps was used to perform the comparisons. The best SA solution (2660) was obtained with a temperature reduction factor of 0.999, an initial temperature of 20000, and 1000 iterations per temperature. This solution is 0.4% away from the optimal solution (2648) obtained with GAMS® and CPLEX®.

Table 2: Comparison between SA and optimal solutions.

Parameters SA			**SA solution**	
Temperature adjustment factor	Initial temperature	Iterations per temperature	Solution value	Deviation (%)
0.8	20000	1500	2711	2.4
0.95	40000	1000	2692	1.6
0.99	40000	1500	2683	1.3
0.999	20000	1000	2660	0.4

Conclusions

In this paper, we have presented a simulated annealing algorithm to solve the log truck scheduling problem, which is a variation of the timber truck vehicle routing problem with time windows (TTVRPTW). Given the computational complexity of the truck scheduling problem, a SA heuristics has been developed, implemented, and tested for a small problem instance, consisting of 30 transport tasks and 10 trucks. Our results show that the best solutions are obtained when the temperature is reduced very slowly (reduction factor of 0.999) in combination with reduced initial temperatures (20000) and number of iterations per temperature (1000). In addition, the convergence of the algorithm is improved when a slow cooling scheme is implemented (slower temperature reduction factor), which results in more stable solutions and lower variance of the deviations in relation to the best single SA solution. Considering all the scenarios evaluated, our best SA solutions resulted in maximum deviations of 3% in comparison with the optimal solutions obtained with commercial optimisation solvers.

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Road transportation of biomass for energy in Ireland – energy balance and greenhouse gas emissions from a life cycle perspective

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Introduction

In Ireland, there is an increasing awareness of the need to reduce greenhouse gas (GHG) emissions and to develop alternative energy sources to reduce dependence on finite fossil fuel resources. The Irish government has adopted the European Union's (EU) Renewable Energy Directive (RED) target of 20% of overall gross energy consumption by renewables by 2020, further driving the need to develop bioenergy resources (European Commission 2009). The production and utilisation of the woody biomass, such as short rotation coppice willow (SRCW) and forest residues, in Ireland is seen as a viable route to reducing greenhouse gas emissions from energy production while helping to realise EU targets.

Transportation of biomass is seen to be one of the key issues in creating environmentally viable and sustainable biomass supply chains. Heinimann (2012) states approximately 60% of the overall environmental burdens of forestry production can be caused by road construction and maintenance, along with long-distance transport. As such, excluding these elements of the production chain from the system boundary could result in significantly underestimating the environmental impacts of wood energy systems. Increasing biomass demand created by the EU renewable energy targets will result in larger areas dedicated to bioenergy cultivation, and as such increased transport distances. The use of transport systems; however, means increased energy input to the bioenergy system, resulting in larger emissions.

In Ireland, transport is a major source of energy demand consuming approximately 30% of all energy. Road freight accounts for 16% of this with an energy demand of about 0.8 M tonne per year. Road freight energy demand has risen by over 119% since 1990 (Howley, Dennehy et al. 2011). In addition to this, by 2007, the road freight transport sector in Ireland had the highest increase in CO_2 emissions across all sectors, at 182% above 1990 levels (Howley, O Gallachoir et al. 2008). As such, it is vital to ensure that any potential environmental benefits from the utilisation of bioenergy are not significantly reduced by increased energy demand in transport.

Materials and Methods

Short rotation coppice willow and Sitka spruce production chains have been modelled for Irish conditions (Murphy, Devlin et al. 2013; Murphy, Devlin et al. 2013). The different methods of harvesting result in payloads with differing bulk densities which in turn affects the volume of material that can be transported. The effects of different payload weights are analysed.

The aim of this study is to further investigate and compare the impact of different road transportation systems on the energy balance and greenhouse gas emissions associated with biomass supply chains in Ireland. The study compares the different transport methods including; 5 and 6 axle truck configurations in relation to the 42,000 kg and 44,000 kg design gross vehicle limits; the different transport configurations such as tractor-trailer, and truck classes; EURO III, IV, V, are taken into account. The effects of varying transport distances will also be examined. A further variable is the biodiesel content of the fuel; increasing in line with EU renewable energy requirements.

The reference functional unit is 1 oven dry tonne of biomass delivered. All of the energy, mass and greenhouse gas flows in the system are normalized to this unit. The boundaries of the system are illustrated in Figure 1. The system encompasses all aspects of the biomass cultivation, land preparation, planting, harvesting, and transport.

Results

The preliminary results of the study identify biomass transportation as the major contributor to both energy demand and GHG emissions, accounting for 70 – 78% of overall energy requirements and (68 – 75%) of GHG emissions. Ideally biomass demand centres could be located close to the source areas to reduce this effect.

The analysis of willow chip transportation (Figure 1) highlights that tractor-trailer transportation over a distance of 50 km causes greater environmental impacts than transporting the biomass by truck over a greater distance of 100 km. This shows that there is a higher impact transporting biomass short distances using agricultural machinery and tractors than compared to the lesser impact of long distance transport by dedicated haulage equipment.

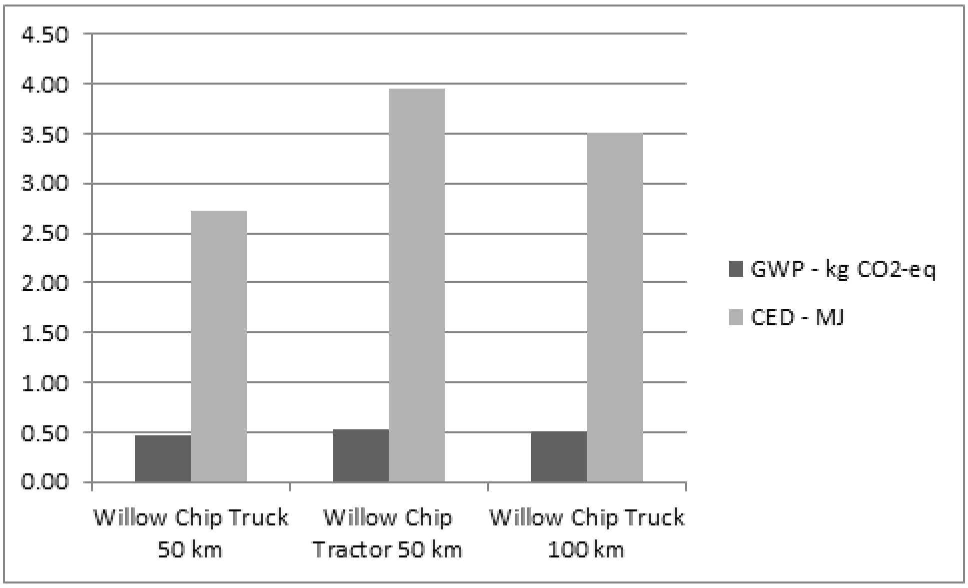

Figure 1: Results of analysis of different transport options for the haulage of willow chip per oven dried tonne

These findings highlight the importance of keeping biomass supply and use on a regional level, to keep transport distances low and thus maximise the environmental benefits attributable to biomass. This echoes the finding by Thornley (2008) that lorry transport makes a minor contribution to overall emissions while tractor transport emissions are more significant.

Conclusion

Preliminary results illustrate the benefits of utilising dedicated haulage systems while keeping transport distances low. It is anticipated that further results will highlight the effects of different transport loads on overall emissions to be evaluated based on differing bulk densities of the different biomass types. The effects of the implementation of the biofuels obligation scheme on the sustainable transport of biomass in Ireland will be highlighted. This research may highlight further areas of research to be explored, such as the effect of GIS routing of transport network on the energy balance of biomass transport.

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Integrated harvest and road upgrading planning

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Background

In most countries with intensive forest industry, there are periods each year when the roads are less accessible, mostly due to variations in temperature and precipitation. The problems with reduced accessibility is the challenge it adds to planning situations. We use a case study from Sweden; however, the problem is very general in nature. The weather conditions in Sweden vary throughout the year (cold winters, warm summers) due to the Nordic climate.

Every year, there is a period of thawing in the spring and typically a period of heavy rain in the fall. During these periods there is uncertainty in the accessibility of parts of the road network due to unfirm ground. This causes the Swedish forestry sector to incur considerable costs. Depending on the soil bearing capacity, there are also limitations in which harvest areas can be harvested during these periods. Pulp-, paper- and sawmills require a continuous wood supply all the year around. In order to satisfy this requirement, forest companies may be forced to use large reserve stocks of raw material located at roads that are accessible all year round. The outdoor storage of raw material generates considerable costs due to extra handling (one more loading and unloading) and deterioration in quality. Sometimes, impassable roads can be avoided by alternative routes, though the increased haulage distance creates significant extra transportation costs. Harvest planning can be done in such a way that some areas are avoided during the thawing periods. However, road upgrading must be done often to provide prerequisites for all year-round accessible harvest areas.

From an integrated forest company's perspective, there are a number of issues with this tactical planning. Even though road investment planning is normally carried out by senior managers with a great deal of experience, it is very time consuming to obtain an overview of the road network, volumes available for harvesting and road upgrade alternatives. Typically, the harvest and road upgrade planning is done on a rotational five-year horizon where the first year's decisions are implemented and the remaining four years are used as an anticipation period. Moreover, the planning is typically done on the district level, which is an organizational unit in large forest companies. Firstly, it is essential to determine which harvest areas to select for each year for harvesting. This step also includes the need to determine the potential number of areas for harvesting. The potential number of harvest areas often exceeds by a large margin what is required to harvest. Furthermore, harvest areas have different accessibility classes for both harvesting and transportation. Secondly, the industrial demand for different assortments should be forecasted over the planning period. In some cases there are long-term contracts to support this but often, it is based on historical information. Thirdly, the logistic operations, including road upgrading, harvesting, transportation and inventory handling must be considered. The standard approach in practice is to plan these activities in a sequential approach. Given the potential areas, a set of areas is selected for harvesting each year of the planning period satisfying an overall demand. Once this is done, the transportation and inventory planning is complete. Thereafter, follows a process where the road upgrades are determined. This may also give rise to revised transportation planning in order to limit the road upgrading cost. There are several reasons for this sequential approach. One reason is that the operations are handled by different parts of the organisation. Another is that an integrated planning requires information from different IT-systems that are not connected and that the underlying models become too large to solve efficiently.

Harvest planning integrated with logistics operations has been the topic in many articles. Some articles dealing with the Swedish situation are the following. Olsson (2005) presents a Mixed Integer Programming (MIP) model for the problem of providing available harvest areas during the part of the year when only roads of the highest standard are accessible (typically 6-10 weeks per year). This model is tested on a smaller case study in Sweden. In Frisk et al. (2006), a decision support system is proposed that is based on the detailed information from the Swedish national road database (NVDB). This includes information about all road segments in Sweden, such as their length, accessibility class and maximum allowed speed. The model used was; however, difficult to solve and some modified models were suggested in Henningsson et al. (2007).

One of the main developments was to suggest a flow model based on paths instead of an arc flow model in order to decrease the model size when the NVDB is used to define the network. The reason for a large model with arc flow is that there is a large number of links in the NVDB. The average length of an arc is over 100 meters. After further analysis with companies, it was clear that additional aspects must be included that have not been addressed earlier. Since the planning horizon is several years, a detailed description of the forest growth and the related net present values is required. For this reason, it was important to integrate with the Swedish Heureka system, see Wikström et al. (2011). This forest management IT-system includes modelling possibilities for both strategic and tactical planning problems. From using CTI trucks (CTI: Central Tyre Inflation) it became clear that truck types must be associated with different road quality. In the previous model, only one type of truck could be used.

The NVDB has many links and to use 0/1 variables or flows on each would generate an extremely large model. Hence, it is important to be able to aggregate the road data directly in the NVDB. In addition, in order to compute correct transport distances, not only must the distance be considered, but also road width, road quality, functional classification, etc. We use the distance computation now used by SDC, an organization administrating all forest transports, which consider 11 different attributes (Flisberg et al, 2012). Another aspect to include in the new model was a generic description between road type, seasonality and truck type. The earlier model also had no generic linkage between seasons and road type.

In order to find a good selection of harvest areas for the next five years, there are several alternatives. The traditional approach using models from forest management is to maximise the NPV value subject to demand constraints. However, such an objective does not at all consider the spatial location and its impact on the logistic costs. A standard approach for operational harvesting is to minimize the logistic costs. On the other hand, this does not consider the NPV values or the status of the forest after five years. This is very important as the potential number of harvest areas available for harvesting the next five years is much larger than the actual number selected. In order to avoid the potential problems with the above approaches, we propose an integrated approach which includes logistic, NPV and forest status.

The research contribution of this work is threefold. Firstly, we propose a new model which integrates harvest and logistic planning where road upgrading is a key aspect. The new model can include any combination of requirements between truck type, season and road characteristic. It also makes direct use of detailed information from the Heureka system. Secondly, we analyse the performance of an integrated approach compared to a traditional approach where the planning is done in a sequential approach. It is clear that the proposed approach has several advantages compared to the traditional approach in terms of costs and forest value. This contribution includes the suggestion of a new objective which models the forest value after the planning period. Thirdly, we propose a solution approach that can solve and establish high-quality solutions to the new optimisation model proposed. This is based on a sequential aggregation that decomposes the model into several smaller-sized problems.

All tests are done on a large case study from the Swedish forest company Sveaskog. The case study includes more than 6000 harvest areas, eight industries, five log assortments, more than 4000 road segments available for upgrading, and a planning horizon covering five years, each divided into four seasons.

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Calibrated route finder – an objective and efficient agreement on transport distance between haulers and customers

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Background

In Sweden forest road transport payment is based on the distance driven. The annual transportation cost in Sweden during 2011 by logging trucks was about US 800 million. The volume harvested was 73 million cubic meters transported by 1.7 million truck loads. Each of these truck loads had an average transportation distance of 98 km and each truck load requires an invoice as the basis for the payment transaction. Historically, many different means of establishing this distance exist, with the consequence that a given assignment can be invoiced differently. The distance is also often determined manually leading to unnecessary administration. Hence, there is a need for an objective and automatic routine that the parties on the forest transport market could agree upon.

Since a few years back, a system called Calibrated Route Finder has been in practice in Sweden. It is administrated by SDC; a central organisation in Sweden often called the IT hub of Swedish forestry. SDC manage and administer all the forestry transportation data in Sweden. They act as an independent organisation to ensure that correct information is used in the invoice handling between forest companies and transportation organisations. From the homepage of SDC or through automatic connections, companies can access the routing system to find the correct distance for invoicing. It is also a possibility to look at the proposed trip.

The Swedish road database SNVDB and distance calculations

SDC is also responsible for maintaining the forestry version of the National Road Database, SNVDB, which is retrieving information from NVDB, the Swedish National Road Database. NVDB was developed in collaboration between the Swedish National Road Administration, the Central Office of the National Land Survey, the Swedish Association of Local Authorities, and the forest industry. The database contains digital information about all Swedish roads: the state road network, the municipal road and street network, and private road networks. All roads, approximately 560,000 km, are described geometrically, topologically, and with detailed information about each road segment. During the past decade, Swedish forest companies have made large investments in order to collect all the necessary data.

To use the SNVDB it is first necessary to convert the basic data from the database into a network of nodes and arcs. Currently this network consists of about 2.20 million nodes and 4.43 million arcs. In the approach to establish the preferred route distance, nine road features are used. Within each feature there is a set of attributes. The total number of attributes (with a weight in the distance computation) is 56. Table 1 provides a summary of the features and attributes used so far in the system. Each of these attributes requires a unique weight in the distance calculations

Table 1: Summary of road features and attributes used in the project.

Id	Feature	No. of attributes	Comments
1	Bearing class	4	Bearing capacity of road (truck weight)
2	Terrain class	5	Suitability of different truck types
3	Road class	10	Classification of road quality from European motorways to small forest roads
4	Maximum speed	13	Different speed limits
5	Road width	16	Division in 0.5 meters
6	Owner	3	Government, municipality or private
7	Timber route	2	Special forest route
8	Passing route	3	Special route in cities through/around city centre
9	Length	1	Length

To find the weight for the attributes, an inverse optimisation approach is used. This involves establishing a set of routes, called “key-routes”, agreed by all parties. These are then used as the optimal solution of an inverse minimum cost model. The main decision variables are the weights and the objective is to maximise the number of key-routes generated as solutions from minimum cost route problems with the found weights. A more detailed description of model, method and analysis is found in Flisberg et al. (2012).

Results and use

Since 2008, we have established and put in operation a number of weight settings in the SDC online system. The number of road features and attributes has increased during the project as routing results have been studied by a project board as well as forest companies and transporters. In addition, a number of mechanisms to control the route selection have been included. One example is passing routes to avoid traffic in cities and another is so-called “approach routes” to industries. If an industry is situated in a town, a local requirement is often to follow a particular (approach) route. During 2009-2010 prototype testing was done and evaluated at six companies located in different parts of Sweden. Each of the six companies selected a smaller district in which to test the system in practice. The result of this prototype testing was very good and several companies have decided to implement the system for all their operations. We have also compared reported distances to SDC during a ten-month period in 2008 which covered all invoiced routes (more than 1.2 million). Since then, the system has been in full production to support participating companies. At the moment (October 2013), 35 % of all invoicing is based on the distance from this system. The vision is 100%.

Now and then the Calibrated Route Finder suggests routes that are not the best ones. In these cases the hauler can create a deviation report. These reports point at deficiencies and development needs. Two of the most frequent complaints are that the route has too much curvature or has too much work going up and down. Both these obviously increase the fuel consumption and the drivers need to be more observant. The impact of introducing a feature describing curvature and hilliness has been examined with encouraging results and it was recently decided to be implemented. A key question is whether or not it is possible to get this information to measure the curvature. Each road segment (link in the network) is given as a point sequence with horizontal and vertical coordinates. With this geographical information as a basis, it is possible to establish a curvature value. Truck drivers also avoid driving on roads with many hills, as it results in increased fuel consumption. However, the vertical coordinates are currently not of the same quality as the horizontal ones. There is a process under way to make information from high-quality aerial surveys available in SNVDB. When this work has been completed, it will be possible to compute the vertical work accurately too. Earlier in October it was decided at SDC to include curvature and hilliness as new attributes. In the presentation, we will discuss some preliminary findings and describe the implementations into a working system.

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Softwood roundwood secondary transport travel speeds over varying road classes, surface conditions and gradients: An Eastern Cape case study

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Introduction

In South Africa, the majority of softwood roundwood is transported directly from roadside landings to processing plants located throughout the country. These plants may be relatively close to the compartment (under 30 km) or in excess of 100 km away. The presence of a good road network is therefore essential for sustainable wood procurement. As the major design criterion of forest roads is to maintain and sustain high vehicle transport speeds (Uusitalo 2010), understanding truck travel speeds over roads of varying condition can help bring improved understanding to the relationship between road class, surface condition, payload and speed.

The objective of this study was to develop predictive models for travel speed for softwood sawtimber roundwood timber transport (RTT) over a range of forest road classes and provincial roads of varying condition for the Eastern Cape forest region. These predictive models will be used as an input layer for a subsequent softwood sawtimber supply chain simulation case-study for the Eastern Cape. This work follows on the already developed input layers included cable and grapple skidder primary transport wander ratios, cable and grapple skidder loaded and unloaded primary transport travel speeds and a fibre recovery assessment.

Methodology

Although the main objective of this study was to analyse RTT travel speeds in the Eastern Cape, data was also collected for contractors based out of Mpumalanga province. Four contractors using five different RTT vehicle types with specific engine kW ratings were tracked during their typical operations using a combination of GPS tracking and remotely sensed data collection. The remote-sensing data was gathered using the online capabilities of the Fleet Manager Professional Version 9 (FM Pro) software suit (MiX Telematics 2013). Through a combination of overlaying the FM Pro data was overlaid with GPS tracks of a particular truck to determine where the RTT vehicle had been operating recently. A field team of road assessors then evaluated the surface condition of the road segments, both paved and unpaved.

Roads were classified using the South African forest road standards as described by Brink (2005). For unpaved roads, three classes (A, B and C; with class A designed for fastest travel speeds) exist and for paved roads, the Provincial classification was used. These roads were assigned classes based on the plantation-owner provided road maps where the roads were already assigned.

Roads were assessed for surface condition based on the visual classification methodology proposed by TMH12 (Jones and Paige-Green 2000). Road defects assessed included: potholes, rutting, corrugations, loose material, embedded stones, loose stones, dustiness and operator driving comfort riding quality. Through the application of formulas taken from TMH12 (Jones and Paige-Green 2000), a visual condition index on a scale of 1 (worst) to 100 (best) was developed for each road segment. Road segments were defined as a section of road that differed in respect of surface condition and slope from adjacent segments.

Payloads were obtained from the contractors for the various trucks and were compared to maximum permissible legal payloads as well as truck manufacturer's specifications. Furthermore, inherent truck engine power (kW) was also provided from the manufacturer's specifications. Payloads were averaged and compared to the permissible legal payload.

The data was validated in two ways. Firstly, the Eastern Cape datasets were compared with the Mpumalanga datasets. Secondly, the haul simulator Otto 2000 (FERIC, 2000) was used to simulate travel speeds on a subset of randomly selected road segments for both provinces. Simulated speeds were then compared with measured speeds.

Results

Predictive models for average truck speeds were developed for both the Eastern Cape and Mpumalanga in both the unloaded and loaded direction. Input variables for model construction included surface condition (VCI), road class, payload volume, average gradient and inherent truck engine power. These models and further results will be presented at the 2014 Precision Forestry Symposium in Stellenbosch, South Africa.

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Theme 4: Improved operational tracking/monitoring technologies

Session Chairs: Bruce Talbot & Tim McDonald

Integration of high-quality harvester data and new log scaling technology for efficient control of wood flow in German wood supply chains

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Introduction

The forest sector in Germany is traditionally diverse in terms of harvesting systems, technology applied and actors involved. Many separate entities are performing discrete segments of the wood supply chain (Figure 1). For planning and control purposes, information about quantities and qualities of the products produced need to be collected and exchanged between involved entities. Although traditional motor-manual logging and skidding systems still play an important role, especially in mountainous regions and in privately owned forests, the forest sector has seen a steady increase of fully-mechanised harvesting systems in the last 20 years, predominantly of single-grip harvesters and wheeled forwarders. Today approximately 50% of the timber is harvested by CTL systems in Germany (Dietz & Seeling, 2013)

During felling and processing of logs, single-grip harvesters collect a wide range of information, such as dimension (diameter, length), quality and product type. Federal laws generally do not allow the use of harvester information, in particular diameter, length and volume, as a base for timber sales agreements (Eichordnung, 2011). However, harvester data, if significantly accurate, can be used for other purposes by using the information along the wood supply chain, for example, as production, logistics and dispatching or control measurement, and for further business processes (KWF, 2013.

In contrast to the preceding harvester processes which automatically collect data, and the subsequent mill intake process with automatic generation of volume and quality data, the processes of forwarding, piling and transport lack tools for efficient process control (Figure 1). The required data is usually either roughly estimated or measured manually, which is accurate but time-consuming. In some German federal states, the state forest service intends to utilise harvester data, and therefore has designed standards for the calibration process of the harvester heads to ensure high quality of the collected data.

Figure 1: Process chain in German CTL systems. The unfilled cells of the processes Forwarding, Piling and Transport symbolize the lack of automatic data generation for process control and show room for optimisation in the wood supply chain.

The goal of this study was to evaluate the accuracy of harvester data collected by harvesting machinery following the new established calibration procedure and to then analyze the potential uses of derived mean log volumes per assortment and photo-optical log scaling methods to allow for automatic estimation of log pile volumes at the landing. This will overcome the disruption in the information flow (figure 1). Once sufficient accuracy of these methods is certain,, the data will be used for varying purposes including quality control of the extraction process, reimbursement of harvesting contractors and control of transportation and delivery volumes.

Material and methods

The study compares the log dimensions (diameter and length) of about 1300 Norway spruce logs of the same sawlog assortment (5 m in length + 10 cm cross-cut allowance), and, from the same stand, derived by three different measuring methods: a) by the calibrated harvester, b) manually according to the national standard and from c) certified mill measurements. In addition, a photo-optical method (PolterLuchs) is used to automatically count the number of logs in the log pile. This count and the average log volume per assortment, calculated from the harvester head data, are combined and result is the individual log pile volume which is again compared to the accumulated volumes of the logs within this pile from a), b) and c).

Results

Preliminary results show that the accuracy of the harvester measurements are comparable to that of manual log measurements in the stand. The mill measurement is the only under bark measurement without the need for standardised bark deduction factors as a function of diameter class – an important error source – and has therefore been set as basis of comparison. For length, harvester data suggest that 98 % of the logs were within a 2 cm range of the order length compared to 92 % in the mill (Figure 2). However, this has no effect on log volumes as these are calculated from mid diameter and nominal order length -provided that the required cross-cut allowance is still respected.

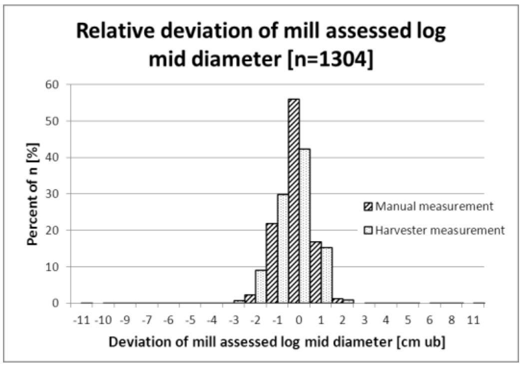

Figure 2: Deviation of mill assessed log mid diameter in relation to harvester and manual measurement

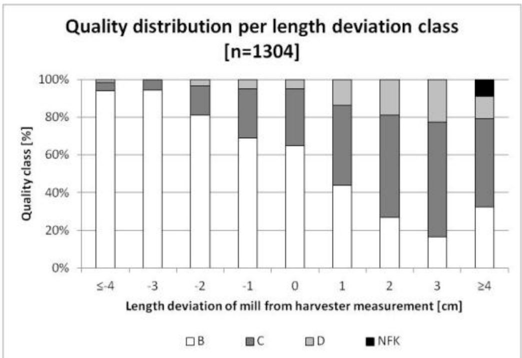

Figure 3: Relationship between log quality grade and length deviation (Quality in descending order: B>C>D>NFK)

The log quality grade in contrast seems to be related to the log length. Longer logs are on average of lower quality (Figure 3). This indicates that log quality features such as branches or deformities have an influence on harvester log length measurement.

The diameter measurement deviation has a direct effect on log volumes. The automatic bark thickness deduction, based on standardised regional bark deduction tables, seems to play an important role here. The comparison between mill and harvester log volume in Figure 4 shows a good coefficient of determination (R^2=0,9629)

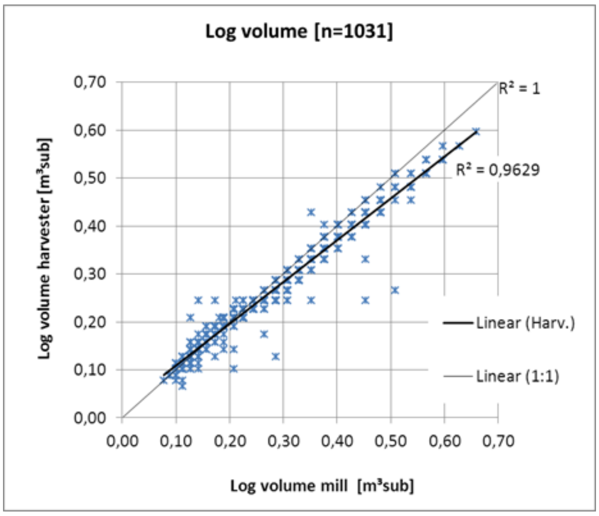

Figure 4: Comparison between mill and harvester log volumes

The comparison of accuracy and time consumption of three different scaling methods for five sawlog piles showed a substantial possibility for increased efficiency by use of automated or semi-automated methods. For sawlogs in Germany, the end-face method is accepted as accurate – in contrast to the harvester data. The aggregated results in Table 1 show that it is neither the fastest nor the most exact method. PolterLuchs uses the mean log volume of a given assortment from the harvester production data to calculate pile volumes based on the captured number of logs per pile. It showed to be the most efficient of the evaluated methods.

Table 1: Time consumption of pile assessment (volume, count, data entry; calculation) in minutes per m³sub and volume accuracy for three different methods

Scaling method	Time consumption [min/ m³sub]	Time consumption in relation to end-face method [%]	Volume in relation to mill volume [%]
Sections	0,310	82,41%	96,89%
End-face	0,376	100,00%	107,08%
PolterLuchs	0,106	28,19%	96,48%

Conclusions

Although harvester measurement of logs is still not as accurate as mill measurement, it is fairly accurate when it comes to log volume. The use of stand specific bark reduction factors or better integrated log specific bark thickness assessment methods instead of standardised tables could improve harvester measurement accuracy. Besides the quality control of processes such as forwarding and transport which are to date usually difficult or time-consuming to examine, the use of harvester data combined with additional photo-optical log count methods is an efficient way to overcome gaps in the wood supply chain while increasing pile volume assessment efficiency. Compared to traditional scaling methods, there is a substantial savings in time without accuracy trade-offs.

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FPInnovations’ FPSuiteTM Monitoring Tools: an integrated platform to monitor the entire forest supply chain.

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Abstract

Several equipment manufacturers and technology suppliers have introduced asset tracking and production monitoring systems in forest machines to monitor different parts of the forest supply chain. However, these systems are mainly designed for environments benefiting from mobile telephone (cellular) connectivity and cannot be used in remote areas where this coverage is unavailable. This is generally the case in Canadian forest operations. Moreover, there was a need to integrate production and efficiency data coming from multiple sources independently from systems associated with specific equipment manufacturers. As a result, FPInnovations developed and introduced the FPSuiteTM operations monitoring platform in 2011 (Figure 1). This technology was designed to collect, automatically transmit and manage production and efficiency data from forest machines regardless of their operating environment and independent of machine make, model or function.

The FPDatTM onboard data logger features a rugged PC computer and touchscreen providing a user-friendly interface, displaying a navigation system and key performance indicators regarding production and efficiency updated in real time. The PC can also be connected to various machine functions as well as the electronic engine data port to collect data on fuel consumption for example.

The FPComTM data communication system is embedded with the FPDat units and automatically captures and transmits the various data streams either via a cellular network modem (if available), but more often via the Iridium satellite constellation. The system does not require any operator interventions thus ensuring a reliable and consistent data flow to the decision centre.

FPTrakTM is a key element of the monitoring platform where production and wood flow data coming from the forest operations are received, managed and made available to the system users via a password protected web site. The information managed in this component is used to generate a variety of tabular and graphical reports, as well as geographic map displays showing work progression and location of machines and wood inventories. The reports are continuously updated as data arrives through the FPDat/FPCom components and can also generate alerts for out-of-range results.

To date, over 300 FPDat and FPCom units have already been implemented in Canadian forest operations from coast to coast. After a first development phase focused on the machine side (data acquisition, navigation, communication and performance reporting), the efforts are now focused on the monitoring of the road construction/maintenance and trucking phases. Also, the platform will soon have the capability to process StanForD data files, allowing it to monitor complete fleets of machines including full-tree and cut-to-length equipment.

Figure 1 - The FPSuite platform components

The presentation will highlight the features and benefits of the platform, as well as potential links with value chain optimisation tools developed by FPInnovations in its Value Maximization and Decision Support research program, a research area focusing on the optimisation of the forest supply chain.

The integration of GPS in harvesters as a tool for site specific management in plantation forests

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Introduction

Innovation is not only to find and develop new technologies, but also to take full advantage of what is already available. One example is the integration of harvester head software and Global Positioning Systems (GPS). Both of these technologies have been used to manage harvesting operations (Folegatti, 2010; Kopka & Relnhardt, 2006; Möller et al., 2011), study environmental impacts of these operations (Bowker et al., 2010; McDonald et al., 2002; Seixas et al., 2003), assess harvesting machine performance (Cordero et al., 2006; Gerasimov et al., 2012; McDonald & Fulton, 2005; Palander et al., 2013; Strandgard et al., 2012), and estimating total biomass from forests (Kiljunen, 2002). However, there are still many opportunities to take advantage of integrating these technologies to improve the site specific management of our plantation forests.

A possible application of such technologies is the generation of productivity forests maps that can help us to recreate with a relatively high level of detail the characteristics of the forest across the terrain. It would create a complete census of all the trees and their attributes at time of harvesting, compared with stand sampling prior harvest, or mill data once the logs are delivered. Having a detailed productivity map could serve as a means to understand variations across sites, and explore the possibility of site specific management – a concept widely applied in agriculture that begins with understanding the variations across the area (Bongiovanni & Lowenberg-DeBoer, 2006). From detailed productivity maps, we can stratify soil sampling, assess site index, and understand what factors are indeed affecting productivity (Gonçalves, 2012) and manage them more efficiently (Ortiz et al., 2006; Vergara, 2004). Harvesters have the capacity of registering and recording data form each harvested tree and each log (Arlinger & Möller, 2007), information that otherwise would be prohibitively expensive to collect by traditional ground methods or LIDAR.

The aim in this project is to evaluate the usefulness of integrating GPS in harvesters in forest plantations as a technology platform to collect individual tree information and geospatial location to allow site specific management, research, and automated machine costing and benchmarking. This objective will be met by answering the following specific questions:

1. What is the accuracy and precision of GPS in a clear-cut environment?
2. What is the level of detail of forestry productivity maps we can obtain from data gathered from GPS-enabled harvesters?
3. Based on the level of detail obtained in 2, is it possible to detect spatial variations in productivity and correlate it to the position on the terrain and stocking?
4. Based on the level of detail obtained in 2, is it possible to establish machine productivity patterns and correlate them to slope, stocking, and tree's individual volume?
5. What are concrete advantages of collecting and processing this data for research and management in the forest industry? What is the cost of this equipment and the work to collect and process this information?

Materials and Methods

We will develop forest yield maps from data automatically collected by a GPS-enabled harvester. The GPS -provided by Waratah New Zealand Ltd- is installed in a Waratah HTH622 harvester head attached to a tracked harvester (Caterpillar, model CAT 541) working in a clear cut cut-to-length harvesting system. The harvester is equipped with standard machine computer under StanForD. The field work has been carried out since October 2013 in cooperation with the forestry company Rayonier Matariki Forests in its current harvesting operations. The sites are located in a thinned Radiata pine plantation in Eyrewell, Canterbury region, New Zealand.

To assess this technology, the information generated by GPS and the machine software is overlaid with other digital information (topographic maps, soil maps, forest maps) in using GIS software. Then the results are checked against inventory data and the productivity across the terrain will be assessed as a case study of the application of forest yield maps.

Furthermore, based on harvester's track maps from GPS data and individual production files (.pri) recorded by the machine's software, we will assess machine productivity patterns related to both terrain classification and stand characteristics (assortment and trees' individual volume). We will use the terrain classification proposed by M. Acuna (comm pers, August 12, 2013) for Australia considering relief, roughness and soil type. The data is managed using the software TimberOfficeTM 5 from John Deere Forestry Oy provided by Waratah New Zealand Limited. Further analysis will be done with a GIS package, spread sheet and statistical package. A conceptual diagram of the project is presented in Figure 1.

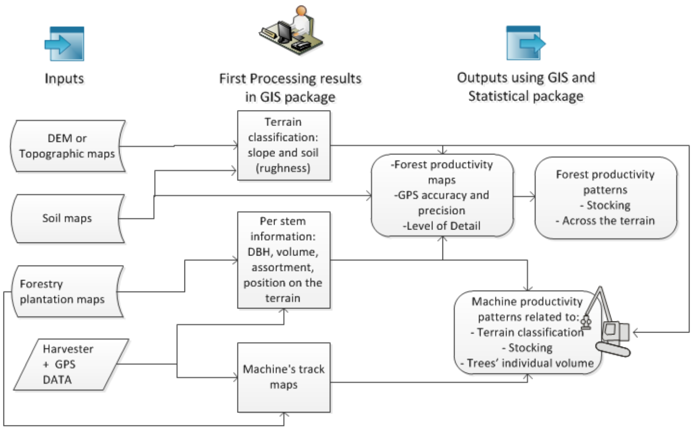

Figure 1: Conceptual diagram of the project

Partial results

The conference presentation will include available results of the on-going project and an overview of next steps. These results will correspond to objectives one to three: a productivity map, accuracy of GPS in this environment and level of resolution of the productivity map.

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Operational monitoring of forest logging activities: an application of Precision Forestry approach for monitoring cable cranes logging operations

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Introduction

An important aspect to Precision Forestry (PFOR) is implementing operational monitoring of forest chain logistics. PFOR can be considered as the application of information technology (IT) to the forest sector. Its introduction has the aim to improve the efficiency and the performances of the forest sector, including all the related monitoring activities to satisfy management tasks. So PFOR has become, similarly to Precision Agriculture, a general reference scheme into which fundamental decision support systems can be framed and used (Lubello et al. 2006). The possibility of automating operational monitoring tasks plays an important role in this framework and this paper describes the inference engine procedure (IEP) that was developed to this aim. An IEP is a tool able to transform – through a set of logical, statistic and physical algorithms – raw data into intelligible management information, such as messages that can be used to take decisions or to perform controlling tasks (Mazzetto et al. 2012). An evaluation comparison of the application results for cable yarding systems will be achieved in two different countries (Italy and New Zealand) and presented in this paper.

Productive and delay time elements are important parameter to be assessed in order to carry out the operational monitoring of the working chain for those tasks where human, machine or combined activities are involved (Mundel and Danner 1994). The basic principle here consists in the application of a GNSS device on the machinery in order to detect management information (McDonald 1999, Veal et al. 2001, Taylor et al. 2001, McDonald et al. 2001, McDonald and Fulton 2005, Cordero et al. 2006, Taylor et al. 2006, Devlin and McDonnell 2009, Horcher and Visser 2011).

Materials and methods

A simple data-logging device, equipped with a single frequency GNSS receiver, was installed on the carriage of the cable yarding systems used in the various test sites: two in Italian alpine region (Province of Bolzano, north-east of Italy), and two proposed sites in Nelson Marlborough, New Zealand. The test sites are charaterised by softwood forest, mainly spruce for the Italian scenario and Radiata pine in New Zealand. All the tests were preliminary carried out setting a fixing period of 2 s.

The IEP was designed to enable the detection and analysis of important operational parameters such as geospatial data-set distribution, advancement direction and travel speed. The assessment of the overall time spent for logging operations was computed, together with the time required for each elementary working phase (i.e.: outhaul empty, hook and lateral in, in-haul and unhook). IEP’s basic procedures provided management information performing a logical sequence in which the following parameters are identified: a) position of the starting point of the logging line, b) travelling direction, c) transport speeds, d) phase of work (Figure 1). The GNSS device provides the required clock reference data. A manual time study with the use of a stopwatch was then performed to validate the IEP’s results.

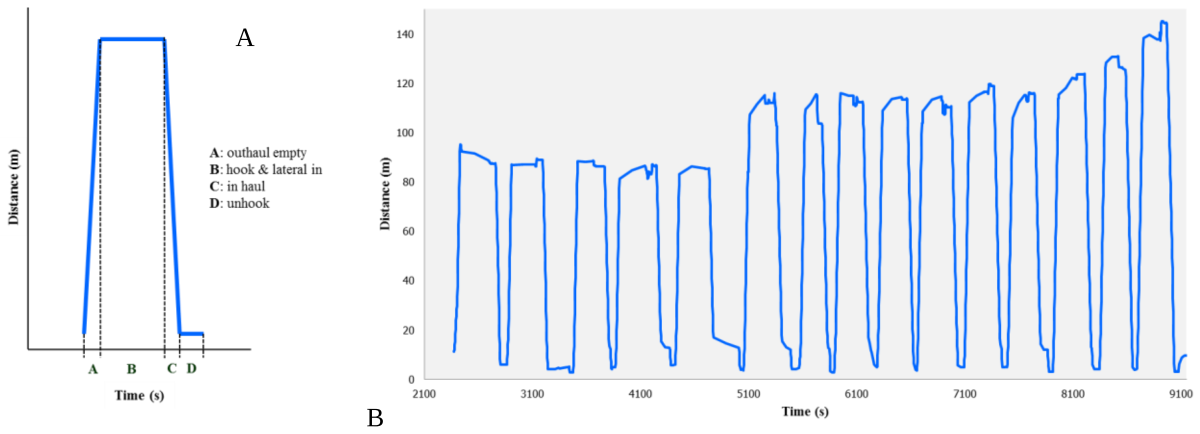

Figure 1: Theoretical working cycle time (A) and the actual working cycle time (B) of an operational monitoring of a tower yarder, case study carried out in Italy. The operative phases of hook and lateral in have been considered together.

Results

In the test carried out in Italy to date, the system was able to detect satisfactorily each single working cycles, thus providing good information on the whole operative phase. As far as the entire working time is concerned, the comparison between the results obtained through automatic and manual study presented a good correlation values ($0.80 \leq R^2 \leq 0.95$).

With regards to each elementary phase, operational times were satisfactorily recognized for hook and unhook phases (R^2 around 0.90), whilst some problems were detected for out-haul and in-haul operative phases ($R^2 \leq 0.60$).The absolute differences between the elemental times automatically recorded with those manually logged by the clock were below 15%.

Conclusion

The research to date has shown that the use of GNSS device presents both an interesting and feasible option capable of performing automatic operational monitoring in forest logging operations. All cycles and all work elements are positively recognized. As such, it can be considered a viable solution for supporting management tasks associated with mechanisation, also in view of the possibility to be integrated with other types of sensors (e.g. able to monitor the weight of biomass transported).

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General productivity model for single grip harvesters in Australian *Eucalyptus globulus* plantations

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Introduction

The ALPACA decision support tool has been developed to assist the Australian forest industry with harvest planning, estimating harvest costs/rates and simulating harvest operations. However, it is largely based on overseas studies due to the lack of suitable Australian studies. Development of productivity models for eucalypt plantation harvesters was identified as a priority because the recent establishment of the Australian eucalypt plantation estate (largely post-1995 (Gavran & Parsons 2011)) means that few harvester productivity models have been developed for an estate that makes up almost 50% of the total Australian plantation resource.

Individual productivity models can be strongly influenced by factors specific to the study, particularly operator performance differences (Spinelli et al. 2010). General harvester productivity models aim to overcome this limitation by using a large pool of data to even out the influence of factors other than tree size (Spinelli et al. 2010) or by developing a series of models that explicitly include one or more important factors such as the operator, tree and site characteristics. Ideally, a productivity model should be produced with the least effort and the highest precision possible (Stampfer & Steinmüller 2001). Detailed time and motion studies can produce high-precision models, but can take days to establish, perform and analyse. In contrast, time and piece counts can collect relatively low-precision data from a large range of stand and site conditions, operators and machines in a relatively short period of time. Automated data collection is another option. However, many harvesters used in Australian eucalypt plantations do not collect data to the StanForD standard.

The objective was to develop a robust, general productivity model for single-grip harvesters performing cut to length (CTL) harvesting at the stump in short-rotation *Eucalyptus globulus* plantations in Australia. This model would then be used to improve the predictive abilities of the ALPACA decision support tool.

Materials and methods

The model was based on over 45 studies from CTL clearfell harvesting operations in short-rotation *E. globulus* plantations from south-west Western Australia and central Victoria. Sites were gently sloping with little undergrowth and few obstructions (typical of the Australian *E. globulus* plantation estate) and covered a range of mean merchantable tree volumes.

The studies were conducted using time and piece counts. For each study, several inventory plots of 30 - 40 trees in total were established in an area to be felled by the harvester. Diameter at breast height over bark (DBHOB) taken at 1.3m of every tree within the plot, and the height of approximately 10 trees per plot was measured. Mean merchantable tree volume was calculated using a single tree volume model supplied by the plantation manager, where available, or using a generic *E. globulus* tree volume model. Delay-free harvester productivity (m^3/PMH_0) was estimated by counting the number of trees felled and processed over a period of at least one hour to obtain trees cut per hour and then multiplying this result by the estimated mean merchantable tree volume.

Harvester productivity estimates were plotted against mean merchantable tree volume and a model fitted to obtain the best goodness of fit and homogeneity of variance of residuals.

Results

The model form that best fitted the harvester productivity data ($R^2 = 0.77$) and achieved homogeneity of variance of the residuals was a natural logarithm transformation of tree volume (Figure 1). The model was compared with harvester productivity estimates from overseas eucalypt plantations and 3 of the 4 productivity estimates fitted the model well (Figure 1).

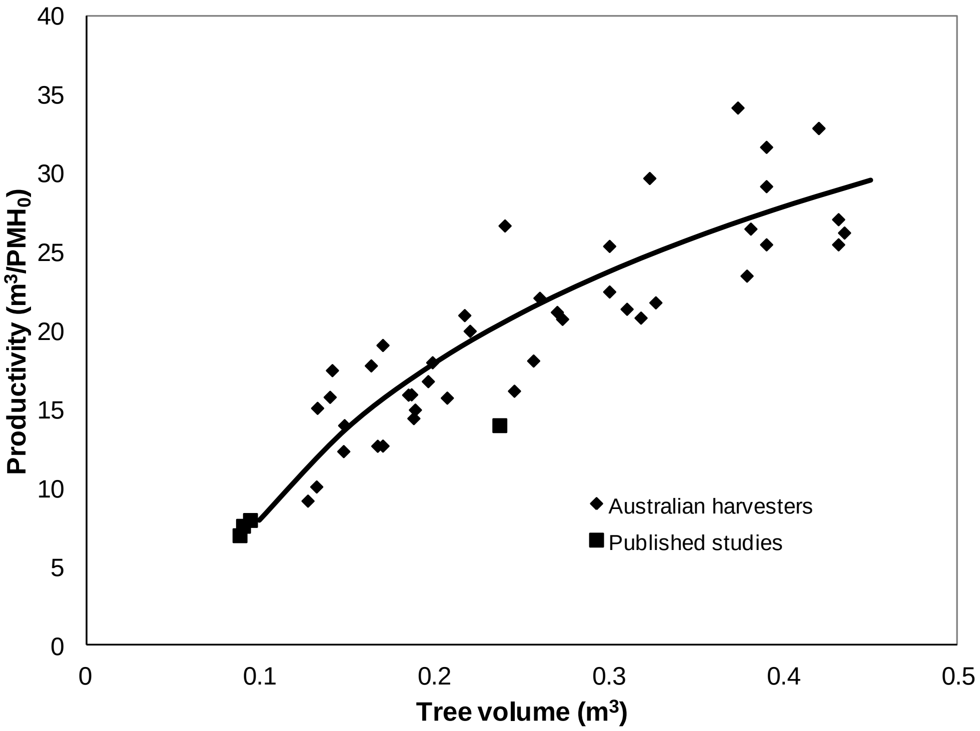

Figure 1: Productivity of sampled harvesters and published harvester productivity data against mean tree volume. Best fit model (derived from the sampled harvester data only) is shown.

Conclusions

Data collected using time and piece counts covering a range of tree sizes, machine types and operators were used to rapidly develop a robust general single-grip harvester productivity model for Australian *E. globulus* plantations for inclusion in the ALPACA decision support system.

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On board computers in forest operations in northern Ontario, Canada

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Introduction

The Canadian forest industry faces many challenges. One of these challenges is obtaining basic operational information from heavy forest equipment. Acquiring this information can lead to various opportunities including developing best practices, identifying operational issues and monitoring costs/operations. The development of Key Performance Indicators (KPI), a data collection/transmission system and customized reports are some of the challenges associated with collecting this information. One tool that may be used to collect this information is On board Computers (OBC).

The main objective of this study was to implement and evaluate the use of a data collection system (multiDAT) to monitor the performance of forest operations, and for their improvement. The hypothesis was that performance would improve for machines equipped with multiDAT OBCs through the utilisation of the detailed KPI data obtained.

Methods

An OBC system was planned and integrated into forest operations in northern Ontario, Canada. In this study 25 multiDAT OBCs were installed in 5 feller-bunchers, 4 skidders, 2 roadside single-grip processors, 5 excavators, 6 gravel trucks and 3 belly-dump gravel trucks. Each multiDat was connected to a Radio Frequency (RF) modem. Each modem would transfer data collected automatically from the multiDat to a custom made computer in the supervisor's pick-up truck when in range. This computer would then automatically transfer the data via cellular modem to a File Transfer Protocol (ftp) site. The data would then be transferred from the ftp site to the multiDAT database for data reporting and analysis. Installation of the multiDATs occurred between May 15 and August 11, 2011. Monitoring of the multiDATs occurred between May 17, 2011 and January 24, 2012.

After initial monitoring of the equipment basic KPIs were developed in order to monitor forest operations. These KPIs were: Approximate Available Machine Hours (~AMH) based on when the master switch was on; Approximate Productive Machine Hours (~PMH) based on the motion sensor in the OBC; Efficiency ((~PMH/~AMH)*100%); and productivity count based on activation of grab arms on feller-bunchers (tree count) and engagement of the bottom saw on processors. The count feature gives an indication of production activity and does not give an accurate measure of tree or log count. During the initial monitoring of equipment, activation of the tracks on feller-bunchers and engaging reverse gear on skidders had no relation to productivity, and these measures were removed.

In order to determine the effect of KPI information and report usage, two separate intensity reporting periods were created. The High Intensity Reporting Period presented weekly KPI reports to staff over a series of months. The Low Intensity Reporting Period did not present weekly reports to staff over a series of months. There were 2,293 shifts in the High Intensity Reporting Parametric and 1,476 shifts in the Low Intensity Reporting Period. Parametric and nonparametric statistical tests were used to determine if there were significant differences in KPI values between the two reporting intensity periods.

In the initial data analysis it was found that the working of the belly-dump gravel trucks was very erratic and they were used for many types of work since they were of a tractor-trailer design and the tractor could be used for other work functions. For this reason data for the belly-dump gravel trucks were deleted from the database and they were removed from the study.

An equipment Rate Determination Model (RDM) was used to estimate possible gains from the use of the multiDATs in the feller-bunchers. In this case the ~PMH value was used as the “utilisation” input in the model; the ~PMH values were found to significantly different between data reporting intensity periods. Equipment rates ($\$/m^3$) where calculated using the RDM for the two reporting intensity periods and compared. The difference between the two was used in the ROI calculation to determine the financial impact of installing the multiDATs over a 3 year period. The “cost of investment” includes the purchase cost of the equipment and installation, purchase cost of the software, and annual operation costs (maintenance, management and data transfer costs).

Results

~AMH and ~PMH KPIs had significantly higher hour values for the High Intensity Reporting period (Table 1). However, significance difference between ~AMH, ~PMH and Efficiency KPIs varied between machine type (Tables 2, 3 and 4).

Table 1: Mean rank and values of nonparametric tests for ~AMH, ~PMH and Efficiency KPIs during High and Low intensity report periods.

Database	Mean K-W Rank		Mean values		Significance level
	High intensity	Low intensity	High intensity	Low intensity	
~AMH	1797.75	1638.36	8.07 h	7.66 h	***
~PMH	1929.25	1813.77	6.72 h	6.42 h	**
Efficiency	1710.19	1764.69	78.29%	79%	ns

Table 2: Summarized ANOVA results and means between individual machine types for the ~AMH KPI.

Machine type	High intensity reporting period ~availability	Low intensity reporting period ~availability	Significance level (p-value)
Feller-bunchers	90.1%	87.9%	0.000***
Skidders	94.5%	92.8%	0.033*
Roadside processors	91.0%	88.2%	0.084^{ns}
Excavators	91.8%	91.0%	0.360^{ns}
Gravel trucks	90.1%	91.5%	0.044*

Table 3: Summarized ANOVA results and means between individual machine types for the ~PMH KPI.

Machine type	High intensity reporting period ~utilisation	Low intensity reporting period ~utililization	Significance level (p-value)
Feller-bunchers	76.6%	74.5%	0.040*
Skidders	77.7%	77.0%	0.387^{ns}
Roadside processors	76.4%	75.8%	0.740^{ns}
Excavators	77.8%	79.3%	0.598^{ns}
Gravel trucks	78.3%	78.0%	0.670^{ns}

Table 4: Summarized ANOVA results and means between individual machine types for the Efficiency KPI.

Machine type	High intensity reporting period ~availability	Low intensity reporting period ~availability	Significance level (p-value)
Feller-bunchers	85.0%	84.8%	0.746^{ns}
Skidders	82.2%	83.0%	0.769^{ns}
Roadside processors	84.0%	85.9%	0.010**
Excavators	84.7%	89.9%	0.000***
Gravel trucks	86.9%	85.2%	0.004**

Feller-bunchers were found to have the highest significant increase in ~AMH and ~PMH KPI values between Reporting Intensity periods, however, the Efficiency KPI was not significantly different. For other machine types there were mostly non-significant differences, most likely due to variability in the data between shifts and machines, and the shortness of the overall study to fully implement improvements.

After identifying significant differences in the ~PMH KPI for feller-bunchers, a ROI was used to estimate the return on OBC investment. During a three year period, an ROI of 105%, and a payback period of 1.46 years, were estimated when considering the implementation of these multiDAT OBCs in 10 feller-bunchers.

Discussion and Conclusion

The objective of the study was to determine whether there were significant differences in equipment KPIs between two different Reporting intensity periods when utilising multiDAT OBCs. ~AMH and ~PMH KPIs were found to be higher in the High Reporting intensity reporting period than the Low Reporting intensity period. This indicates that data usage from OBCs did increase these KPIs for feller-bunchers. For other machine types insignificant differences were mainly found. The Count KPIs had too much variability due to site and stand conditions. The OBC count; however, was found to be highly correlated to the tree (or log) count. This indicates that an approximate measure of productivity between the two can be established. This measure still requires additional field testing to determine the various work factors which may affect this correlation.

The High Reporting intensity period was found to have less of an effect on KPIs than anticipated. This may be because there was not enough of an effort to improve KPIs as opposed to simply reporting them. The development and implementation of strategies to improve KPIs may have led to a more pronounced difference between reporting intensity periods. Additional data sharing and more widespread reporting may have also led to an overall improvement of KPIs.

Further data on site and stand conditions would have been valuable. This would have helped categorize data in order to compare shifts with similar characteristics between reporting intensity periods. Also, additional data regarding operator tracking would have been valuable to determine whether there were any additional effects from different operators. KPIs may also be affected by seasonal effects. Additional data collection over a longer time period and multiple seasons would prove to be valuable in order to determine these effects (if any). Collection of AMH, PMH, Efficiency and productivity data prior to installation of the multiDATs would have been valuable also.

ROI was done by comparing RDM results. Utilisation inputs were modified according to the values for the ~PMH KPI in High and Low Reporting intensity periods. Since only feller-bunchers were found to have a significant improvement in the ~PMH KPI values between reporting intensity periods, only the ROI for feller-bunchers was calculated. According to the estimated cost savings ($\$/m^3$) it would be valuable for a medium to large sized contracting firm to implement this OBC system in feller-bunchers. A ROI was found to be 105% after three years with a 1.46 year payback period.

Based on this study, one could suggest that there are seven major steps to the implementation of OBC systems in forest operations. They can be considered as:

1) Identify problems and set goals
2) Study local forest operations
3) Identify KPIs
4) Design and implement OBC system
5) Collect information
6) Analyse, report and identify opportunities
7) Constantly re-evaluate

Although a significant improvement in the ~PMH was found only in feller-bunchers, the contractor has found it valuable to implement multiDAT OBCs in all equipment to facilitate automatic monitoring of shift lengths and equipment usage.

The use of truck tracking systems to optimise forest biomass planning in Ireland

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Introduction

There is currently strong demand for wood from sawmills, panel mills and from the emerging wood energy sector in Ireland. It is estimated that by 2020, there will be a supply gap of 1.252 million cubic metres (Irish Forestry and Forest Products Association 2012). This situation will create a tight supply/demand situation. Therefore, wood biomass resources must be used as efficiently and as cost effectively as possible.

Although the government has provided subsidies for biomass to become a viable alternative, there are still economic barriers to the widespread utilisation of biomass for energy. Since last year the Irish forestry sector has been incorporating new technologies (GPS fleet tracking systems) in order to improve the efficiency of the supply chain. Road transportation is the main method for distributing wood to the processing plants, and this will remain as the most important mode of transport in Ireland (Devlin et al. 2008). It is recognised that secondary transport can be responsible for 20% to 40% of the supply chain costs (Weintraub et al. 1996)

The aim of this study was to analyse the road-truck-driver interactions, and incorporate this information to a decision support systems that optimises the forest biomass supply chain in Ireland.

Material and Methods

The study consisted of two stages:

Stage 1: Travel data by road type was gathered using a fleet management system built into a range of trucks with different number of axles, configurations, payloads and volume capacities. The GPS was set to record its position every one minute along the routes; other information gathered consisted on average speed, trip time, distance, loading and unloading time, and payloads.

The information gathered was linked to ArcGIS 10.1 to analyse each trip and to create a GIS-based Irish road transportation network that provides travel distances, by road type, for a user defined route. The road network was analysed with ArcGIS extension Network Analyst in order to determine the best routes under cost, weight and speed restrictions.

Stage 2: Optimal routes generated by the Network Analyst tool populated the second stage of the study which consisted of the development of a spatial model that optimises forest biomass supply in Ireland. The linear programming model was developed on MS Excel®. It plans harvesting, storage, chipping and transporting operations over a two year period using the moisture content (MC) as determining factor. Two supply scenarios based on trials carried out in Ireland were analysed:

Supply chain I (SCI): Thinnings producing standard shortwood (3 m) assortment. Mechanically harvested producing de-limbed stems; chipping is carried out at the forest. Woodchips then are transported directly to the plant using walking floor trucks.

Supply chain II (SCII): This supply chain includes short wood produced with the same method described above, and also whole trees from thinnings, produced through manual harvesting. Chipping is carried out by a wholetree terrain chipper Silvatec. A chip forwarder unloads the chips at the landing for reloading by excavator onto walking floor trucks and transports them to the plant.

The parameters used in this study are based in different studies (Table 1). The ForestEnegy Programme in Ireland by Kent et al.(2011) provided basic density, bulk density and bulk-solid volume conversion factor. The Net Calorific Value (NCV) for Sitka spruce was derived from European standards for biofuels (CEN 2010). The average truck's volume and weight capacities were gathered in field operations in Ireland carried out by the authors.

In addition, woody biomass loss due to storage was assumed to be 0.059kg/m3 per year based on studies under Irish conditions from Olajuyigbe et al. (2011).

The storing cost approach in this model was used by Acuna et al. (2012), and it is based on the interest of the harvesting cost, this interest cost is incurred because holding the wood does not allow the producer to either pay off debt or to invest income from the wood (i.e. the opportunity cost of not selling) (Dhuyvetter et al. 2007). An annual interest rate of 6% was used for the analysis, as it has been suggested and used in previous biomass studies in Finland (Laitila 2006).

Due to the lack of a predicting drying model in-forest for Ireland, the approach taken was to utilise the drying model developed by Sikanen et al. (2012) as it provides the detailed MC changes over the planning period estimated for this study (Figure 1).

Table 1: Parameters and conversion factors for Sitka spruce.

Parameters and conversion factors	SCI	SCII
Net Calorific Value at 0% MC (GJ/t)	19.10	19.20
Basic density (kg/m^3)	377	377
Bulk density (kg/m^3)	275.86	287.38
Bulk/solid volume conversion factor	2.90	2.90
Truck maximum legal payload(t) *	-	-
Truck maximum loose volume capacity (m^3) *	-	-
Round trip distance (km)	**from stage 1 (routing tool)**	
Material loss rate (kg m-^{3} year ^{1})	0.059	0.059
Interest rate %/month	0.50	0.50

* Varies for each truck configuration.

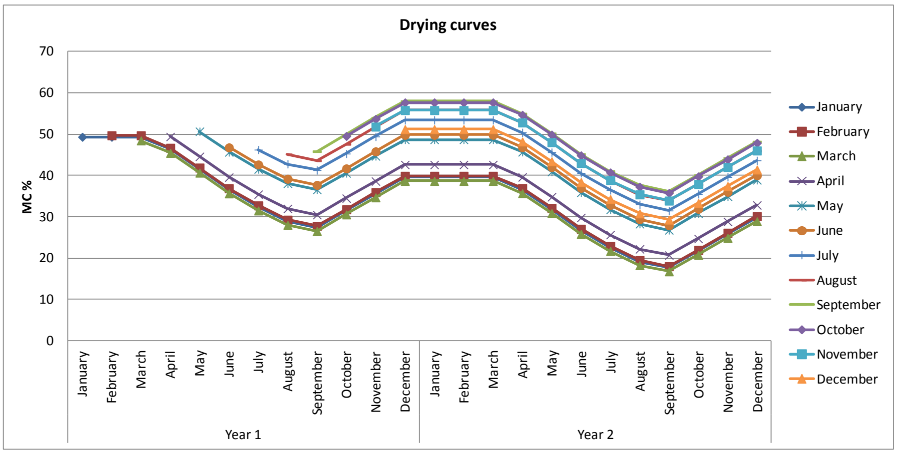

Figure 1: MC of biomass material thought out two year period at different felling times

Results

Figure 2 shows different routes from the forest to the plant and the uses of the road network in terms of distance, time and average speed. In general, results showed that it could be possible to use the routing algorithm in Network Analyst within the GIS to model real-life truck movements across the Irish road network with quite a high degree of accuracy.

Figure 3 shows the costs of the two supply chains analysed under two different scenarios, scenario one was based on the assumption that the plant accepts material at any MC percentage, so the MC is no restricted. A second scenario consisted in the plant demanding material with MC from 30% to 40%.

The analysis of SCI presented higher supply costs than SCII (9,78 % higher in SCI). This is due to the inclusion of whole trees in the supply. Despite the higher chipping costs of whole trees, the cheaper harvesting costs of whole trees makes SCII the most economic viable. The moisture content scenarios studied, showed that by constraining the MC from 30% to 40% the supply chain costs increased by an average of 5,27%.

Figure 2: Two routes tracked, and the use of the Irish road network

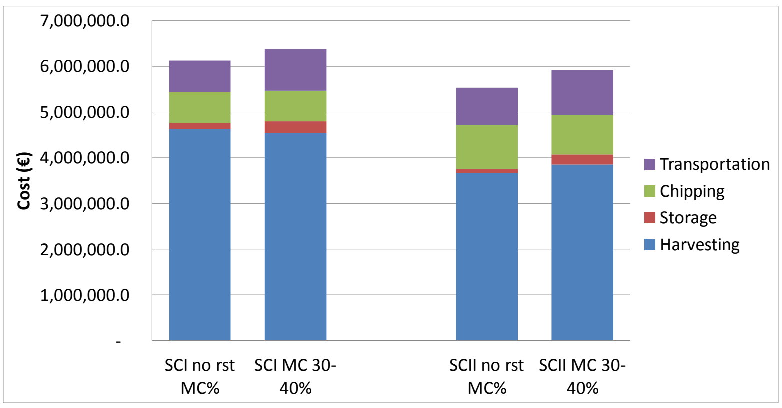

Figure 3: Supply chain costs under different MC % scenarios

Conclusions

Gaining a better understanding of the tradeoffs associated with the storage of biomass materials before they are delivered to energy and heating plants is the key to meeting the energy demand at minimum cost.

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Improving parameter estimates in modelling the influence of pitch and roll on forwarder driving speed

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Introduction

Mechanised cut-to-length (CTL) systems including a harvester and forwarder account for the vast majority of Scandinavian and a strongly expanding share of the Canadian annual cut. In boreal forests with low road densities, extraction distances can often be long (>1 km) and in difficult terrain which restricts driving speed to under 2 km h^{-1}, causing excessive and costly cycle times on the forwarder. Such conditions are prevalent in Norway.

As highly detailed digital terrain models (DTMs) derived from aerial laser scanning (ALS) are becoming commonly available to researchers and operations managers, it has become possible to develop models that reflect terrain conditions in the forest with far greater accuracy than before. Examples of this include calculating earthwork volumes required in road construction (Contreras et al., 2012) or in determining good corridor profiles in planning cable yarding operations (Chung et al., 2004).

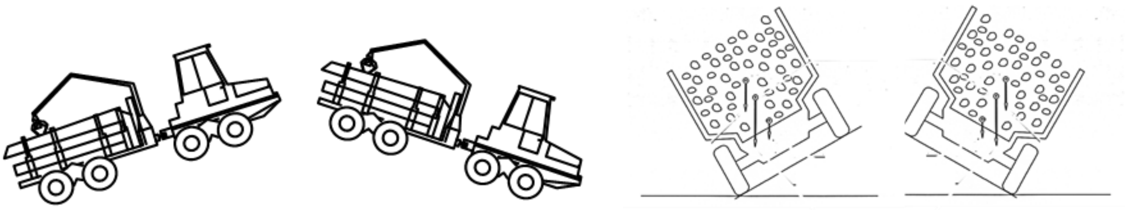

Figure 1: Illustration of the pitch (uphill, downhill) and roll, measured in the study

Harvesting performance prediction models can potentially be developed on more detailed terrain data than those to date. In fully utilising the level of detail that LiDAR brings, predictive models in the future could be based on performance analysis over the entire stand surface. This is especially useful in planning extraction trails where there is an option of circumventing difficult areas. Søvde et al. (2013) provide an example of a model that takes into consideration terrain slope on each 1m^2 pixel in the LiDAR derived DEM. Here, the distance based component of forwarding (variable cost) is penalised by varying degrees of pitch (inclination in driving direction, equation 1) and roll (inclination perpendicular to driving direction, equation 2). The penalty is introduced to reflect a corresponding reduction in speed, and thereby increase in time consumption per load due to terrain conditions.

$$P_{pitch} = 1 + (2p)^4, \quad where \quad p = \frac{|z_A - z_B|}{d_{AB}} \qquad [eqn..1]$$

$$P_{roll} = 1 + (10r)^4, \quad where \quad r = \frac{|z_{lft} - z_{rght}|}{d_{lft-rght}} \qquad [eqn. 2]$$

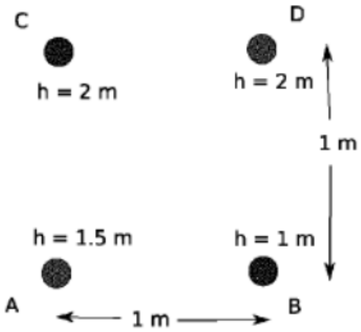

Figure 2: The equations requiring verification in the model, and (right) illustration of 4 points representing vertices in the 1m x 1m DTM.

The penalty for pitch calculates the inclination as the height difference between two vertices over the distance between them (equation 1). Roll is calculated in a similar manner, but is increased with a factor 10 in emphasizing the far greater sensitivity to roll than pitch. These are the parameters this work seeks to verify. While parameters in such a model can be determined through dynamic analysis (Hunter, 1993), there is no information available on how the machine operator perceives and compensates (reduces speed) for pitch and roll (figure 1). In this study, we used empirical measurements of actual driving speeds as a function of pitch and roll in calibrating model parameters.

Materials and methods

Accelerometers were fitted to the loadbed of a Ponsse Buffalo S16 forwarder, fitted with tracks, operating in moderately steep conditions in the inner Hardanger fjord in western Norway. The stand of circa 4 ha was on a slope of around 45%. The instrument, a Hobo® pendant G, measures acceleration in x-, y- and z- dimensions and converts this data in deriving pitch, role and yaw of the machine. Location and heading was recorded on a Garmin62s GPS. Measurements were carried out at 1 s intervals over a period of 4 working days. Travel speed and heading was calculated from the GPS registration points and this information was merged with the pitch and role angle of the machine at the same point. The data was then correlated with the underlying LiDAR terrain model.

Results and Discussion

Preliminary analysis of the data showed only relatively weak relationship between pitch, roll and driving speed. The effect of pitch on driving speed differed depending on whether it was uphill or downhill driving and whether the machine was loaded or unloaded. Roll was somewhat underrepresented in the dataset, as the contractors had partially levelled the extraction trails where they traversed the slope. The weak relationship is partially due to the lack of micro-topographic information, as this cannot be obtained from normal aerial laser scans but also plays an important role on driving speed (figure 3). Therefore, there is still a dependency on describing surface conditions subjectively with a terrain classification system. However, recent work with highly detailed photogrammetry derived terrain models appears to offer a method of obtaining surface roughness information autonomously, and will likely allow for model parameters to be further refined.

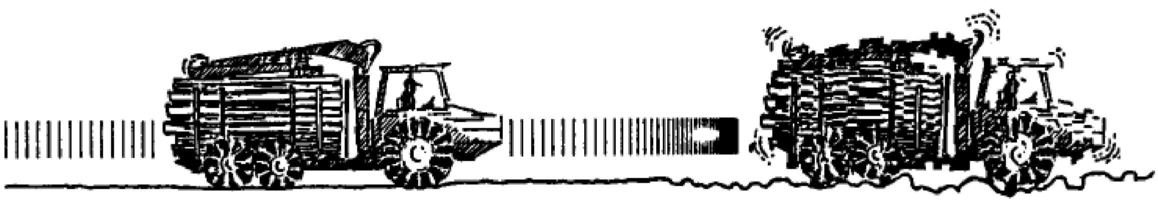

Figure 3: In addition to or in combination with pitch and roll, micro-topography also determines driving speed but is not easily obtainable from LiDAR DEMs.

Successful verification of a model such as this offers considerable potential future for making extraction cost assessment charaterised by increasingly detailed and available digital terrain models. Applied as a module in a larger spatial planning context, an improved model could be used for stand-, forest-, or even landscape level costs assessments.

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Theme 5: Decision support developments in forest operations

Session Chairs: Reino Pulkki & Dirk Längin

Assessing the quality of a surface model generated from the images obtained from inexpensive hobbyist aircraft (IHA) using structure from motion (SFM)

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Introduction

Unmanned aerial vehicles (UAV) have recently become a commonly applied tool for remote sensing. They are a cost effective alternative for efficient data acquisition and allow for images to be collected in a flexible way. The temporal resolution of conventional systems is limited by the availability of aircraft platforms and orbit characteristics of satellites (Turner et al. 2012). For the purpose of monitoring highly dynamic vegetation, satellite sensors are often limited due to unfavourable re-visit times (Berni et al. 2009). The UAV platform allows studying changes in vegetation in a temporal context, but also rapid terrain and surface alterations due to abrupt events like forest harvesting, landslides or windthrow.

In this study we perform surface reconstruction of a harvest area that was carried out using a wheeled harvester working alternately with an excavator which opens temporary access trials.

The aim is to derive two terrain models reconstructed from images coming from 2 UAV platforms and to compare them with a reference terrain layer which is derived from a LiDAR point cloud. Two image datasets are processed using Structure from Motion (SFM). Using Computer Vision (CV) a dense point cloud is created in arbitrary coordinate system that is later transformed to a geographical coordinate system.

Materials and Methods

A 7 ha stand in western Norway (UTM32-E 364 323m, N 6 741 123m) which had been harvested with excavator assistance was used as a case study. The stand extended from 220 m AMSL at the lowest to roughly 400 m AMSL at the highest point.

The stand was flown with two UAV's. A fixed wing plane, the Gatewing X100™ from Trimble® flew in an automated flight path perpendicular to the slope direction (Figure 1), while a multi-rotor helicopter was used in a fully manual flight, up and down the slope. Figure 2 shows the direction of flight and the calculated camera positions and orientation.

Figure 1: The flight path flown by the Gatewing aircraft – the yellow polygon represents the stand of interest.

The flights were carried out in different light conditions, the Gatewing photographing a predominantly shaded slope during the morning while the multi-rotor photographed a well illuminated slope in mid-afternoon. Their respective camera details are given in Table 1.

Table 1: Details of the cameras and their settings on the two UAVs

Camera details	Gatewing	Octocopter
Manufacture - model	Ricoh GR Digital IV	Sony NEX-5N
Focal length, mm	6 (~28 on SLR)	16 (~24 on SLR)
Sensor size, mm	7.6 x 5.6	23.5 x 15.6
Resolution, pixels	3648 x 2736 (4:3)	4912 x 3264 (3:2)

With the help of a CV, feature extraction, feature matching and bundler adjustment was performed (Rossi et al. 2012). This process combines Multi View Stereopsis (MVS) in retrieving camera position and orientation, and feature detection using Scale Invariant Feature Transformation algorithm (SIFT) (Lowe 2004). Both image datasets were missing external orientation parameters but those were reconstructed using SFM. Using bundler software (Snavely et al. 2006) it is possible to reconstruct a sparse point cloud from unordered images. Dense reconstruction was done applying Patch-based Multiview Stereo (PMVS2) software (Furukawa and Ponce 2010). Also CMPMVS – Multi-View Reconstruction Software was tested to execute dense reconstruction (Jancosek and Pajdla 2011).

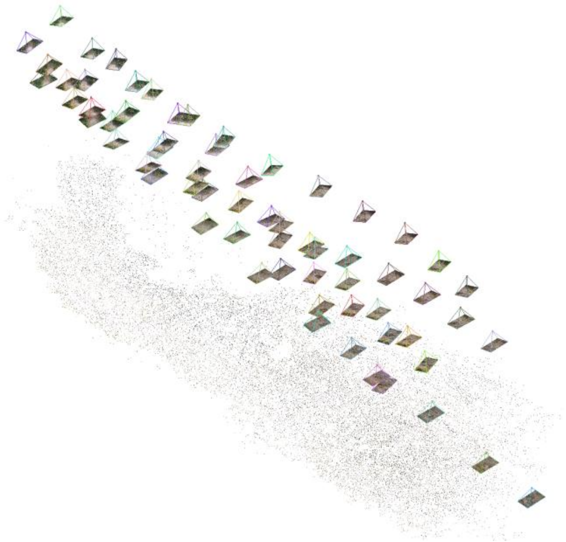

Figure 2: Camera position and orientation retrieved from MVS.

For point-cloud geo-referencing, eight ground points were demarcated in the stand using fluorescent colouring and positioned using DGPS. The fluorescent ground points were recognizable in the point cloud on the basis of their retained RGB values. The point cloud was transformed from the internal coordinate system to the UTM system by using Helmert Transformation.

Results

The multi-rotor derived cloud gave the highest point density (30 pts m^{-2}). The point cloud (Figure 3) includes both x,y,z data and RGB data derived from octocopter, allowing for a range of analyses to be carried out.

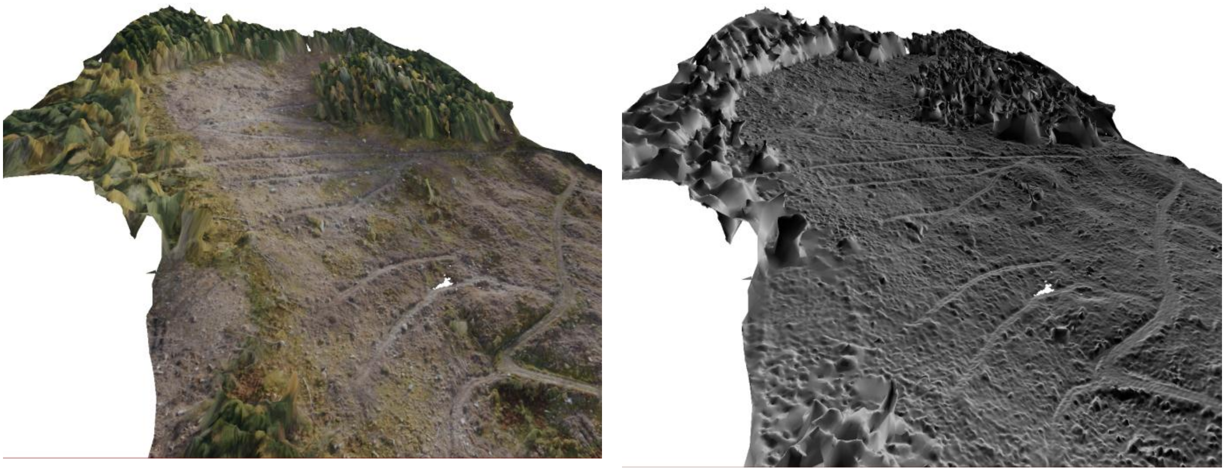

Figure 3: Meshed point cloud with RGB values on the left and on the right, model showing the surface texture by applying electronic microscope shader in Meshlab.

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The design of a Decision Support System (DSS) for sustainable and profitable hardwood silviculture on public lands in New Brunswick, Canada

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Introduction

When managing forests for timber production, one of the main objectives is to implement strategies that will yield acceptable returns on investments while meeting other obligations. On New Brunswick Crown Lands, silviculture programs are not necessarily developed with a clear vision of short, medium, and long-term economic objectives. Generally speaking, forest management activities (silviculture) are not defined within a long-term financial and ecological framework. The focus is on treatments, not regimes, and much debate exists about attaining timber objectives and the cost of harvesting.

The Northern Hardwoods Research Institute (NHRI), a partnership between forest companies, governments and the Université de Moncton in New Brunswick, Canada, is building a Decision Support System (DSS) for the management of hardwood-dominated forests. The goal is to build a tool that will allow the optimisation of value over different temporal and spatial scales. The DSS will make use of high-definition forest inventory, consider expanded silviculture regimes complemented with financial indicators, and use novel approaches for mechanised forest operations (Figure 1).

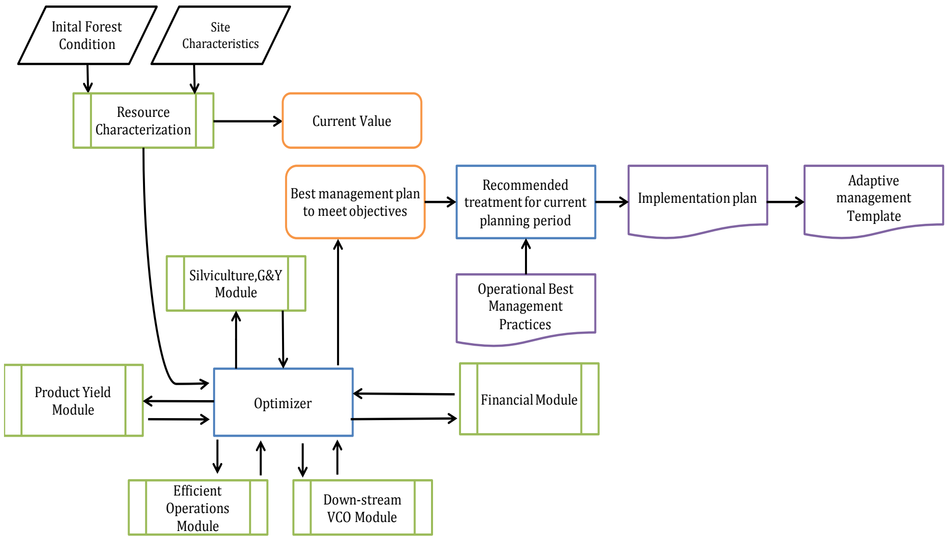

Figure 1: Framework of the Decision Support System (DSS) for sustainable and profitable hardwood silviculture on Crown Lands in New Brunswick, Canada

High Definition Forest Inventory for Better Planning and Efficient Operations

For the pilot study, aerial LiDAR imagery (ALS) was acquired and used to produce detailed tree and stand information matrices. Multi-spectral imagery will also be utilised to map tree health and to differentiate tree species. Product distribution and potential value are predicted by using newly available product recovery matrices and referenced to the new NHRI tree classification system. The stand-level inventory is generated at the forel level with a spatial resolution of 20 m. This HD forest inventory feeds the DSS allowing more precise tactical planning and more efficient equipment layout (Figure 2). These HD maps are directly imported in the harvester's on-board GPS unit to instruct the operator on the location and type of silvicultural treatment required. Preliminary results indicate that by identifying areas that can be avoided due to low volume, machine productivity expressed as cubic meter harvested per linear meter of trail can be increased by an average of 10% compared to conventional methods.

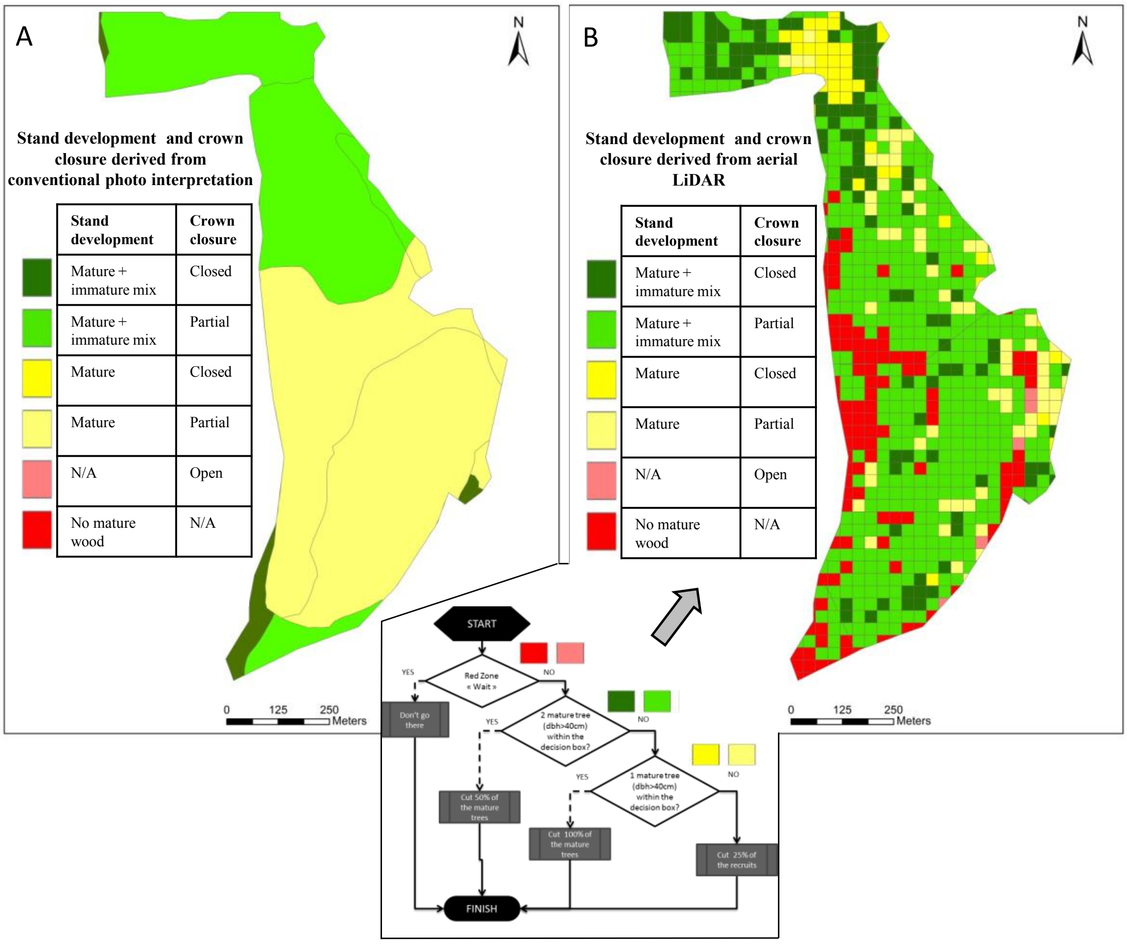

Figure 2: Stand development and crown closure derived from A. aerial photo interpretation and B. aerial LiDAR on a 20 m resolution.

Profitable and Sustainable Silviculture

Currently, hardwood-dominated stands in the Province of New Brunswick are complex and highly variable as a result of past practices, forest health issues, and adaptation. A new silviculture guide is being produced where elaborate regimes will be designed for dominant stand types. For each regime and stand type combination, actions will be mapped on a timeline and become the basis for simulation. The DSS will explore multiple alternatives with the help of a new growth and yield model and yield curves that are specific to the new silviculture regimes that will be created.

A wide range of alternatives needs to be considered, from uniform shelterwood to selection cuttings, in addition to variants of the irregular shelterwood system (Raymond et al. 2009). If the broad principles of these systems are known, specific field applications to northern hardwoods are still under development. Indeed, the mechanisation of forest operations and the emergence of new silviculture problems, such as the management of highly heterogeneous stands resulting from previous exploitative partial cutting, require the development of innovative and adapted harvest and regeneration methods.

As an example, the “1-2-3” approach developed by FPInnovations offers a rational framework to conduct partial cutting systems (Meek & Cormier 2004, Meek & Lussier 2008, Meek et al. 2012). For each alternative silviculture system, a treatment schedule is determined, associated with a trail layout that allows a rational deployment of the operation through the sequence of treatment required by each regeneration system. Rules for tree selection for cutting on each side of the trails are defined, to attain the silviculture objectives of each phase of the treatment. The optimisation of these parameters (schedule, trail layout and tree selection rules) is a complex exercise, taking in account (a) the expected long-term growth response of the stand, (b) the multiple and often conflicting management objectives and (c) the complexity of stand structure. The DSS will allow the user to simulate the effect of a partial cutting silviculture system based on variants of the multi-treatment approach on the size structure of each forest from a high-resolution maps generated by ALS (Figure 3). Considering the size structure of each forest, tree selection rules can be adapted, in a multiple-treatment mode (Meek & Lussier 2008), by recognizing pre-mature, mature and mixed micro-stands.

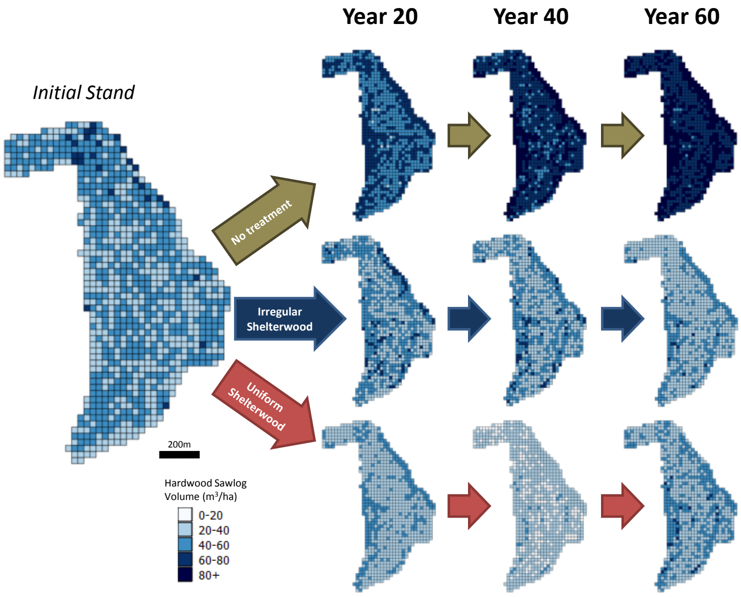

Figure 3: Example of the simulated evolution of the within-stand variations of hardwood sawlog volume following three silviculture alternatives.

The growth model coupled to the DSS allows simulation of the growth and regeneration process after each intervention for a 100-120-years horizon with 10-year time steps. Stand table data can then be compiled to assess the evolution over time of harvest and standing yields and financial values, and to calculate performance indices related to key ecological attributes (Figure 4). The DSS will allow the user to explore multiple treatment alternatives for single stands, and measure their performance in regards to financial and ecological objectives. This approach allows explicit monitoring of the internal variation in stand structure, an important factor for silviculture prescriptions, and also a key ecological attribute for most ecosystem management strategies.

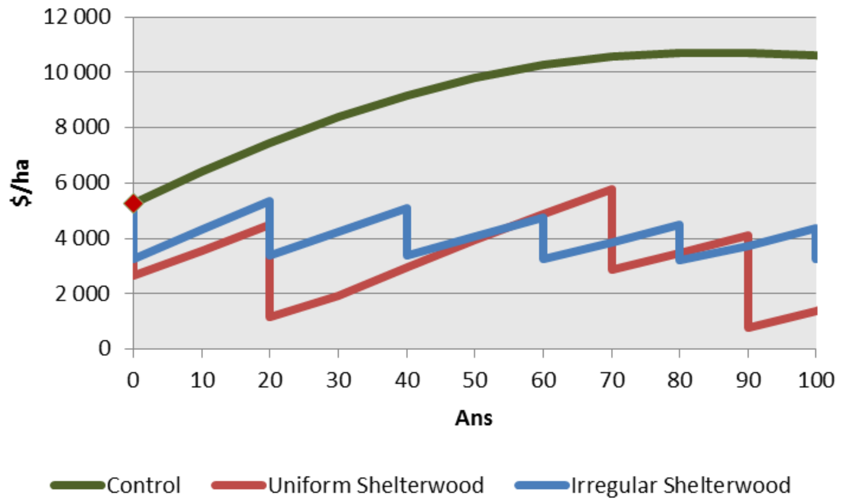

Figure 4: Standing value of timber following the three silviculture alternatives presented in Figure 3

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Swedish forestry heading towards increased precision and new value chains

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Background

During the last years' economic recession, Swedish forestry has intensified the strive to increase productivity, both by walking the traditional road via decreasing costs, but also via looking into opportunities with new value chains to maintain and increase revenues.

The goals to reduce carbon footprints, and the on-going debate with society in general and NGOs in special concerning awareness of biodiversity and avoiding physical disturbances, especially rutting after logging operations, are very much in focus.

According to the Swedish forestry, the road ahead to meet these challenges, productivity, new value chains, decreased carbon footprint and increased consideration in the logging operations, are spelled through increased precision in planning and execution of the logging and transport operations.

This focus can also be seen in the goals and organizational structures both at Skogforsk and SDC, two organizations with close relations to the Swedish forestry sector.

Potentials with increased precision – industry perspective

Skogforsk and SDC have together with its common member companies conducted two cost benefit analysis with focus on potentials to reduce cost and increase revenues in a developed it-structure within the Swedish forestry.

Given a future with a developed IT-structure at all levels in forestry, individual entrepreneurs, forest companies and at the SDC, the Swedish forestry common IT-company, the potentials was estimated.

The area with greatest potential to reduce costs was considered to be found in the transport of roundwood and forest fuels. The total potential to reduce costs and fuel consumption in the transport area was estimated to 10 – 20 %. The savings were assigned to possibilities to increase bartering between forest companies, precision in allocation and better route planning for the individual transport company.

The area with greatest possibilities to increase revenues was considered to be where the match between highly articulated demand from industry could be combined with forest operations. These operations would have a high degree of precision in their knowledge of wood properties, both in standing forests and logged volumes, combined with developed decisions support tools to steer logging operations, storage and wood flows from stump to mill.

Potentials with increased precision – Research perspective

Skogforsk has together with its partners in RoD and Swedish forestry companies looked for potentials and developed prototypes to encourage forestry to develop its logistics. Much of this work comes under the umbrella of precision forestry.

Some examples of this work where Skogforsk via Research and cooperation with industry supported development of precision forestry are;

- National Road Database
- Mobile broadband in forestry
- Standards in forestry, i.e. StanFord 2010 and the new Standard for describing standing forest and the use of forest.
- FlowOpt – decision support for strategic and tactical steering of woodflows
- RuttOpt – decision support for operational planning of truck transports
- Roadupgrading – decision support to allocate upgrading in the road network due to woodflow
- Logging resource optimisation – strategic and tactical planning of logging resources
- Planning tools for routing of forwarders at harvest areas
- Planning of harvester and forwarder operations

Implementation of these examples are much in focus in Sweden and considered as vital parts to facilitate the strive to reduce cost, decrease carbon footprint and increase future revenues via existing and future value chains.

Development of the IT-structure in Swedish forestry

The SDC has together with its member companies and Skogforsk looked closely on the information model in Swedish forestry. This work is now a base for the work to develop an enhanced exchange of information to develop precision and business transactions from stump to mill. A special component in the Swedish context is the blend of ownership and typically the large number of suppliers to a single industry. This gives the SDC a special role as information hub and developer of different IT-structures.

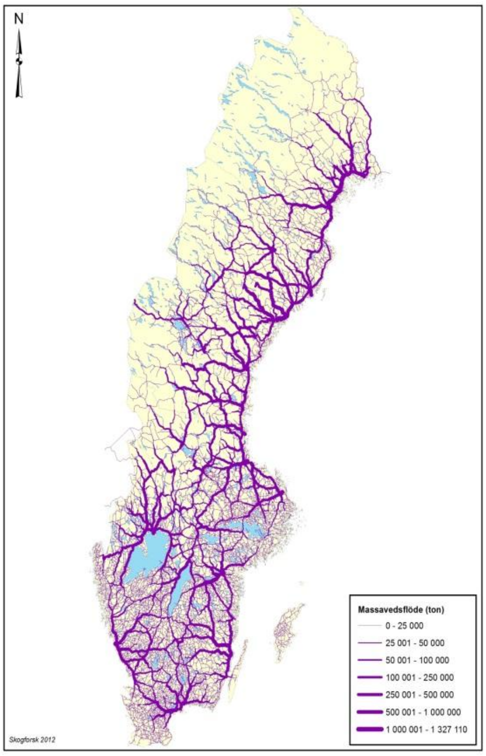

Figure 1: Pulpwood from approximately 140 000 logging sites to hundreds of industries and terminals, example of the complex wood supply web with many partners involved.

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Standardised electronic data exchange in the French wood supply chain

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Introduction

In France, more and more wood supply companies are using an IT system to manage their businesses. IT developments can be specific to a company or shared between several companies joined in a community of interests. In this case, web-based solutions are used. This computerization of companies throughout the wood supply chain generates an increased need for numeric data. However, it is clear that at the moment “true” electronic data exchanges[1] are not common. Moreover, when they are used, their implementation requires manual tasks and case-by-case IT development. This means that each company has to manage many import or export interfaces (one interface per supplier, client or contractor with which the company needs to exchange information). This hinders business to business interchange.

In this context, a French national project called eMOBOIS (for electronic wood supply) has started in order to define rules and umbrella framework to facilitate connections between the huge varieties of IT systems. A first step has consisted in building infrastructure specifications. A second step has started to implement a data exchange pilot between French companies.

This paper reports on methodology and developments made, gives feedback on the problems encountered and the means used to overcome them.

Materials and methods for the preliminary study

As the goal of the project is to connect French wood supply chain stakeholders (forest companies and contractors, transport companies, sawmills, pulp mills, energy plants), a considerable amount of time has been spent on explaining issues and gathering national representatives of each part of the logistics chain. More than two years were necessary to set up the steering committee and to find sponsors. This project is supported by the French Ministry of Agriculture, the National Association “France Bois Forêt” and regional public sponsors. The following work was carried out.

First, an inventory of service portals deployed in the French wood supply chain was made. The aim of this task was to understand the technological infrastructure developed, business models built, problems faced by project leaders including persistent problems, changes in-management support and adoption by users. In short, the goal was to capitalize on experiences, to identify good practices regarding the successful deployment of a service portal, and to find compatibilities with the eMOBOIS project.

Second, user priority needs were identified. A survey was conducted to clarify requirements throughout the supply chain. Two types of services are expected. The first type concerns electronic data exchange and the survey enables the identification of priority eDocuments[2] to implement. The second type deals with geographic services. There is a significant need to standardise, collect, centralise, and mutualize forestry geographic data in a national and homogeneous way and forest road data is a priority. Another important aspect is to allow small companies to use these data. Of course, there is a link between these two types of services; for example, a user can wish to visualize in a geographic viewer information exchanged in an eDocument (for instance the location of supply points in a Delivery Instruction).

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[1] Transfer of structured data, by agreed message standards from one computer system to another without human intervention.
[2] Electronic document: information recorded in a manner that requires a computer or other electronic device to display, interpret and process it.

Third, a standardization task was carried out. This involved participating in the papiNet Forest Wood Supply User Group. This European workgroup adapts existing papiNet eDocuments and creates new ones, if needed, in order to respond to logistics processes and use cases from forest to mill. At the moment, a set of XML eDocuments is available and ready to use. papiNet is an international initiative dedicated to the paper and forest industry. The standard is based on the SCOR (Supply-Chain Operations Reference-model) supply chain model. Further work was carried out to standardise the French list of codes to be used in eDocuments in order to harmonize data exchanged and to simplify implementation in an IT system. Products were a key point and a difficult topic to manage because a lot of characteristics can be used to define a product. Indeed, each company which uses an IT system has defined its own list of products. It is easier if a company only has to manage one mapping (from its products to a common list of products instead of *n* mapping if this company exchange with *n* others companies).

Next, the technical infrastructure was specified as a service infrastructure based on four modules: a data exchange platform, a web portal, a mapping manager, and a GIS module. It is worth noting that the purpose of the project is not to interfere in the internal processes of a company, or in its data mining tools or its data calculation. Rather, the purpose is to connect stakeholders who exchange business information. The data exchange platform provides a data exchange service ensuring confidentiality, authenticity, integrity and non-repudiation of exchange eDocuments. The web portal affords an online interface for managing interchange and for using GIS module to georeference geographic data. The mapping manager gives access to standard lists of code used within the network and allows a company to manage the mapping with its own list of codes.

One strong expectation voiced towards the infrastructure was that it must be compatible with the diversity of companies. Indeed, some companies have an ERP system and an IT department but there are many others, mostly the small ones, which do not. Moreover, some companies may prefer to manage data exchange with their business partners by themselves or with their own IT contractors. This is why the defined infrastructure can satisfy three types of users: Web EDI (Electronic Data Interchange) user, EDI user, Other User. WEB EDI user represents users without an information system and who participate in data exchange by using the web portal. EDI user represents users equipped with an ERP connected to the data exchange platform. Other user represents users who just need to download standard specification (eDocuments, rules and common code lists) and who manage all the data exchange process by themselves. The real interest of using standardization is to accommodate several companies with their own strategies.

The figure below sums up the modular infrastructure to respect the diversity of the users and their information systems.

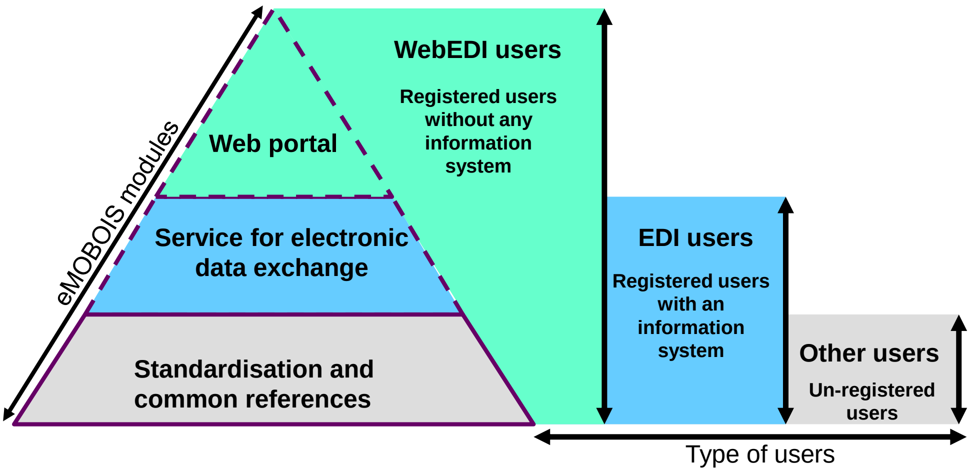

Figure 1: A modular architecture for different types of users

Following this, a business model was built. Obviously, the infrastructure must be sustainable and self-financing; therefore, two main topics were specified. The first one is the governance, on the one hand, standardization works and on the other hand the service infrastructure. The second topic is the economic model based on an income statement. Several scenarios have been developed and one should be selected at the end of the pilot.

Results and on-going pilot

After this preliminary study and before considering a deployment, it is necessary to build an operational pilot in a limited framework, in terms of number of partner companies, of eDocuments exchanged.

The implementation of the pilot is on-going and the developments should be finished in February 2014. The goal consists in validating the mapping manager, in having a showcase (concrete demonstrator) with two types of users (EDI and WEB EDI users), in demonstrating the added value of this infrastructure, in boosting successful membership for the deployment step. Ten companies (4 wood suppliers, 4 transportation companies, 2 mills) are participating in the pilot and three eDocuments are implemented: the Measuring Ticket, the Delivery Instruction and the Shipment Status.

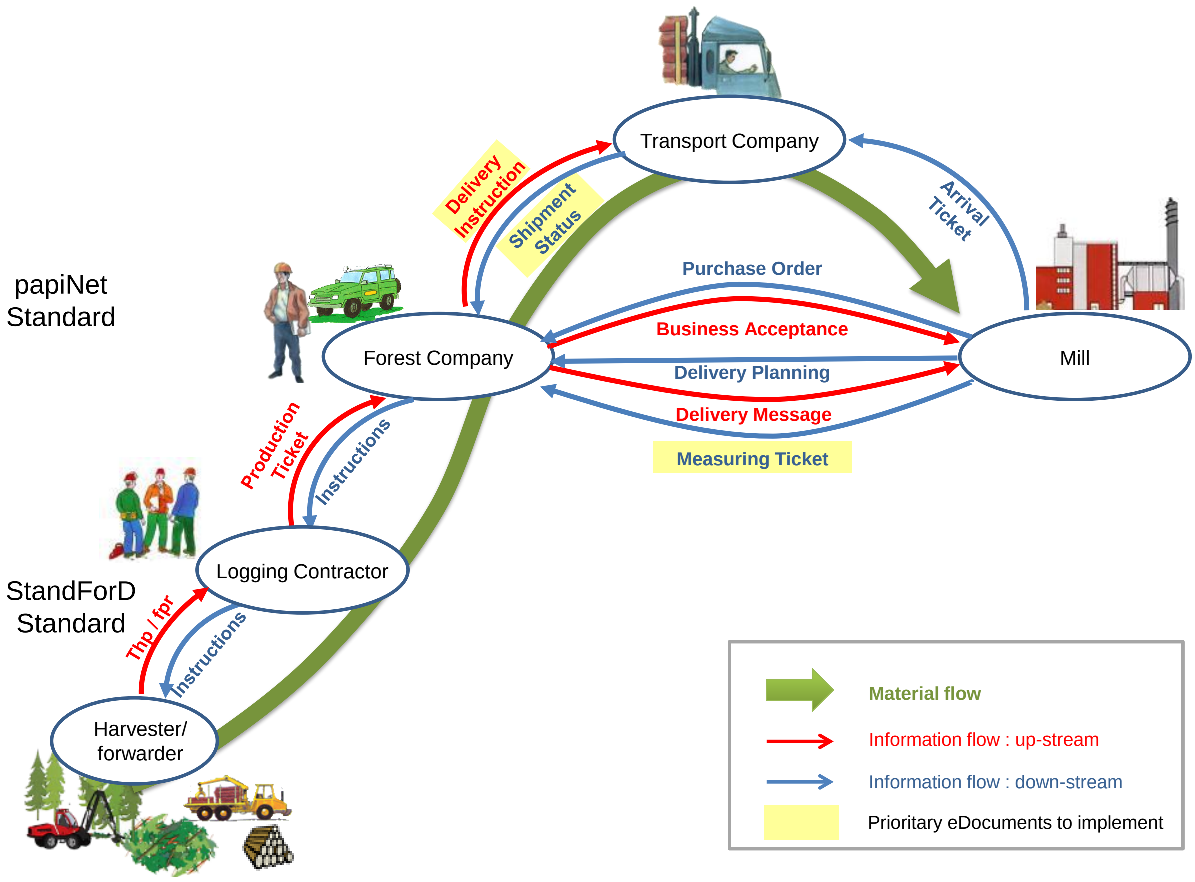

Figure 2: eDocuments prioritized for the pilot

Conclusions

This national project, based on Information and Communication Technologies, is the beginning of a structuring program for the French wood supply chain. This umbrella framework specifies a standardise service infrastructure in order to gather and connect existing IT developments such as EXPLOTIC (Arraiolos A. et al, 2011) but also future developments by the way of interoperability. However, beyond technical, organizational and financial considerations, success of this action depends first and foremost on assimilation, motivation and engagement of French stakeholders.

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Comparing four harvesting methods using multiple criteria analysis in Western Australia

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Introduction

Selecting the most efficient harvesting system is a difficult, decision making process and includes different environmental, economic and social factors. The multiple-criteria analysis (MCA) seems to be an effective methodology for helping foresters decide what system to apply depending on their operations specifications (Lexer et al. 2005).

In Australia, different individual case studies have been carried out by CRC for Forestry and AFORA to evaluate the productivity and costs of various harvesting systems. However, there has been no study to consider different economic and environmental criteria as a unit research project for helping industry managers with their decision making process under different impacting criterions. Thus this study was carried out to achieve following objectives;

- Assessing the preference of the industry users on the importance of different economic and environmental criterions.
- Evaluating the operating cost, yield, remaining slash, fuel consumption and bark content of four harvesting methods.
- Ranking the harvesting methods.

Materials and Methods

The study area was located in a *Eucalyptus globulus* plantation in south-west Western Australia, 58 km from the delivery point for all the products—the Albany Plantation Export Company (APEC chip mill). The study site covered 5.95 ha of flat terrain. Average diameter at breast height over bark (DBHOB) and tree volume were 17.8 cm and 0.207 m^3, respectively. Four different harvesting methods were used to harvest the site; cut-to-length (CTL), in-field chipping using a delimbing and debarking flail integrated with the chipper (IFC-DDC), in-field chipping using a chipper with a separate flail machine for delimbing and debarking (IFC-F/C), and whole tree to roadside (WTR).

A detailed time and motion study was used to evaluate machine productivity (Magagnotti and Spinelli 2012). Productivity was calculated from the delivered green metric tonnes (GMt) (derived from truck weights) and productive machine hours, excluding all delays (PMH_0). The ALPACA (Australian logging productivity and cost appraisal) model (Acuna 2012) was used to estimate the cost of operations. The alternatives included four harvesting methods; CTL, IFC-F/C, IFC-DCC and WTR. The decision criterions consisted of total operating cost (from stand to mill gate), yield per ha, harvesting residues, fuel consumption and bark content of the chips. An online survey was carried out with 30 participants from the forest industry sector in Australia to evaluate the importance of each criterion. The usual preference method was applied to run Promethee method to evaluate the harvesting alternatives using Decision Lab software. The Promethee-GAIA methodology was applied as one of the most efficient but also one of the easiest decision aid methods in the field (Brans et al. 1986).

Results

Table 1 presents the total harvesting cost and fuel consumption for the harvesting methods. WTR method was most expensive method with highest fuel consumption while IFC-DCC method resulted in lowest operating costs compared to the other methods.

Table 1: Total operating cost and fuel consumption of the harvesting methods

Harvesting method	Cost ($/GMt)	Fuel consumption (l/GMt)
CTL	36.62	3.33
IFC-DCC	23.74	4.76
IFC-F/C	25.77	4.05
WTR	38.12	6.53

The CTL harvest method retained higher biomass residues on the site after harvest (58.7 GMt/ha). The other methods left very small amounts of biomass at the site, as they extracted the whole trees to the roadside. Removal of the tree crown in whole tree extraction resulted in low retained biomass scattered on the sites (Table 2).

Table 2: Retained biomass after harvesting operation

Harvesting method	Retained biomass (GMt/ha)
CTL	58.7
IFC-DDC	4.2
IFC-F/C	6.5
WTR	7.7

The yield per ha was recorded based on bone dry tonnes (BDT) by using 40.75% moisture content for the chips from CTL and WTR methods, and 43.5% for the IFC-DDC and IFC-F/C systems (Table 3). Chip produced by IFC-DDC had highest bark content while chips delivered by CTL method consisted of only 0.02% bark content.

Table 3: Yield and bark content of the chips for different methods

Harvesting method	Yield (BDT/ha)	Bark content (%)
CTL	81.4	0.02
IFC-DDC	92.0	0.67
IFC-F/C	90.3	0.18
WTR	84.0	0.11

Ranking harvesting methods by Promethee method

Table 4 shows the ranking of the harvesting methods for the case of maximising harvesting residues and yield and for minimising operating cost, fuel consumption and bark content. Based on the calculated Φ (Promethee partial and complete ranking), the best alternative was IFC/DCC method due to its very low operating cost and high yield compare to other alternatives (Table 4). CTL method was ranked as third alternative as it resulted in highest harvesting residues after the operations (Table 4), but as its operating cost was higher than IFC/DCC or IFC-F/C and this criterion had highest weight according to the industry’s preference. Thus, the IFC/DCC dominated the ranking despite leaving less harvesting residues. WTR method was ranked as worst alternative, mainly due to its high operating cost and fuel consumption.

Table 4: Ordinal and cardinal ranking according to the Φ^+, Φ^-, and Φ values for the harvesting methods (maximising harvesting residues)

Ranking	**1**	**2**	**3**	**4**
Harvesting method	IFC/DCC	IFC-F/C	CTL	WTR
Φ^+	0.59	0.56	0.55	0.31
Φ^-	0.41	0.44	0.45	0.69
Φ	0.18	0.12	0.10	-0.38

The ranking of the harvesting methods for the case of minimising harvesting residues, operating cost, fuel consumption and bark content and for maximising yield per ha was similar to the Table 4 (maximising harvesting residues). For this scenario, both in-field chipping operations methods was ranked higher than CTL method due to lower harvesting residues left on the site following harvesting operations. As IFC/DCC had lower harvesting residue and operating cost than IFC-F/C, it ranked better than IFC-F/C. Using same weight for all criterions and aiming to minimise harvesting residues, the ranking from the best to worst was as follow; 1) IFC/DDC, 2) IFC-F/C, 3) CTL and 4) WTR. When the analysis was run for same weight of the criterions objecting to maximise harvest residues, the CTL method was ranked as the best system while the second ranking belonged to IFC/DDC, third for IFC-F/C and WTR method was worst alternative.

Conclusions

The study confirmed that in-field chipping operations (IFC-DCC or IFC-F/C method) resulted in lower operating costs cheaper than CTL or WTR harvesting methods. WTR method was found to be most expensive harvesting method in the case study area. Main finding of the multiple criteria analysis was that if the weight of harvesting residue criterion is assumed to equal to the others (such as operating cost and yield), then the CTL method can be ranked as the best harvesting alternative.

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Assessing the impact of wood procurement systems agility on long-term wood supply

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Introduction

Developments in forest inventory techniques have made collection of accurate data possible, thus enabling improved alignment between supply and demand. Such tools are imperative in today's setting where markets are characterised by turbulence and volatility (FPAC 2010). Access to accurate information enables practitioners to remain agile under such circumstances and respond to emerging demands (Christopher and Towill 2001). Agility in their decision-making, however, is limited by the manner in which forest management planning is conducted. Forest management plans are generally developed through a top-down hierarchical process where the lower levels are constrained by the upper levels (Bettinger 2009). Such an approach is necessary; it reduces complexity of the problem whilst ensuring long-term sustainability of forest resource. Nevertheless, it may reduce the precision with which wood supply operations can fulfil short-term market demand for specific wood products. The lack of agility in decision-making at the operational level can be detrimental to firms operating under turbulent and volatile market conditions (Christopher 2000). More specifically, this study targets agility concerning silvicultural decisions; forests are heterogeneous, thus the array of procurable products depends on the silvicultural treatment applied to it. Fixing such decisions at an upper hierarchy without accurate information about the market can negatively impact supply chain performance. A mathematical model has therefore been proposed to support decision-making on silvicultural treatment to be applied at the operational level (Gautam et al. 2013). However, its impact on the long-term wood supply has yet to be studied.

Various approaches have been proposed in the literature to link different forest management planning hierarchies to assess the feasibility of plans at different levels. Nelson et al. (1991) proposed a top-down and bottom-up approach where a long term timber harvest schedule is first developed using stratum-based LP approach. Subsequently, the volumes are allocated to blocks for the first few periods using a Monte Carlo integer programming model. The long term stratum-based model is once again solved with the area based plan forced into the solution. Davis and Martell (1993) designed a top-down modelling approach linking long-term strategic plans with a tactical plan. First, a strata based model is solved for the long-term. Subsequently, a variable time period model is run that includes cutblocks delineated using GIS for the first ten 1-year periods and longer periods for the remaining periods. Other approaches have also been proposed (Boston and Bettinger 2001; Gunn 2009). However, to the best of our knowledge, an approach to incorporate the long-term impact of silvicultural treatment flexibility at the operational level to meet prevailing demand has not been studied. Thus, the objective of this study is to develop a methodology to evaluate the impact of operational level wood procurement systems' agility on the long-term sustainability of wood supply.

Methodology

A decision support tool for formulating short-term wood procurement plans is first developed. The objective function of the mixed-integer programming model will be to maximise profit in light of the prevailing demand. Decision variables of the model will include the cutblocks to be harvested, the time periods in which to be harvested as well as the silvicultural treatment to be applied. The model is to be executed on a rolling planning horizon basis to render the wood supply system more agile. Subsequently, a long-term model will be built with an objective function of maximising the annual allowable cut. A link will then be established between the two models to assess the direct impact of agility oriented short-term planning approach on the long-term wood supply.

Implementation

The short-term model will be coded in AMPL and solved using CPLEX. The long-term model will be developed in Silvilab, software developed specifically for forestry applications by FORAC research consortium. Growth simulation and optimisation capabilities of the software will be used to observe the fluctuation in AAC. Results based on application to a case study in Québec, Canada will be presented.

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Theme 6:Matching available fibre qualities to new bio-pathways

Session Chair: Dirk Längin

Real-time measurement of biomass properties using infrared reflectance and capacitive sensors

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Introduction

Using biomass as a raw material in an industrial process can be challenging, especially as a feedstock in complex conversion processes, such as those yielding advanced drop-in biofuels. Ash content, for example, is known to be a crucial factor in Fischer-Tropsch synthesis of biofuels. Relatively small concentrations of metals, especially silicon, are particularly effective in poisoning catalysts used in FT synthesis and ash tends to be rich in those types of compounds. Moisture content is another important property of biomass feedstocks, as a contaminant (or necessary precursor, in hydrolysis processes for example) or as a waste material diluting their value and increasing pre-conversion costs.

Because they are important in determining the success or failure of a conversion process, a means of sensing these properties on large quantities of material, or on-line in conversion streams, is important in designing procurement and handling systems for large-scale bio-based industries. In this report, we demonstrate and evaluate sensing technologies for determining ash and moisture content, plus mass flow rate, appropriate for use at strategic points along the biomass procurement chain. The application of these sensing technologies could assist in scaling up the use of biomass as an industrial feedstock in two ways; firstly, by providing a means of establishing value of bulk materials. Ash content, for example, can be limited by how the biomass might be treated during the harvesting process, but without a convenient means of measuring it a buyer relies on the harvest contractor's word that practices consistent with reducing ash have been employed. Secondly, sensing systems could be used to blend feedstocks having undesirable characteristics with those of higher quality to meet minimum requirements for a particular conversion process. The blending process would, however, be dependent on a method for accurately measuring the property of interest in a timely manner.

Methods

Sensing technologies were chosen based on success in other applications, and perceived robustness. In general, near-infrared spectroscopy (NIR) sensing has been applied in sensing properties of many biological materials and can, if properly calibrated, provide accurate measurements for a variety of properties. It suffers from two distinct problems, however, making it more difficult to apply in the field. First is the necessity of maintaining a clear line of sight to the material. NIR works best as a contact-type measurement in which the sensor and material being characterised are in close proximity, but this arrangement is difficult to maintain in a production setting. The second problem is related to the field of view for a given measurement, which is quite small. A single NIR measurement is normally made on a very small area and, as such, is representative of only a tiny fraction of the material being characterised. It is not immediately clear, therefore, how best to sample a large quantity of material and calculate a meaningful value for some property.

The other sensing technique applied in this work, electrical capacitance tomography (ECT), solves the sampling problem because it measures bulk properties. It is not as well developed, however, to be an off-the-shelf technology and is also not as useful as NIR in measuring a broad range of characteristics. We therefore chose to apply it strictly in measuring moisture content.

NIR experiments focused on evaluating alternative sampling procedures. Samples were generated from 30 individual trees by first clean chipping them and capturing part of the chipper output from the bottom and top halves of the stem. Eight individual chips from each of the samples were randomly selected and NIR spectra collected. Five NIR spectra were collected on the single wood chips (approximately 10 grams), three on one side and two on the opposite. The chips were then ground to a 20-mesh size and the NIR sampling repeated. Finally, the chips were destructively sampled to measure ash, lignin, energy, extractives, and moisture contents. Samples were randomly split into calibration and validation sets. The calibration set was used to develop models relating measured properties with NIR spectra. The models were used to predict properties of the validation set and the predicted values were compared to those measured directly.

Systems for measuring capacitance of a bulk material were developed using a 15-cm diameter PVC pipe as a model for biomass conveyance. The objective was a system that could be affixed to a chipper's spout to measure moisture content of a stream of chips as they were blown into a van. The ECT system measured dielectric constant between pairs of copper plates encircling the sampling container and these values were used to reconstruct a 2-dimensional map of capacitance within the enclosure. Capacitance of the sample (loblolly pine chips) within the enclosure was related to its moisture content. Accuracy of the system was evaluated by placing known arrangements of chips at defined moisture levels within the sampling enclosure and comparing this to the resultant images generated using the ECT system.

Results

Detection of ash using NIR was possible, but likely not accurate enough to replace lab-based measurement. Measured ash contents on the 60 samples ranged from 0.2% to 0.43% by weight, with an average of 0.3%. The accuracy of the assessment was related to sample preparation and sampling strategy. Milled samples had the highest coefficients of determination (R^2) between measured and predicted values for the validation data set ($R^2 = 0.61$, Table 1). Single NIR measurements exhibited greater variability ($R^2 = 0.33$) and had a Ratio of Performance to Deviation (RPD) of 1.6, barely above the 1.5 value used as a threshold to indicate a measurement system effective for use in process control applications. Results for the calibration dataset, as would be expected, indicated higher accuracy would be possible, but the lack of predictability in the validation set would suggest it could be problematic using it as a sensing technology in practice. Results from measurements other than ash indicated variability within chip samples was on the same order as that between chips, and NIR sampling on fast-moving streams of material should be useful in characterising bulk samples given sufficient replication.

Table 1: Summary of performance of NIR in predicting moisture and ash content in clean loblolly pine chips. The sensor performance tests were replicated on individual chips (10 g weight) either intact or after milling to 20 mesh. The intact measurements included averaging of multiple spectra, or a single NIR spectrum.

Property	Sample Type	Calibration Set		Validation Set		RPD
		R^2	SE (%)	R^2	SE (%)	
Ash	Milled	0.85	0.025	0.61	0.037	1.97
	Average of 5 Spectra	0.8	0.028	0.51	0.044	1.9
	Single Spectrum	0.72	0.03	0.33	0.052	1.6
Moisture Content	Milled	0.96	0.32	0.89	0.45	3.6
	Average of 5 Spectra	0.90	0.25	0.77	0.34	3.7
	Single Spectrum	0.87	0.33	0.70	0.43	2.9

Moisture content measurements using NIR were reasonably good with standard error of predictions about 0.7 and RPD of 2.9 for chips sampled once. ECT measurements of moisture also showed high correlation with moisture content. Summed averages of sensor outputs from all capacitance electrodes correlated very well with bulk moisture (R^2 above 0.9) over a broad range. The dielectric measurement, properly calibrated, appears to be useful for monitoring moisture content in relatively harsh conditions and could be practically applied in the field.

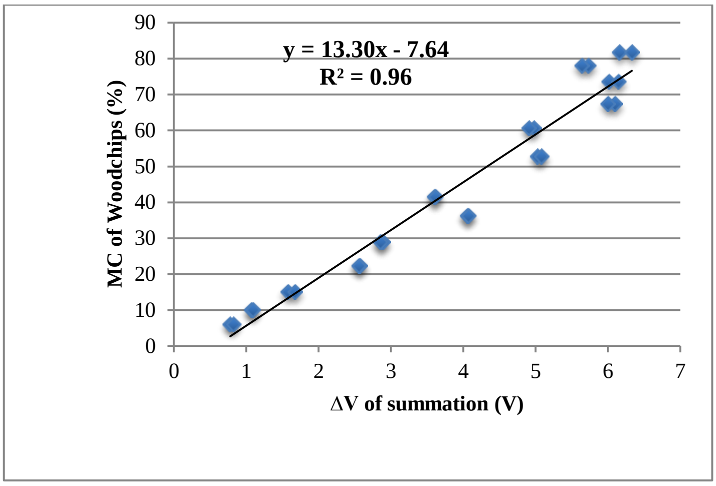

Figure 1: Relationship between ECT sensor output and moisture content of clean loblolly pine chips. Sensor output was the averaged sum of voltages from all pairs of capacitor electrodes, and actual moisture content was established using oven drying.

Imaging of the distribution of moisture was also feasible, although less work has been completed in verifying its accuracy. The 2-dimensional aspect of the approach could be applied in situations where biomass might become stratified by moisture content, which seems plausible given moisture content and mass of chips are related. It could also be used in measuring moisture and mass flow of chip streams simultaneously.

Poster Session

The effect of site on selected anatomical properties of mid-rotation *Pinus radiata*

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Introduction

Pinus radiata is a key raw material for the sawmilling, particleboard and plywood industry in South Africa, and knowledge of its properties is vital for its proper utilisation. Wood properties are affected by various factors, such as site quality (soil quality, temperature, light, and water availability), silvicultural practices, geographic location, and stand density; some of the external factors that affect wood and fibre properties and thus wood quality. Watt *et al.* (2009), for example, found that various structural variables in *P. radiata* stands (tree height, root collar diameter, stem slenderness, green crown width and relative green crown height) showed significant variation between sites. Wright (1988) studied the density and within sample variation for two pine species *(P. oocarpa and P. patula ssp. tecunumanii)* from different provenances at six sites and found significant differences. The modulus of elasticity (MOE) was significantly affected by site quality and they found a threefold increase (1.58 to 5.26 GPa) in MOE in six year old *P. radiata* across 30 sites in New Zealand. They concluded that sites with low temperature, high soil fertility, and low competition for light tend to produce low stem slenderness and low MOE wood. Oppositely, sites with high temperature, low fertility and high competition for light produced trees with high stem slenderness and high MOE.

The expected worldwide climate change will also affect South Africa. Mean annual temperature (MAT) is expected to rise between 1 and 3°C (van Jaarsveld and Chown 2001) and the mean annual precipitation (MAP) is expected to decrease for most of the Western Cape region. The simulations predict weakening winter rainfalls and slightly increased summer rainfalls (Midgley *et al.* 2005). Generally the winter rainfall season will be shorter. Similar trends have been recorded during the last three decades.

The aim of this project was to predict the effects that this change in climate can be expected to have on the properties of *P. radiata*, especially with regards to the water availability as a base for future models to predict the effect of climatic changes.

Materials and Methods

Six trees per site were felled and disks with a thickness of ± 25mm were cut at DBH from Grabouw, Kruisfontein and Blueliliesbush plantations. These plantations were selected to ensure that a wide range of water availability was covered, while all other site properties were kept as constant as possible (Fischer 2011). Furthermore, only sites with available weather data were chosen. The water supply/demand ratio (ETa/ETp) was determined after estimating the daily actual and potential evaporation with the HyMo mode, and from the daily actual and potential evapotranspiration the monthly and yearly average ETa/ETp was calculated for each site.

The ring properties were determined on sanded disks and the wood anatomical properties (per year ring) were determined from 20µm thin sections and macerated fibres. Various microscopes with magnifications up to 400x were used for the analysis.

Results and Discussion

Fibre and ring properties were recorded per site and were “de-trended” to eliminate the age factor and then plotted as a function of water availability (ETa/ETp).

The correlation between fibre/ring properties and Eta/ETp was determined from a linear regression. Figure 1 shows an example of these correlation plots for the cell wall thickness of latewood.

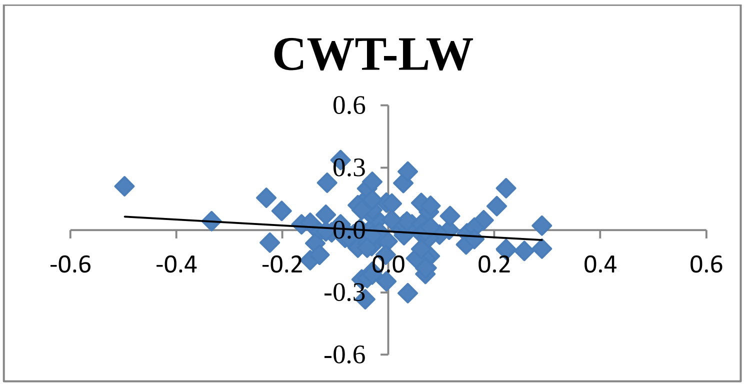

Figure 1: Correlation of cell wall thickness (latewood) and ETa/ETp

According to literature, fibre diameter, lumen diameter, early/latewood ratio and ring width can be expected to increase with increased water availability, whereas cell wall thickness and fibre length are expected to decrease with decreased water availability.

Table 1 below shows the results. No significant correlations were found between any of the ring or fibre properties and water availability at a significance level of $p<0.05$.

Table 1: Correlation of fibre properties with water availability with $p<0.05$

Wood Property	R^2	p
Ring width	0.002	0.703
Earlywood/latewood ratio	0.0	0.48
Fibre length	0.001	0.770
Fibre diameter (Earlywood)	0.000	0.948
Fibre diameter (Latewood)	0.008	0.408
Lumen diameter (Earlywood)	0.001	0.792
Lumen diameter (Latewood)	0.003	0.628
Cell wall thickness (Earlywood)	0.005	0.526
Cell wall thickness (latewood)	.020	0.185

Conclusion

These first results indicate that the effect of water availability on ring and fibre properties was insignificant, as no correlations between ETa/ETp and any of the ring or fibre properties could be found, which suggests that water availability has no effect on wood quality of *P. radiata*. However, the trees used for this experiment were fairly young and contained a large portion of juvenile wood which could explain the weak correlation between ring/fibre properties and water availability. The sampling was, however, done at the lower end of the log, which means the wood is representative for the cambial tree age, which was 14-16 years.

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Effect of tree spacing on selected biomass characteristics of *Eucalyptus grandis* with regards to energy production

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Introduction

With the increasing shortage of non-renewable fossil fuels, alternative fuels such as biomass are attracting more interest. Bioenergy, such as from combustion, gasification, pyrolysis or co-firing with coal, is a good contender against other renewable energy sources. Fast growing wood species can be a viable source of "energy wood", and could be planted in plantations especially for the purpose to produce energy. Examples for energy wood from Europe include birch, poplar, or willow and their rotation time is significantly shorter than, e.g. in pulp wood stands. Depending on the site, the wood can typically be harvested after three to seven years (ÖBV 2010). In South Africa, eucalypts would be a good choice for energy wood, and more specifically, the fast growing *E. grandis*.

With such short rotation times, the tree spacing can obviously be smaller than in conventional plantations, with the harvesting feasibility as the only limiting factor. However, the tree spacing is known to affect biomass properties (Bernardo et al. 1998) and the aim is to optimise wood yield, as well as biomass properties.

In this study we determine the effect of spacing on selected biomass characteristics of *E. grandis* that are important for the energy conversion process, namely energy-, ash- and volatile – content, and elemental composition.

Obviously a high wood yield would be desirable and with regards to energy conversion; a high density, carbon and energy- content and a low as-, volatile-, nitrogen, silicon and sulphur content are aimed for.

Materials & Methods

The wood samples originate from a Nelder trial in Swaziland and tree spacings ranged from 275 to 6809 trees/ha. Five trees at half-rotation age (7 years) were sampled per spacing and density, and other macroscopic wood properties were determined in a different study (du Plessis 2012). For this project wood from the disks obtained at DBH was milled and combined into one representative sample per tree spacing.

Moisture content on a dry base was determined by the oven-dry method. The ash- and volatile content were determined in a furnace according to European Standard testing methods. The energy content, or calorific value (CV), was determined in a bomb calorimeter. The elemental composition was determined with Atomic Emission Spectroscopy (AES) and trace elements, such as heavy metals, were detected with x-ray Fluorescence Spectroscopy (XRF).

The biomass yield per spacing was estimated with the species-specific equation based on the Schumacher and Hall model (Bredenkamp 2012).

Results

Table 1 gives an overview of the estimated wood volume, the wood density, energy-, ash- and volatile content, carbon (C), nitrogen (N), hydrogen (H), chlorine (Cl), silicon (Si) and sulphur (S) content. The optimum values are highlighted.

Table 1: Biomass properties for different tree spacings

Trees / ha	Wood volume / ha	Wood density	Energy content	Ash content	Volatile content	C	N	H	Cl	SiO_2	S	FVI
	m^3	g/cm3	MJ/kg	%	%	%	%	%	%	%	ppm	
275	309	0.544	19.8	0.35	93	45.7	5.54	0.18	0.13	0.1	393	804
801	526	0.519	19.9	0.34	96	45.7	5.94	0.17	0.14	0.1	310	1225
2336	650	0.494	19.2	0.27	96	45.3	5.86	0.21	0.12	0.05	293	1778
6809	516	0.422	19.3	0.36	98	45.2	6.01	0.19	0.14	0.2	291	1844

It can be seen that the estimated wood volume has a maximum at 2236 trees/ha. The density is, as expected, the highest for the largest tree spacing. The CV depends directly on the density and carbon content, and is subsequently the highest for the larger tree spacings. The ash-, chlorine and silicon content are at a minimum for 2236 trees/ha and the S-content decreases with decreasing tree spacing. The volatile content increases with increasing number of trees/ha, which is directly linked to the decreasing density.

A typical way to rank biofules is through the Fuel Value Index (FVI) (Deka et al. 2007), in which positive properties are divided by negative properties. Modified for our study, the FVI can be defined as:

$$FVI = \frac{Volume(m^3) \times CV(MJ/kg) \times density(g/cm^3) \times C(\%)}{AC(\%) \times VC(\%) \times (N(\%) + Cl(\%) + Si(\%) + S(\%))}$$

The best FVI value is obtained for a tree spacing of 2336 trees per hectare.

Conclusions

Although small, the effect of tree spacing is notable in most biomass properties that are important for energy conversion and an optimum value can be defined. This will probably be species specific and results might differ accordingly.

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Advances in forestry control and automation systems in Europe – FOCUS: the concept idea in a multinational EU research project

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Abstract

The improvement of forestry and forest-based products production towards overall sustainability and efficiency is a key issue for the European economy and the development of rural areas. Forest-based industries provide income for almost 16 million forest owners, employ over 3.35 million people, and contribute to 1% to 4% of the national gross domestic product of European Countries.

Recent developments in precision forestry apply Global Positioning System (GPS), Radio Frequency Identification (RFID) and similar technologies for monitoring forest production and forest operations, including logistics. Yet, isolated solutions prevail, tailored to specific application contexts and running independently from the planning and workflow processes.

The objective of the FOCUS project is to develop an innovative platform for integrated planning and control of whole tree-to-product operations to be used by forest-producers to industry players for a selection of four main forest-based value chains in Europe (lumber, pulpwood, biomass, cork).

For this purpose, FOCUS brings together leading SMEs, experts and organisations in the fields of forestry, sensors and automation, and software development for improving and assembling the technologies that are best suited for planning and monitoring forest growth, harvesting, wood transportation and industrial processing:

- State-of-the-art planning software will foresee the optimal execution of operations across the value chains from the long-term to the operational level, setting strategies, future targets, plans and schedules that assure the best use of the available production resources.
- Advanced harmonised sensors and automation systems will collect data from multiple sources for tracking and tracing the execution of operations on-site in order to evaluate current operations' performance and report centrally executed updates to dashboards.
- New, model-based control solutions will rely on simulation software for anticipating how the entire value chain will perform during the plan execution and in the event of changes in physical conditions (such as weather, productivity rates).
- Automation technologies and mobile communication devices will further provide precise and accurate instructions to workers and equipment for guiding/automating the execution of operations on-site in accordance to plans.
- The sophisticated infrastructure relies on interoperable software components and hardware solutions, enabling planning and control towards (near) real-time. Therefore, local events will be monitored centrally so that it is possible to change strategies rapidly, supporting adaptive planning and producing new instructions for readjusting workforce and production equipment.
- The tracking and tracing functionality in all these processes will open the option to set up a chain of custody at a new precision and accuracy level.

The FOCUS platform concept and its components will be tested by creating prototypes that will be assessed in 4 pilot case studies in Portugal, Finland, Belgium, Switzerland, Germany and Austria.

The results of the project will contribute to improving long term sustainability and efficiency in forest-based supply chains, and also promote marketability and quality of the forest natural resources. The technological solutions will improve the work of forest planners, wood logistics entrepreneurs and industry experts promoting collaboration among the players of the supply chain. Furthermore, the FOCUS innovative technological solutions will boost new business opportunities for SMEs, to jointly offer integrated products and services, thereby strengthening European leadership in this field.

Linking of CAN-Bus machine data to forest operations: a description of a software add-on.

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Abstract

Forestry machines – like any other vehicles nowadays – are using the controller area network (CAN) bus for sending communication messages on engine and machine status. These messages contain information which may become interesting not only for pure engine monitoring, but also on a higher level, as they are in particular useful in combination with the operation, which these machines conduct.

With the IEMS (Ziesak, 2010) a software package exists which has the ability to link site data with the active adjustment of tyre inflation pressure of machines. Additionally, it can also link with electronic scales for controlling the loading cycles such as on forwarders. With this ability to interact with machines, it therefore was obvious to extend this platform with the ability to connect to the CAN Bus. This extension is meant as a propriety independent access means to these data, well knowing that there exist solutions coming from manufacturers.

From the data level, typical elements which can be read from the CAN Bus include diesel engine parameters like revolutions (per minute), engine load per cent, fuel consumption on an intermittent and cumulative level; but also other signals which broadcast over the CAN Bus may be collected. These could be system pressure and flow data for the hydraulic system, but might also be operator generated signals for controlling the machine.

The options for using this data link are quite enormous; the following selection makes clear how wide the applications for such a data link may be, as described from several authors:

- Nuutinen, 2013, for instance, is using CAN-bus data for doing time studies.
- Lamminen et al. 2012 wants to use harvester CAN-bus data for mobility mapping.
- Suvinen and Saarilahti, 2006, used the CAN-bus together with GPS data for terramechanical studies measuring the mobility parameters of forwarders.
- Svenson and Fjeld, 2012 use CAN-bus readings for fuel efficiency considerations in the transport process with logging trucks.

Some details are given on the development of this data link in the presentation, as well as the encountered challenges and difficulties.

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