EFFORTE –
'Efficient forestry by precision planning and management for sustainable environment and cost-competitive bio-based industry'

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Work Package 4 – Validation and analyses of expected impacts		
Task 4.10 Plan for suggested fast tracks from project fulfilments to complete innovation		
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Validation and analyses of expected impacts

D4.10 - Plan for suggested fast tracks from project fulfilments to complete innovation

August 31, 2019

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1. EFFORTE project objectives

EFFORTE is a research and innovation project providing the European forestry sector with new knowledge and knowhow that will significantly improve the possibilities of forest enterprises to assemble and adopt novel technologies and procedures.

The project aims at enhancing the efficiency of silviculture and harvesting operations; increasing wood mobilization and annual forest growth; increasing forest operations' output while minimizing environmental impacts; and reducing fuel consumption in the forest harvesting process by at least 15%.

The project is based on three key elements of technology and knowhow:

1) Basic understanding of fundamentals of **soil mechanics and terrain trafficability** is a crucial starting point to avoid soil disturbances, accelerate machine mobility and assess persistence of soil compaction and rutting. The key findings and recommendations of trafficability related to EFFORTE can immediately be adapted in all European countries.

2) Due to decreasing Cost-competitiveness of manual work and maturity of technology it is now perfect time to realize the potential of **mechanization in silvicultural operations**. EFFORTE pursues for higher productivity and efficiency in silvicultural operations such as tree planting and young stand cleaning operations.

3) 'Big Data' (geospatial as well as data from forestry processes and common information e.g. weather data) provides a huge opportunity to increase the efficiency of forest operations. In addition it adds new possibilities to connect knowledge of basic conditions (e.g. trafficabillity), efficient silviculture and harvesting actions with demand and expectations from forest industries and the society. Accurate spatial information makes it possible for forestry to move from classic stand-wise management to precision forestry, i.e. micro stand level, grid cell level or tree-by-tree management. EFFORTE aims at achieving substantial influence to the **implementation and improved use of Big Data within Forestry** and through this increase Cost-efficiency and boost new business opportunities to small and medium size enterprises (SME) in the bioeconomy.

EFFORTE researchers will develop and pilot precision forestry applications that, according to the industrial project partners, show the greatest potential for getting implemented immediately after the project.

2. Introduction

In the EFFORTE project we have identified, developed and tested several digital tools that have great potential in supporting forest managers to execute environmentally sound and efficient forest operations. The most promising tools that support logging operations has already being thoroughly described in EFFORTE deliverables D3.3, D3.4, D3.5 and D4.5. The tools that have been developed and tested to improve silvicultural operations have been presented in D3.6, D3.7, D3.8 and D4.6. In this deliverable we will focus on implementation. We will especially concentrate on tools that have the greatest potential to be implemented immediately or after short period. We will analyse technical and economic feasibility of these tools as a commercial product and/or we will point out the most important actions needed to be carried out to achieve TRL9. The identified tools will be categorized in two groups: 1) Tools that has highest potential to be raised fast up to TRL9 and 2) Tools that have already been adopted by the companies (outside EFFORTE resources). The technical readiness is graded by the Technical Readiness grading system by the Horizon 2020 (figure 1).

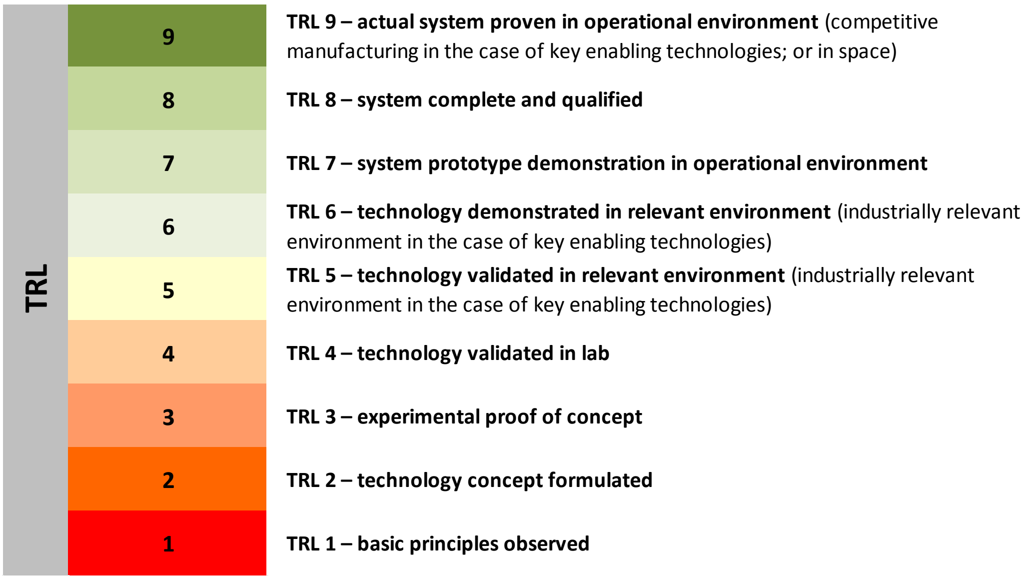

Figure 1. Definitions for the technology readiness levels (TRL 1-9) according to the Horizon 2020 – Work Programme 2014-2015 (Horizon 2014)

3. Overview of the tools developed in EFFORTE

In the EFFORTE project we have developed and tested several digital tools that have great potential in supporting forest managers to execute environmentally sound and efficient forest operations. The most important tools have been listed and shortly overviewed in table 1. From these nine tools/applications we categorize four tools to category 1 that has highest potential to be raised fast up to TRL9. These tools are more thoroughly discussed in chapter 4.1. In addition, we will also raise up two tools that have already been adopted by the companies (outside EFFORTE resources). These two tools will be introduced in chapter 4.2.

Table 1. General description of the technical and economic feasibility of the EFFORTE tools developed for supporting logging operations.

Tool	TRL	Technical Feasibility	Economic Feasibility/applicability
Depth to water map (DTW)	9	In practical use	No commercial expectations
The static trafficability map	9	In practical use	The maps has been created with governmental funding In Finland – use of data is free
The dynamic trafficability map	4	Academic development continues	No commercial expectations – the tool has high potential to be linked with other tools
Bestway/ Timbertrail	6	Development continues by Skogforsk and Creative Optimization	High potential to be widely applied in forestry
Ajourakone	5	Development continues by CGI and Metsäteho	High potential to be widely applied in forestry
Scheduling of harvesters	5	Development continues by Skogforsk	Potential to be applied in larger forest companies
CAN-bus trafficability mapping	5	Some additional research needed. Standardization process to be started soon.	Machine manufacturer's should take the leading role Market is waiting for the first generation products

Automatic (post) harvest quality control	3	Technical development needed	High R&D costs still needed – low commercial expectations
hprProp	2-6	High added value expected – Models for predicting different wood properties (TRL 2-6, depending on property). Standardized information systems (harvesters-landings) at TRL5	High potential gain in process and product value by implementation in value chains. Further R&I needed to realize value chain effects.

4 Chosen fast track tools and actions needed

4.1 Tools that has highest potential to raise fast up to TRL9

4.1.1 Optimal routing during forest operations

Short overview

During forest operations the forwarding of forest products (mainly timber and pulpwood) from the forest to roadside have a large impact on the economy of the forest operations. Each forwarder may load up to 20 m^3 and as final fellings on average often include 2000 m^3 there will be about 100 forwarding rounds to compile all wood. Shorter transportation distance will have a large impact on the economy, but there is also a great need to avoid damage on water and soils to reduce nutrient leakage into streams, lakes and rivers.

In the Efforte project two calculation models have been developed, *Bestway* (figure 2) and *Ajourakone* (figure 3). Both models produce route networks from the cutting area to the landing at roadside. The utilise detailed digital elevation models and may also consider depth to water models and detailed distribution of timber volume. Based on the Bestway model an application, *Timbertrail* (figure 4), was used during the validation. Ajourakone is a web-based interface service.

Figure 2. Demonstration of the layout of the main extraction routes created by the Bestway-model. Example site from Sweden.

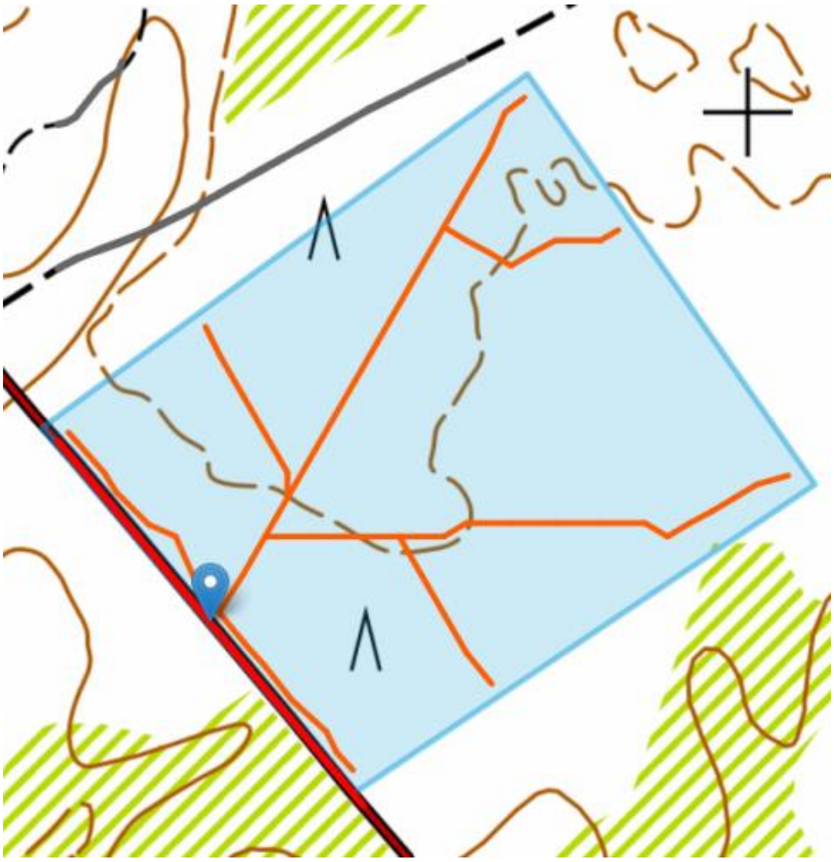

Figure 3. Demonstration of the layout of the main extraction routes created by the Ajourakone-model. Example site from Finland.

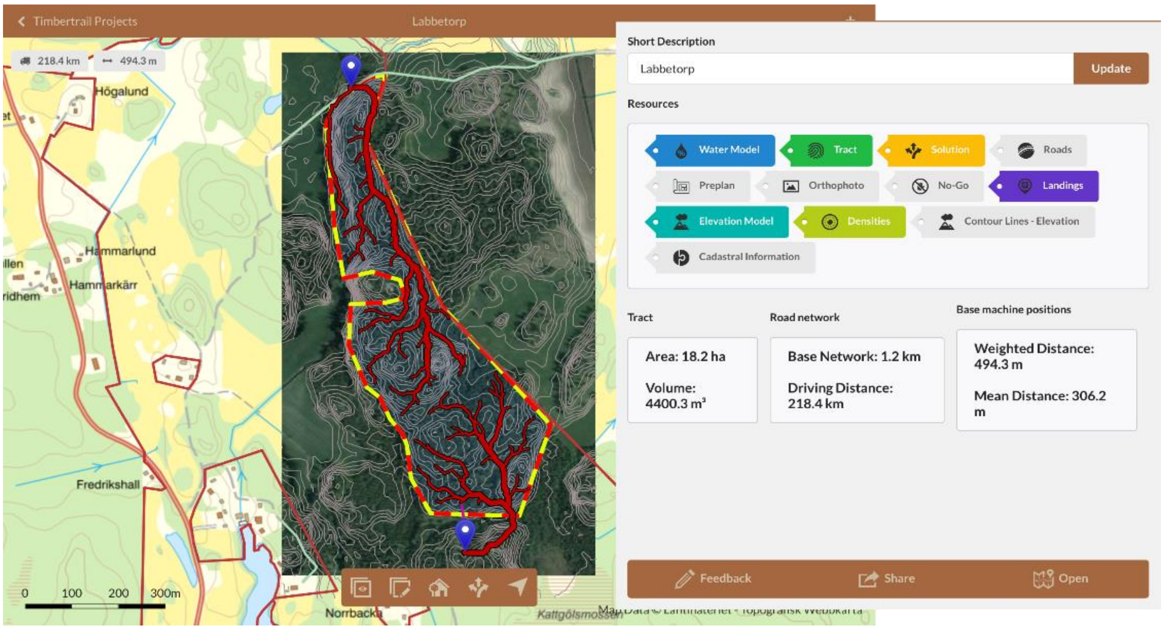

Figure 4. Timbertrail application based on the Bestway model.

Implementation

The Bestway model serves as a platform for further R&D and additional funding has already been gathered within the research programme Mistra Digital Forest[1] for another four years. The R&D focus will be to include automatic identification of landings included in the model and also tree species to separate different wood products to separate landing sites.

The Bestway model also served as an example for the forest company SCA when they in Mat 2019 implemented their own version developed by a geospatial service provider, Dianthus AB[2]. Dianthus AB developed an application based on available technical documentation of the Bestway model.

The application Timbertrail also serves as an example to further refine and offer as product or service to forest companies. Creative Optimization been demonstrating the application at forest fairs in Sweden during June 2019. During 2018 the company also got funding from Sweden´s innovation agency, Vinnova, for product development of the application. The forest company Södra validated the application in the Efforte project and plan to proceed and implement the application during 2020.

The Ajourakone model will be implemented as an interface service for wood supply information systems of forest companies UPM, Metsä Group, Stora Enso and state-owned

[1] https://www.mistra.org/en/research/mistra-digital-forest/
[2] https://www.dianthus.se/eng/

forest management enterprise Metsähallitus in Autumn 2019. Ajourakone model will be further validated during the implementation. R&D company Metsäteho has participated the development of Ajourakone from the beginning. From now on CGI company takes the leading role in implementation since CGI owns the product rights of the Ajourakone. Metsäteho will have an interface to the Ajourakone service for R&D purposes.

IPR

The Bestway model is developed and owned by Skogforsk that continuously develop and update the model. It is however considered to be a R&D platform and not commercialised. The TImbertrail application is owned and developed by Creative Optimization AB.

The Ajourakone service is designed and programmed by CGI company in cooperation with Metsäteho and its shareholders definitions and feedback. Ajourakone is mainly financed by Metsäteho and its shareholders. CGI owns the product rights.

Conclusions

Within the Efforte project, several tools been developed that optimal routing during forest operations. It has been proven operational increasing the efficiency in harvesting operations taking environmental considerations into account, including avoidance of rutting during forest operations. During the project it has been possible to get additional funding both for further R&D and product development. Some forest companies have plans or have already implemented models for optimal routing. It is a tangible result from the Efforte project with a clear path, in some sense already passed, to TRL 9.

4.1.2 HprProp

Short overview

HprProp is software module for wood and fiber property characterization operating on standardized CTL-harvester production files (hpr/StanForD). The models predict wood and fibre properties along stems and logs of Norway spruce and Scots pine. Based on scientifically developed models (TRL3-6) native wood and fibre properties and, after further development also chemical content (TRL2), can be predicted. Example of native properties predictable by *hprProp* are basic and green density, heartwood, branch thickness, sound/loose knot zones, bark thickness, earlywood/latewood content, fibre length, width, and cell-wall thickness (table 2).

The accuracy of the models vary by property (each specific model), the precision of stem size and stand age (tree classes) information. Diameter, length and log position in each stem is directly available during and after CTL-harvesting, but it can also be generated before harvesting by laser scanning, tree models and/or imputation technology now under strong development. Information on stand(tree) age is also a prerequisite, commonly available by earlier registrations/forest plans. In connection to the native wood and fibre properties, strength properties of wood and fibres, durability, pulp and energy yield have been modelled at TRL levels 3 to 4.

Chemical content (Cellulose, lignin, hemicellulose, extractives) of stem-wood, branch-wood, bark and needles can be modelled with the same concept (TRL 1-2). So far, the property models behind *hprprop* is valid for Norway spruce and Scots pine in Sweden, but it can be adapted to other regions and species.

Due to the StanForD (Standard for Communication with Forest Machines, the defacto world standard for CTL-harvester production control and reporting, jointly coordinated by Skogforsk and Metsäteho) all larger CTL-harvester brands, world-wide are able to produce hpr-files. Utilization of *hprProp* into improvements into industrial advantages (different value chains) has now been initialized by SCA and StoraEnso in Sweden.

As a strong contribution to implementation Sveaskog has also started a software implementation of *hprProp* and other CTL-harvester information (StanForD) and laser scanning driven software modules into their company-based ICT-systems. Holmen Skog is also involved in testing of some features becoming available by *hprProp*. Finally, Swedish Biometria (former SDC) (The information HUB for all wood merchandized at the Swedish wood market) are also planning to include software modules based on the *hprProp* module, planning to start with a test environment at Biometria labs in collaboration with Skogforsk.

Finnish forestry and forest companies have also shown a clear interest of the *hprProp* idéa and have already developed the prerequisites for utilizing CTL-harvester information for further model implementation aimed for property predictions. Latish forestry have also shown operational interest for detailed yield predictions including the *hprProp* module adjusted for Latish conditions and precision yield imputation technology Nevertheless a lot of additional work may be subject to more R&D&I in of additional models, validation of models and value chain utilization of the *hprProp* module and other system components aimed for improved of integration of forestry and industry processing for improved and in the long run also possible new products.

Table 2. List of properties predicted (average per log) by *hprProp* software module (and hprCM for branches and needles) by input from CTL-harvesters. *HprProp* (and hprCM) operates on ordinary CTL-harvester production files (hpr,during real harvesting or for analyses by simulated harvesting).

Predicted property within log	**Short description**
Knot types/structures (sound/loose)	Sound or loose knots. Average distance between branch whorls (over 1,3 m from ground)
Maximum knot diameter/whorl	Average maximum knot diameter/whorl within log
Density (Basic and green)	Basic density=Dry weight(0% MC)/water saturated (~green) volume. Green density=Total weight(fresh)/total volume at harvesting (both under bark
Juvenile wood zone	Wood from the 15 innermost annual rings in log expressed as diameter (mm) or % of total wood volume
Heartwood	Heartwood diameter from pith (mm) or % of total wood volume
Number of annual rings	Volume weighted average number of rings in the log given an input of number of annual rings at breast height (normally 1,1 m above ground stump height). Used as input parameter for ring(age) dependant models
Bark	Double bark thickness
Latewood percentage	Latewood percentage of total wood volume (u.b.). Remainder is earlywood.
Fibre length	Average fibre length (length weighted) of log
Fibre width	Average fibre width (FiberMaster) of log
Fibre wall thickness	Average fibre wall thickness (SilviScan) of log
Carbon content	Percentage carbon and kg/log percentage*dry substance
Branches tops and needles of processed stem	*By hprCM module (Skogforsk)*

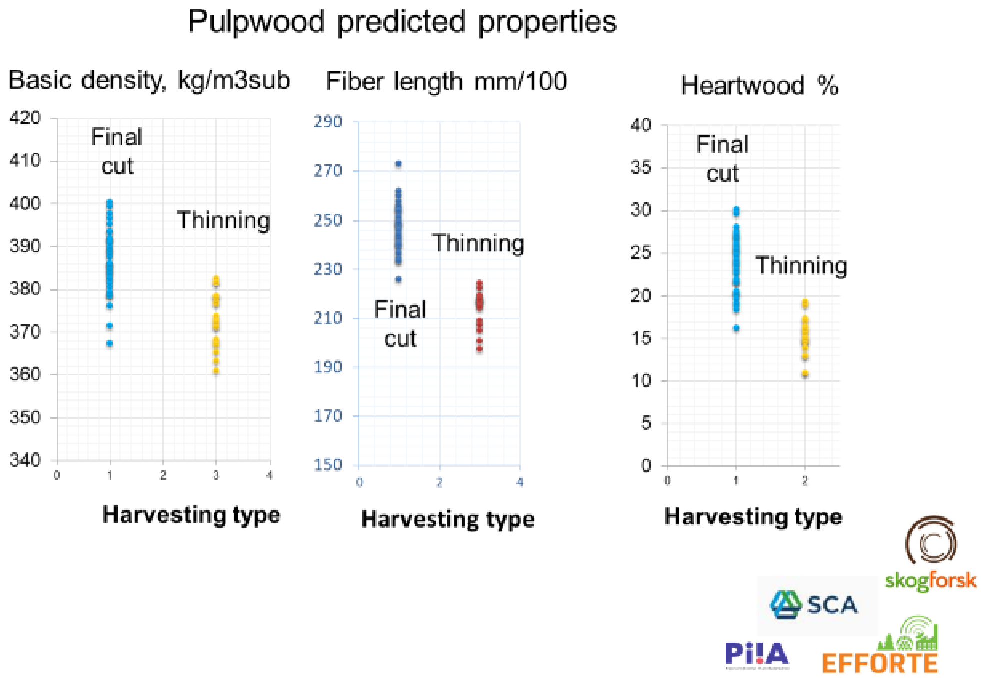

Figure 5. Example of some fibre properties of Scots pine (stand averages from 60 stands at SCA) predicted by hprProp (fibre models from RISE-Innventia/Skogforsk cooperation).

IPR

The package of hpr-file based program modules of which *hprProp (tested and further developed within EFFORTE)*, *hprCM* (*hprAnalys*) and *hpr-imputation* have been utilized in EFFORTE. All these modules are originally developed and owned by Skogforsk of which some in connection with Skogforsk's partner companies. They are originally developed outside EFFORTE, Further development, tests and some extensions have been performed by contribution from EFFORTE and programme modules, like hprAnalys and *hprProp* have been tested by project partners without cost. The different software modules can also be further utilized by the EFFORTE project partners after "fair and reasonable compensation" to Skogforsk.

Conclusion

The *hprProp* and connected software modules (e.g. *hprCM* and *hpr-imputation* developed in some other projects) may provide a paradigm shift in wood and fibre characterization from forestry – affecting operations in both forestry and industry into improved forest to industry value chains. EFFORTE has pushed these possibilities towards higher TRL-levels and a consequent investment in this field will probably result in a fast track and large-scale implementation of property characterized wood for pilot cases, if successful then followed by further properties, boosted industrial processes and feasible products. Since the start of

EFFORTE some such R&D&I projects aiming at further implementation, and probably more to come maybe somewhat changing the paradigm of forestry-industry integration.

4.1.3 Sequencing in operational planning

Short overview

Scheduling harvest resources and planning which areas are to be harvested, and in what order, is an important part of the forestry planning process. Scheduling is complex, because many different decisions must be made, and a large amount of detailed information must be processed. Skogforsk has developed a planning model that generates proposals about which stands are to be harvested, when, and by which harvest team. Costs of harvesting, transport to industry, movement of machines between areas, and work team movements to and from the area are minimised, while maximising the value of the harvested forest. The yield from the harvested stands is matched against the company's specific delivery requirements for different recipient points.

The result is a schedule, figure 6, for a harvesting plan that can be incorporated in existing decision-support systems. The model generates detailed information about use of resources in the forthcoming month, and a more long-term tactical plan for up to a year ahead.

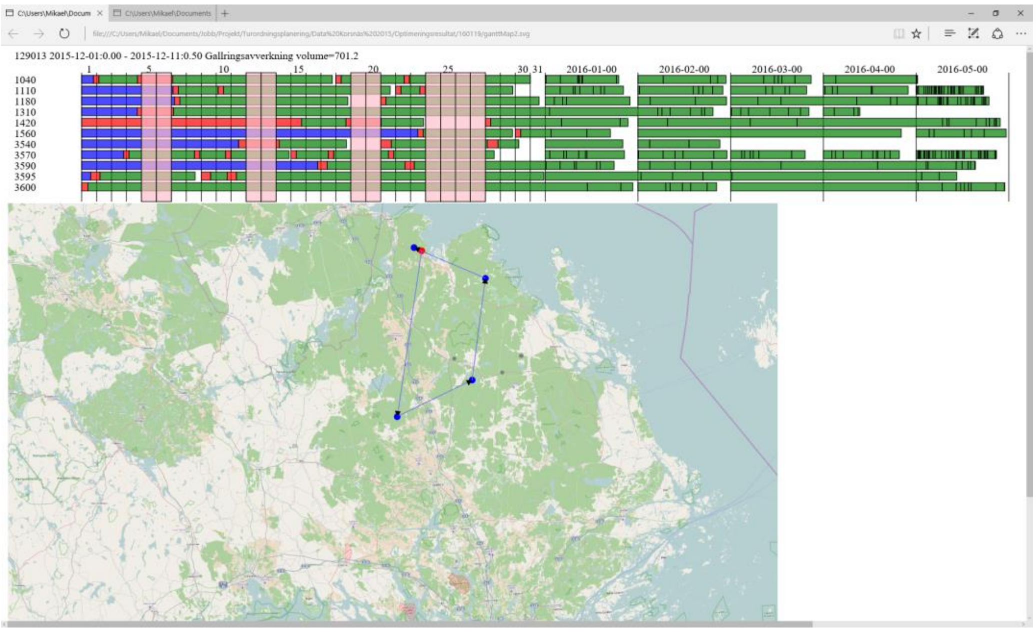

Figure 6. Model for scheduling of harvesters. The monthly schedule of cuttings is presented in the map.

The model has been tested and evaluated with good results in case studies involving two Swedish forest companies. The tests were based on authentic data for actual planning on five occasions. Evaluation showed that many of the scheduling proposals generated by the optimization model were feasible and formed a good basis for an operative plan. In those cases where the model's proposals were not feasible in practice, possible reasons included incorrect definition of when the harvest areas would be accessible.

Implementation

At least two Swedish forest companies have shown an interest in using the model. During the project a pre-study for implementation has been discussed with the IT company (CGI) responsible for the geospatial tool used by the forest companies. It is however very busy days and other IT-projects with higher priority currently and the pre-study has not started yet.

A model for scheduling of harvesters is also discussed at Biometria[3], the company collecting all forest production data and serving all forest companies in Sweden. As a application for scheduling of harvesters might be an interest for all major forest companies there might be a joint implementation.

The main challenge for the model is the large amount of input data required and the data quality differs along forest companies. All companies hold the data, but as it is not used in optimization models today it might not be of the required quality. This needs to be further addressed in a pre-study prior to a broad implementation.

Further R&D of the model include new derived datasets as for example dynamic trafficability maps or improved forest yield estimates as well as ongoing R&D with models for predicting wood product properties (*HprProp*). It would also be possible to develop an AI tool based on the model and actual use of harvesters at different sites to improve the model.

IPR

The model for scheduling of harvesters is developed and owned by Skogforsk that continuously develop and update the model.

Conclusions

The model for scheduling of harvesters is a true Big Data application using 20+ different databases. All databases exist at the forest companies, but sometimes at different departments and might therefore be challenging to collect. It is however possible to automate, and this would be required for an operational application.

[3] https://www.biometria.se/

4.2 Tools that have already been adopted by the companies (outside EFFORTE resources)

4.2.1 DTW model

Since 2014, DTW maps have been used in practical forestry in Sweden. This is a product created from the DTM layer. The idea is taken from Canada and the University of new Brunswick (Arp et al. 2008). By conducting flow analyzes for water on the soil layer that constitutes the DTM layer, it is possible to accumulate water in the landscape and see where surface water wants to flow and collect. On the basis of these flow channels where the water accumulates, a map is created where an inlet of at least one hectare and a certain height difference (in this case one meter) constitute basic factors for how the water will spread and create moist soil in the area around the flow channel.

This maps and models of soil moisture in the landscape are used in planning of forestry measures and are also available as an interactive layer in most forest machines. By utilizing soil moisture models (DTW) in operational forestry, efficient planning of forest activities is possible. Through good planning both before the action and during the work, it is possible to create a strip-road system where sensitive areas are avoided. In addition the maps are used to identify where to make a crossing over a stream or a wet are (if needed) and were and how to build a bridge. The maps has also made it possible to improve logistics in the site and optimize the strip-roads concerning transport distances and energy consumption (e.g Best Way model in chapter 4.1.1).

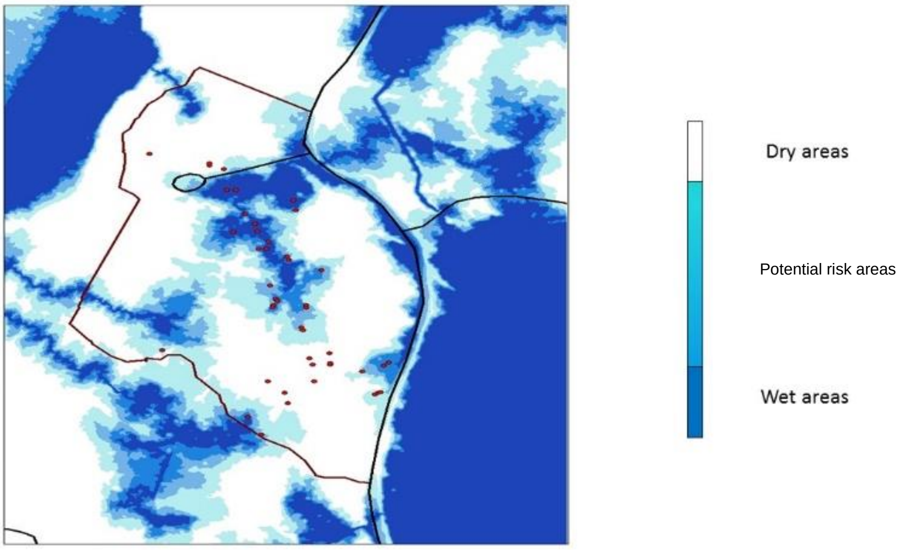

Figure 7. DTW model with rutting marked as red dots.

4.2.2 The static trafficability map

Short overview

The static trafficability map presents the classification of forests different trafficability classes. The map provides information about the season when harvesting operations may take place with standard logging machinery (i.e. a harvester and a forwarder) without causing substantial damages on forest soil. The mapping unit is a pixel of 16m size compatible with the forest resource information provided by the Finnish Forest Centre. Each pixel is classified in one of the following classes:

1. Operations possible in all seasons
2. Operations possible in summer, mineral soils
3. Operations possible in summer during dry season, mineral soils
4. Operations possible in summer, peatlands
5. Operations possible in summer during dry season, peatlands
6. Operations possible only during frost or thick layer of snow
7. Open water
8. No data (missing airborne laser scanning (ALS) data)

Implementation

The methodology that has been improved and validated in EEFORTE is now ready and the application is now in operative use. The service, where the maps can be downloaded, is maintained by The Finnish Forest Centre and the project has been financed by governmental sources. The current data coverage is presented in figure 8. The data coverage increases annually following the national ALS program and ALS-based forest inventories.

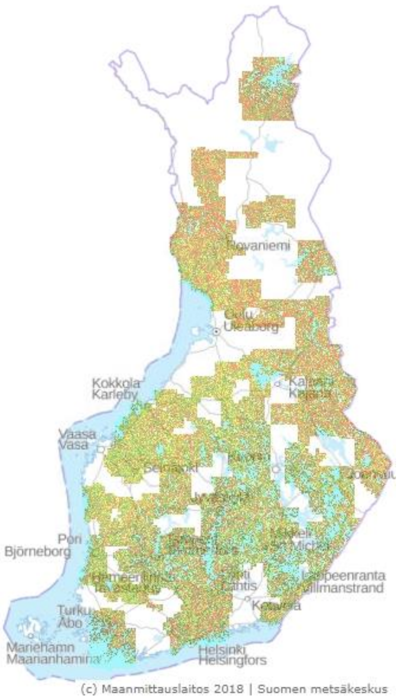

Figure 8. Data coverage of static trafficability maps on 15th May 2019 (a screenshot from The Finnish Forest Centre's map application).

IPR

The model is developed and owned by Arbonaut Ltd that continuously develop and update the model. Arbonaut Ltd is globally operating company in developing information gathering and GIS solutions for forest inventory and natural resource management (www.arbonaut.com). Downloading of maps for practical use from the Metsaan.fi –server is free of charge.

5 General conclusions

During the last years significant steps has been taken in forestry to utilize digital information largely available in most European countries. Despite important steps taken in EFFORTE, we believe that we are still positioned at the first frontier of digitalization of forestry processes and operations. Our attempts in EFFORTE prove that significant steps in rather short period of time can be taken if all important players (research, industry, technology providers and governmental bodies) work together.