Del. no.	5.4
WP no.	5000
Date	29/10/2012
Version	1.0
Revision	1
Confidentiality	PU

FlexWood

Flexible Wood Supply Chain

Summary of WP 5000 - Novel Harvesting and Logistic Concepts for Integration of Forestry with Industry

Delivable 5.4 - Novel Logistic model – Optimisation model for tactical and operational planning of the logging- and transport operations including data management

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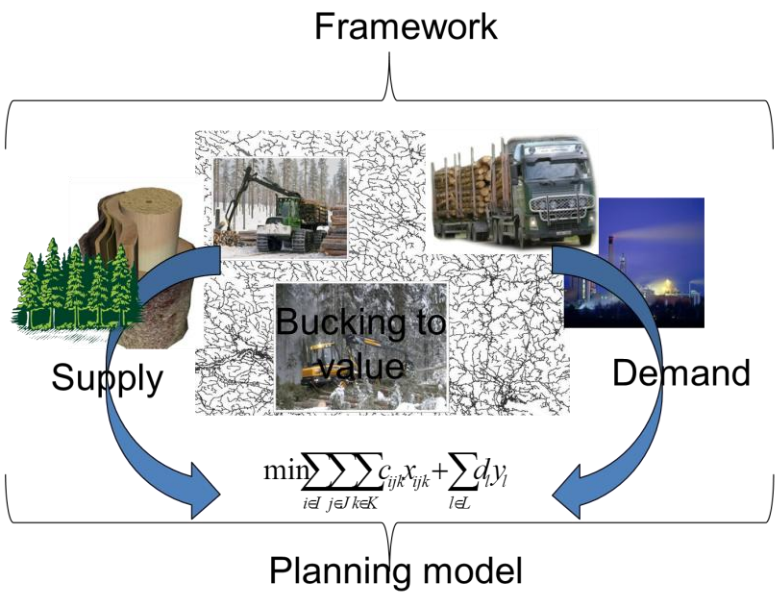

The FlexWood project is funded by the European Commission within the Seventh Framework Programme (FP7). The Collaborative Project (small or medium sized focused research project) contributes to "Meeting industrial requirements on wood raw-materials quality and quantity" activities.

FP7 GRANT AGREEMENT No. 245136

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SEVENTH FRAMEWORK PROGRAMME

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FP7 GRANT AGREEMENT No. 245136

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1. Abstract

One objective of FlexWood was to propose a novel wood supply chain (WSC) that increases value recovery through higher flexibility and tailoring capabilities. The objective for workpackage 5000 was to develop and evaluate novel logistic concepts able to match industry demand with forest resources under varying conditions. To be able to develop such core modules into a demand driven novel logistic concept we divided the work in work package 5000 into five tasks :

In task 5100 a framework for describing different wood supply chains (WSC) in a generic way and assessing their agility and tailoring capabilities was developed. The studied WSC comprised the planning and execution, at the operational level, of all activities, from selling agreements to delivery of forest products at the mill yard. These include the purchase or selection of harvesting blocks, harvesting scheduling and execution, as well as transportation scheduling and execution. The framework includes a set of descriptive templates including e.g. a description of the actors, their planning and execution processes, the decoupling points used, together with information, material and financial flows.

Three basic designs of planning systems were identified: 1) integrated sourcing and harvesting planning, 2) integrated harvesting and transportation planning, and 3) decoupled sourcing, harvesting and transportation planning. We also identified six logistics techniques to adjust supply to demand.

The agility capabilities of the WSC were assessed in four dimensions: customer sensitivity, process integration, information drivers and network integration. A WSC should strive towards proper agility capabilities in response to uncertainty in their environment.

Finally, tailoring capabilities were assessed, based on the location of the decoupling points and their respective order fulfilment cycle time. Two processes were identified, where most of the product differentiation activities along a WSC occur: harvesting with the CTL method and merchandising at a roadside landing using the FT method. The capabilities to tailor product specifications are superior before rather than after one of these processes.

In task 5200 we studied harvesting in small private forest ownership in Europe. Currently, the share of private forest ownership in Europe is around 50 % with great variations between countries. Set in the context of forest industry, logistic concepts are usually developed for larger entities of forest ownership or integrated forest industry. In order to cope with other property conditions, which account for a large share of the forest resource throughout Europe, we investigated specifically how small private forest ownership could be tied to these concepts.

The divergence regarding small private forest ownership throughout Europe is high, not only due to variable definitions of small-scale forestry within European countries. Thus regional circumstances need to be considered and have to be scrutinized case by case to see how small non-industrial private forest ownership can be integrated in advanced harvesting and logistic concepts such as Flexwood. This relates to the widely discussed topic of wood mobilization and constraints in private ownership, which arises amongst others from the fact that for instance in Austria and Germany the ratio between increment and felling is significantly higher in small private forests than in larger properties.

Novel logistic concept are particularly attractive where forest function and ecosystem services are segregated from each other (e.g. plantations) and in timber-oriented, highly mechanized forestry regimes with high levels of accessibility and infrastructure. Furthermore up-to-date inventory and mechanized harvesting systems are prerequisites for advanced data acquisition and transfer, while small holdings lack detailed inventory data and restrict

the use of mechanized harvesting systems for various reasons. This may inhibit their participation in advanced wood supply chain systems and may restrict their market access

However, there remain other possibilities. Cooperatives can play an important role as providers for the required knowledge, services and technology. In addition, the modules of Flexwood separately offer large potential for the wood mobilization from small private forests. This is for example the case for the application of novel technologies for forest inventory and the web-based platform approach. These can furthermore be possible tools visualize the potential benefit of the utilization of their forest resource and stimulate forest owners to consider harvesting. This may be especially well-suited to address younger generations of forest owners, which will be an increasingly important aspect in the next years, but is certainly not limited to that.

In task 5300 procedures and processes for the allocation of forest raw material to the industry was described. It builds the link between industry and forestry. Basis is on the one hand the data on the industrial requirements towards forest raw material; this has been elaborated in WP3000 and WP5300 and on the other hand the data on the forest resource from novel inventory technology - the outcome of WP5300 and WP4000. Following the principle of demand-driven wood procurement, starting point are the industrial requirements, which are converted and condensed into an appropriate format, common across the participating European countries which contains both dimension and quality information.
In a second step the results of the inventory based assessment of the existing forest resources are converted into a format, which is compatible to the list of requirements.Technically different inventory concepts have been alternatively developed in the Flexwood project and are applied in the different use cases. Therefore the matching procedure may (technically) differ from case to case Impact and possibilities regarding market conditions and different suggestions for developing the interface industry – forestry when operating forestry within a Cut-To-Length system is described as the Nordic perspective.

In task 5400 we analysed how the bucking optimization could be controlled and developed according to increased agility in relation to specific industrial demands (WP 3000, WP 6000) and the improved information on the standing trees (WP3000, 4000 & 5400). Ideally, the bucking process should be a fully integrated, efficient part of each industry. As the wood flow becomes controlled by advanced logistic tools, it becomes increasingly important to support the system with an efficient bucking control, including description of the logs by individual characteristics and predictions of total product yield. To achieve the objectives of a novel logistic concept, the system need new tools for automatic and more flexible bucking control, with respect to alternative customers' and pricelists in question for specific harvesting objects
In task 5400 methods to support the Flexwood scheduling optimization module (5500) with adapted production data in a standardized format according to StanForD 2010 and adapt and test the control messages to control the harvester with production instruction according to the needs calculated in the Logistic novel Flexwood scheduling optimization tool.

In task 5500 we have developed a solution approach and models aimed to schedule harvesting resources (i.e. harvester, forwarder and harwarder) in combination with the selection of stands to be harvested under restriction of fulfilling demand from industry and minimizing the overall logistic cost. The purpose was to create an operational plan on which stands are to be harvested when in time and by which harvesting machine team. The logistic cost includes costs for harvesting, transportation of round wood from forest to mill and moving machines between stands. The outcome of the harvested stands (volume per assortment) was matched with the demand from pulp-mills, sawmills and CHP-plants.
In order to get the right outcome from the stands the solution approach suggested which bucking instruction to be used for each stand.

Results from the five tasks in work package 5000 are core modules building a novel logistic model for efficient wood supply integrating forestry with industry.

2. Background

The objective for WP 5000 was to develop and evaluate novel logistic concepts able to match industry demand with forest resources under varying conditions.

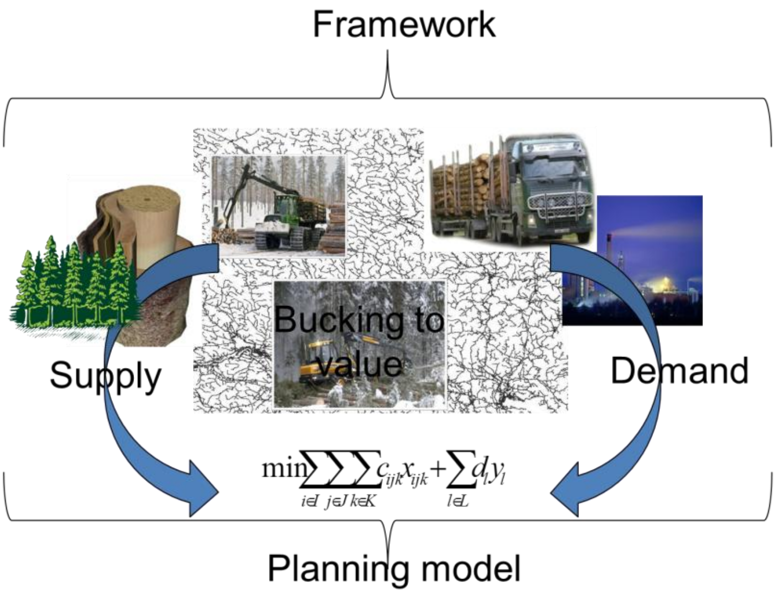

Figure 1: Overview of work package 5000. First we developed a generic method to describe and measure different wood supply systems (task 5100). According to that we also described the special circumstances for small private forest owners situation in central Europe (task 5200). Then we described data needed to build a planning model, specialy supply descriptions of forest stands via laser scanning and industrial demand (task 5300). We also looked into more flexible means to adapt the bucking processes in the cut to length harvesters (task 5400) and finally developed a planning model to match industrial demand with forest supply efficiently using operational means i.e. harvest- and transportequipment and road network.

To reach a better understanding of the structure of different Wood Supply Systems we developed a framework to describe alternative logistics concepts. The configuration of the main stakeholders and planning systems to provide higher agility and tailoring within the wood supply chain was described. The work is presented in deliverable 5.1, *General framework for describing different wood supply chain systems*, responsible partner is Université Laval (Task 5100). In connection to describing different Wood Supply Systems we also mapped and analyzed the structures of forest owners, available forest data, preferences and information requirements in the test areas. Specially the small forest owners perspective was analyzed. This work was carried out by FobAwi (Task 5200) and is discussed in the end of this deliverable.

To be able to match industry demand with forest resources the structure the data on industry requirements towards forest raw material on the one hand and of the forest resource from novel inventory technology on the other. Different inventory concepts have been alternatively developed in the Flexwood project and are applied in the different use cases. Therefore the matching procedure may (technically) differ from case to case.

The other deliverables include D 5.2 Others (Month 24): Interfaces and procedures for existing harvesting and logistic concept.• Responsible participant: ALU-FR-FobAwi

Here the goal was to create automatic product breakout simulations for efficient valuation of different possibilities to meet customers' end product demands. As well as to create a new optimisation model for both tactical and operational planning and bucking that can adapt (tailor) the wood supply from the standing forests to different demands from sawmills, pulp & paper mills and combined heating & power plants.

D 5.3 (Month 24): *Software and optimisation models for novel logistic and harvesting concepts*.• Responsible participant: Skogforsk

Finally, this deliverable D 5.4 (Month 27) Novel Logistic model – *Optimisation model for tactical and operational planning of the logging- and transport operations including data management*.
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3. Work package 5100

We have proposed a framework for describing WSCs. This framework uses a formalism that can be applied in a generic way to present different WSCs. It also allows an assessment to be made of their agility and tailoring capabilities. The framework consists of five main components: *1) external environment, 2) competitive business and supply chain strategies, 3) supply chain structure, 4) enablers and practices,* and *5) performance.* These fives components were detailed and analysed through a series of case studies. This led to the development of a set of interrelated templates to describe a WSC, including e.g. a description of the actors, their planning and execution processes, the decoupling points used, and the information, material and financial flows. Moreover, using the four dimensions of an agile supply chain proposed by Christopher (2000), the framework provides a novel assessment methodology of WSC agility capabilities. The developed methodology used a 0-4 scale to rate how well different enablers and practices identified along the main processes within a WSC contribute to each of these four dimensions. Furthermore, tailoring capabilities were assessed, based on the location of the decoupling points and their respective order fulfilment cycle time.

The framework is useful to public and private organisations interested in a describtion of their WSCs and the capacity to assess its agility and tailoring capabilities. A schematic and functional representation of the wood supply chain(s) to which an organisation belongs will make it easier to understand the constraints and objectives of each actor contributing to its processes. Moreover, such an exercise should ease the introduction of a new actor into the WSC. By assessing the tailoring and agility capabilities of a WSC, the framework can support an organisation in an exercise of self-diagnosis that leads to the identification of improvement opportunities to work on. Moreover, by assessing its WSC according to different scenarios (e.g. introduction of new technology, addition of a new value proposition for customer), an organisation can anticipate the impacts of changes.

Finally, the framework introduced a common vocabulary to be used by researchers and practitioners in different disciplines (e.g. forest engineering, management sciences, industrial engineering). It represents an original attempt to develop a reference model for future research on WSCs. Yet, to have significant impact, it needs to be further disseminated and tested within the respective communities.

Introduction

A novel logistics wood supply system (WSS) is described by three main aspects:
- an enhanced description of the demand;
- an enhanced description of the available supply;
- an enhanced planning system for the coupling of the demand with the available supply.

One objective of FlexWood is to propose a novel wood supply chain (WSC) that increases value recovery through higher flexibility and tailoring capabilities. To support the design of this novel WSC, a generic framework for describing it and assessing its agility and tailoring capabilities was developed.

Agility means to respond quickly and efficiently to sudden and unplanned changes in the environment of a WSC (Li et al., 2009). Conceptually, agility capabilities consist of flexibility capabilities with the notion of effectiveness. Tailoring (known as customisation or personalisation in the literature) refers to a supplier's design of its value proposition (i.e. the product and logistics services in a WSC) to targeted customer segments.

Previously, timberland was owned in many forested countries by companies that also owned the processing facilities (e.g. sawmills, pulp and paper mills). Standing timber was harvested and hauled to the mill gate by employees according to internal planning processes. This situation leads to a closed and fairly stable wood procurement system in which the available supply dictated the demand requirements. However, in most countries today, wood procurement systems generally consist of several independent business entities interacting through complex business relationships involving material, information and financial flows. All execution and planning processes are no longer handled exclusively internally. Nowadays, it is the norm for contractors to carry out harvesting and hauling activities for companies that either own the timberland and/or the mills. Mills serve national-to-worldwide markets subject to sudden changes and have higher product and logistics service expectations. This, in turn, requires the supply of raw material in more precise quantities and qualities and with flexible logistics service, raising new challenges to wood procurement systems. Today, wood procurement systems constitute complex supply chains with different components (**Fehler! Verweisquelle konnte nicht gefunden werden.**2). The field of supply chain management is well suited to address their challenges. We refer the reader interested in the supply chain management of the forest products industry to the reviews by Rönnqvist (2003), Weintraub et al. (2007), D'Amours et al. (2008) and Carlsson et al. (2009). Moreover, the cost of raw material accounts for a significant part of the total cost of the final wood products (e.g. between 26-30% of the cost of a metric ton of pulp for an average Swedish pulp mill). Given this large amount of money spent by wood procurement systems, a small cost reduction can lead to important savings.

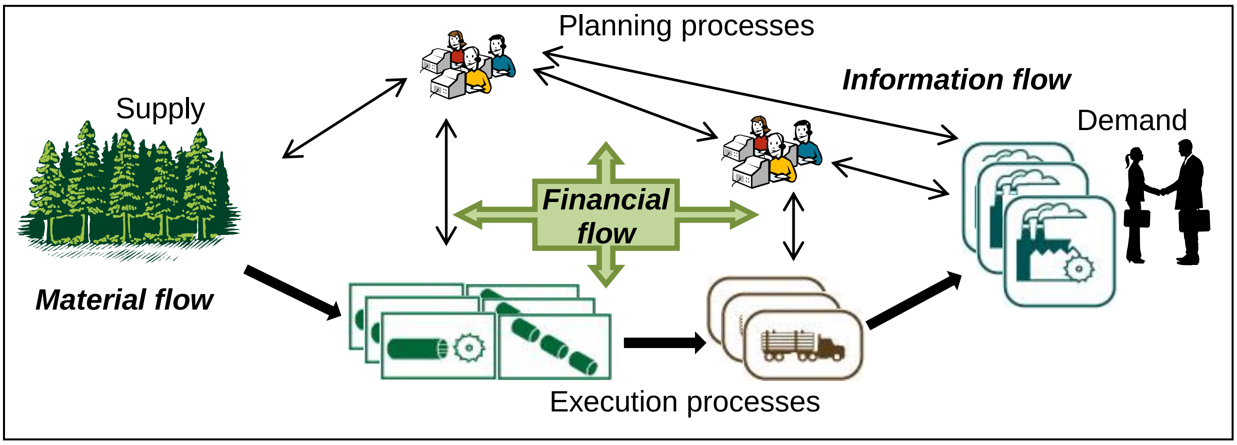


Figure 2: The main components of a wood supply chain.

A supply chain can be defined as a ''network of organisations that are involved, through upstream and downstream linkages, in different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer" (Christopher, 2005). There are two core ideas in the supply chain concept:

a) Better collaboration between companies in the same supply chain will improve delivery service, better manage utilisation and save costs, particularly for holding inventories (Alicke, 2005);

b) Individual businesses can no longer compete as solely autonomous entities, but rather as supply chains (Christopher, 2005).

Supply chain management is ''the task of integrating organisational units along a supply chain and coordinating material, information and financial flows in order to fulfil customer demand with the aim of improving the competitiveness of a supply chain as a whole'' (Stadler and Kilger, 2008). That is why, rather than acting company by company, clusters of connected companies (i.e. supply chains) make up a more meaningful cohesive system that can be analysed and managed when it comes to logistics.

The supply chain modelling methods available are generic and usually applied to one single company, with only a superficial description of the other partners and their involvement in the supply chain. The performance and competitiveness of a supply chain, as well as its contributions to the performance and competitiveness of its individual companies, are also diffuse knowledge domains, with no formal consensus on the best performance measurements and competitive strategies to follow.

With these current challenges in mind, and with the aim of supporting the design of a new innovative WSC for the forest industry which provides higher agility and tailoring capabilities, a generic framework for describing different WSCs was defined. Following the scope of Working Package 5000, the WSC analysed comprise the planning and the execution of all the activities involved from selling agreements to delivery of products at the mill yard. These activities include the purchase or selection of harvesting blocks, harvesting scheduling and execution, as well as transportation scheduling and execution.

The framework was applied to six case studies of WSCs from different parts of the world. It clarified the role of private and public institutions and market mechanisms, as well as key issues in coordinating the different parts of the WSC. These cases led to the identification of three basic designs of the planning system.

In summary, the three objectives of the project were to:

1. Develop a generic framework to describe any WSC and evaluate the agility and tailoring capabilities of the system;
2. Use the developed framework to study WSCs in different forested countries;
3. Analyse and compare each studied WSC to identify the basic designs of planning systems.

3.1 Description of work

A framework for describing different wood supply chains (WSC) in a generic way and assessing their agility and tailoring capabilities were developed. The studied WSC comprises the planning and execution, at the operational level, of all activities, from selling agreements to delivery of forest products at the mill yard. These include the purchase or selection of harvesting blocks, harvesting scheduling and execution, as well as transportation scheduling and execution. The framework includes a set of descriptive templates including e.g. a description of the actors, their planning and execution processes, the decoupling points used, together with information, material and financial flows.

The proposed framework was applied to case studies in six countries (Canada, Chile, France, Poland, Sweden and USA) where fieldwork allowed us to collect information from 94 local actors and experts. The case studies allowed a list of options (i.e. catalogues) to be generated for different descriptive elements within the framework. We generated catalogues of 16 types of actors involved in a WSC, seven locations of decoupling points, four types of value commitment processes, eight standing timber and harvest timber pricing mechanisms and several payment methods for standing timber, harvested timber, harvesting and primary and secondary transportation. We also developed 17 generic processes for any planning and execution activities within a WSC, as well as 13 generic planning decisions at the operational level.

Three basic designs of planning systems were identified: 1) integrated sourcing and harvesting planning, 2) integrated harvesting and transportation planning, and 3) decoupled sourcing, harvesting and transportation planning. We also identified six logistics techniques to adjust supply to demand.

The agility capabilities of the WSC were assessed in four dimensions: customer sensitivity, process integration, information drivers and network integration. The developed methodology used a 0-4 scale to rate how well different enablers and practices, identified along the main processes within a WSC, contributed to each of these four dimensions. A WSC should strive towards proper agility capabilities in response to uncertainty in their environment. The agility capabilities evaluated in the case studies and those theoretically required by the environment's uncertainties were compared and discussed. Finally, tailoring capabilities were assessed, based on the location of the decoupling points and their respective order fulfilment cycle time. Two processes were identified, where most of the product differentiation activities along a WSC occur: harvesting with the CTL method and merchandising at a roadside landing using the FT method. The capabilities to tailor product specifications are superior before rather than after one of these processes. Moreover, a typology of assortments according to the level of tailoring is provided and the financial incentive to produce a basket of assortments with a higher level of tailoring is discussed. Finally, when comparing the location of the decoupling point, the agility capabilities and the average order fulfilment cycle time, it was possible to reinforce the results from the literature, which state that supply chain agility is linked to shorter lead-time.

Finally, the framework introduced a common vocabulary to be used by researchers and practitioners in different disciplines (e.g. forest engineering, management sciences, industrial engineering). It represents an original attempt to develop a reference model for future research addressing WSCs.

The description of different WSCs and, with the objective of supporting the design of an innovative WSC, their impact on supply chain agility and tailoring capabilities, is a complex task applied to a complex system. Research questions initially defined were:

a) What are the business entities comprising the WSC, their roles, their decisions and objectives?
b) What are the interactions between them?
c) What are the material, information and financial flows between them?
d) How do we evaluate the competitiveness of a WSC?
e) How do we evaluate the agility and tailoring capabilities of a WSC?
f) How are agility and tailoring capabilities impacted by WSC configuration?

As the nature of the research questions are "what" and "how", the variables cannot be easily identified beforehand and there is no specific theory or model available on WSCs. For the development of the framework, the research methodology adopted was grounded theory[1]. With grounded theory, the rules of a process, action or interaction of participants in a study are derived by the researchers through the structured organisation of collected data (Corbin and Strauss, 2008). Data collection was based on case studies with interactive and iterative communication with interviewed actors during fieldwork as well as with experts in forest engineering, forest management, forest economics, industrial engineering and management sciences. As represented in 3, the research methodology was organised in three main steps discussed below.

Step 1: Experimental design
- Exploratory literature review.
- Design of basic questionnaire.

Step 2: Case studies
- Researchers gather information through case studies (e.g. interviews, observations).
- Researchers ask open-ended questions to participants and record field notes.

Step 3: Analysis and results
- Researchers analyse data to form themes or categories (initial framework).
- Researchers look for broad patterns, generalisations, or theories from themes or categories (Results).
- Generalisations, or theories to past experiences and literature (Future research).

Figure 3: Research methodology. Adapted from: Creswell (2003).

A summary of the six case studies are shown in

[1] Grounded theory is a specific methodology with the purpose of building theory from data, through techniques and procedures for gathering, analysing, examining and interpreting data in order to elicit meaning, gain understanding and develop empirical knowledge (Corbin and Strauss, 2008).

Table 1; variation was sought in the organisation's size to which the interviewed actors belonged (small to large), in forest types (plantation and natural), main commercial species, nature of timberland ownership and in the general location of the operations. A total of 52 interviews were conducted with different actors from the public and private sectors who are involved in the WSC in the countries visited.

Table 1: Summary of the six main case studies.

	Chilean case 1	US case 4	French case 11	Canadian case 15	Polish case 18	Swedish case 19
Organisation size	Large	Small, Medium, Large	Medium, Large	Large	Medium, Large	Large
Forest type	Plantation	Plantation	Plantation	Natural forest, plantation and extensively to intensively managed natural forest	Natural forest, plantation and extensively to intensively managed natural forest	Plantation and intensively managed natural forest
Main commerical species	Pine, eucalyptus	Pine	Pine	Spruce, pine, fir, birch, poplar	Pine and several hardwood	Spruce, pine, birch
Timberland ownership	Private industrial and individual	Private industrial and individual	Private individual	Public and private individual	Public	Private industrial and individual
General location	South America	North America	Continental Europe	North America	Continental Europe	Scandinavia
Specific region	Concepcion and Valdivia	Alabama, Georgia and Mississippi	Aquitaine	Quebec province	Northwest	South and middle
Local host	Universidad Austral de Chile	University of Georgia, Mississipi State University	Institut technologique forêt cellulose bois-construction ameublement	Université Laval	Instytut Badawczy Leśnictwa	The Forestry Research Institute of Sweden (Skogforsk)
Number of interviews (total number of interviewed actors and experts)	14 (26)	13 (22)	15 (21)	3 (8)	7(10)	0 (7)
Total cases identified	3	5	6	3	1	4

3.2 Results – Proposed Framework

The challenge of this research is to better understand a WSC, represented centrally by the description of the structure of the WSC. It became clear, however, that the framework should also include the relationships of the supply chain structure to other key elements supporting the description and analysis of a WSC, as well as the assessment of its agility and tailoring capabilities. Therefore, besides the component for studying the WSC structure, the framework includes four additional components introduced below.

The five components forming the developed framework are illustrated in figure 4.

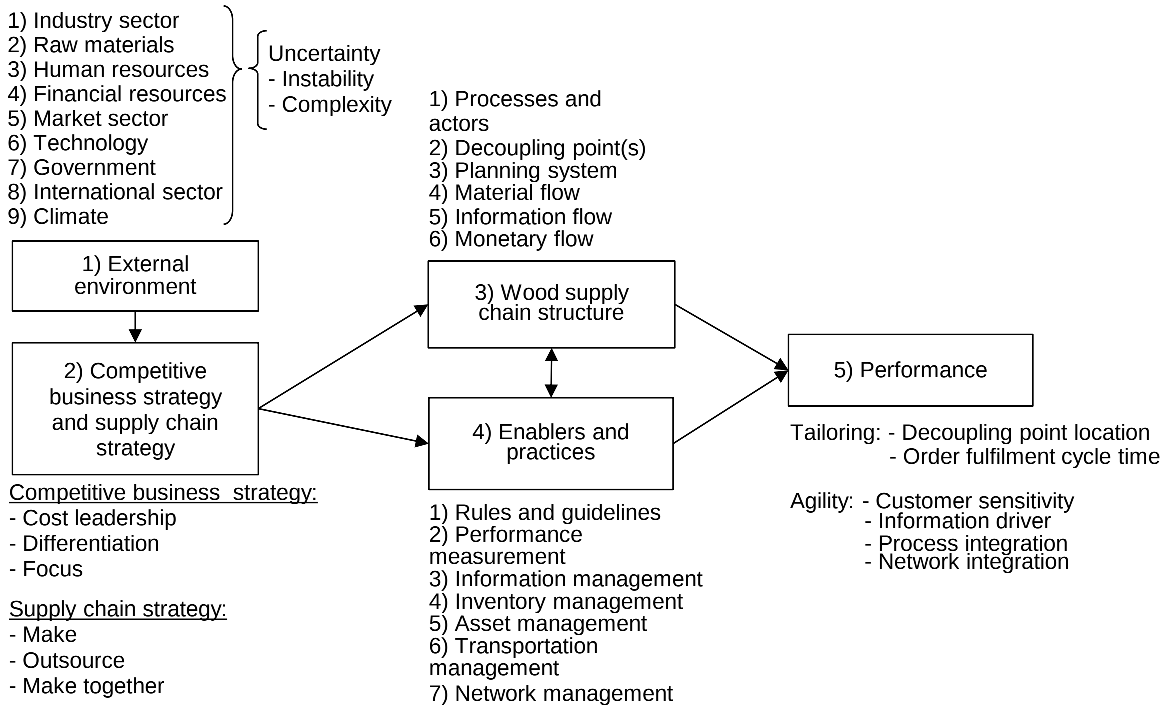


Figure 4: A contingency framework to analyse wood supply chains.

3.2.1.1 Component 1: External environment

To support the contextual description of a specific WSC, a set of environmental elements was adapted from Daft and Armstrong (2009): internal industry sector, raw materials, human resources, financial resources, technology, government, international sector and climate.

Moreover, the uncertainty of each environmental element is considered. Uncertainty is driven by changes in volume, variety and variability which, in turn, increase demand or supply unpredictability. Uncertainty is a function of instability and complexity (Daft and Armstrong, 2009). High instability in the wood industry can mean that some environmental elements shift abruptly and unexpectedly in a matter of days.

3.2.1.2 Component 2: Competitive business strategy and supply chain strategy

The competitive business strategy addresses "how an organisation chooses to compete in a market, particularly the issue of positioning the company relative to competitors with the aim of establishing a profitable and sustainable position'' (Hallgren and Olhager, 2006). How to describe a competitive strategy is still an open question in the literature. Distinguishing among three major business strategies for competitiveness (i.e. cost leadership, differentiation, and focus), the typology for the competitive strategy of a company developed by Porter (1998) is one of the most well-known and adopted.

a) Services: a broad offer of personalised services (e.g. delivery time windows, payment conditions, packaging) and/or of additional services (e.g. maintenance, training, planning).

b) Product: products with higher quality, reliability or durability, frequent new product development, a high share of new products in the product portfolios, and the realisation of value-added transformation activities by the company.

c) Marketing: differentiation is achieved through branding, control of distribution channels, exclusivity contracts and innovative marketing techniques.

Several authors reduce the three strategies of Porter to two: cost leadership and differentiation, as a focus strategy is considered a "stuck in the middle" approach used by companies that are ineffective at concentrating on one strategy to implement it well (Davis et al., 2002; Hansen et al., 2006). We use such a simplification in the framework.

Yee and Platts (2006) notably propose a practical approach to portray and analyse the interaction of firms in a supply network and its linkages to the competitive business strategies deployed by the firms. It consists of describing, for each company in the network, the i) adopted competitive business strategy and ii) the implementation approach. The implementation approach refers to how a firm is willing to implement the adopted competitive business strategy: in an offensive, defensive or diversifying way, and with an individual or cooperative approach.

Once the business strategy and implementation approach are identified, it is time to define the supply chain strategy. From a value creation network perspective, an effort has to be made to determine which of the processes should be executed and/or controlled by the organisation, and which ones should be made by another enterprise. This is what we call the supply chain strategic options of make, not make, outsource or make together (Poulin et al., 1994).

3.2.1.3 Component 3: Wood supply chain structure

One main question for the description of a supply chain structure is to determine which structural elements should be described. Based on five criteria defining a reference model, Blecken (2009) provides a review of six reference models addressing tasks and activities of supply chain management and logistics. One of them is the SCOR model, which were chosen to support the description of the planning and execution processes in a WSC. The SCOR model has been developed to describe the business activities associated with all phases of satisfying a customer‘s demand and is organised around five macro-processes (Plan, Source, Make, Deliver and Return) that each include a set of generic processes (Supply Chain Council, 2008). In the proposed processes of a WSC, we limited our use of planning processes to the Source, Make and Deliver macro-processes. The research project focuses on the planning and execution activities at the operational level. Thus, for the sake of brevity, we excluded the Plan macro-process. For its limited contribution to the research project, we also excluded the Return macro. According to the level of detail aimed for in the research project, the proposed WSC processes are an aggregation of SCOR model generic processes. A non-aggregated adaptation of the generic processes in the SCOR model to a WSC can be found in Schnetzler et al. (2009). The processes in the Source macro-process are related to the supply in standing timber, while the process in Deliver (Value commitment) is related to the sales of harvested timber. The processes in the Make macro-process are related to harvesting activities, while the processes in Deliver (secondary transport) are related to transportation activities.

In addition to processes, other elements are part of the WSC structure. One of these is the decoupling point. Wikner and Rudberg (2005) define the decoupling point as “the point in the flow of goods where forecast-driven production and customer order-driven production are separated” In a supply chain structure, a relationship exists, therefore, between the capabilities to tailor the attributes of a value proposition to a customer, the processes and the potential localisations of the decoupling point. In the case studies, we condensed the attributes detailing the demand to three: product specifications, price and payment conditions, and quantity and delivery conditions.

The planning system is another important feature to be captured, described and analysed as part of the structure. To do so, the decisions to be taken or executed in each process, the actors responsible for them, the planning horizon, the planning period, the update frequency, the required inputs and resulting outputs also need to be captured. Material, information and monetary flows between the processes and actors can then be properly discussed.

3.3 Component 4: Enablers and practices

Enablers and practices are implemented in a WSC to make the linkage between the competitive business strategy and the supply chain structure. The utilisation of adequate enablers can help the supply chain to achieve its business objectives . Enablers are the means to achieve the expected end results.

Following the macro-processes of the SCOR model, a set of seven categories of enablers and practices was identified. The objective here is not to judge whether the enabler/practice is good or not, but rather to identify and describe what was observed during the fieldwork. The evaluation of pertinence and contribution of enablers and practices is the objective of the next and last building component of the framework, more information can be found in Audy et al. (2010), Table 3.

3.4 Component 5: Performance

In the work definition of the research project, the performance attributes of a WSC to focus on are: agility capabilities, tailoring capabilities and competitiveness. The several definitions of these attributes and, in the context of this project, the lack of practical evaluation methodology in the literature, as well as the intrinsic limits of access to quantitative data, made it more suitable to use mainly non-financial qualitative metrics. For each attribute, we discuss the developed assessment methodology, which relies on one or more components of the framework (see 5).

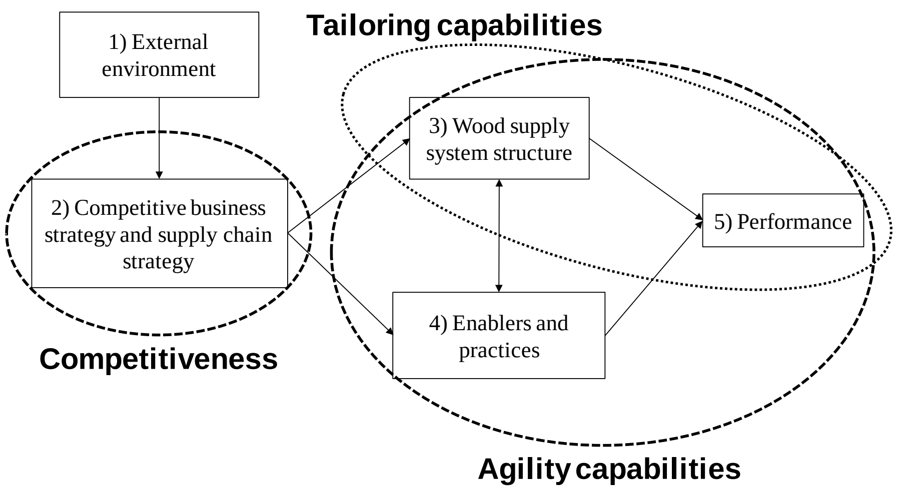


Figure 5: Components involved in the assessment methodology of each performance attribute

In this project, the supply chain agility framework proposed by Christopher (2000) was used. This framework defines supply chain agility according to four dimensions: customer sensitivity, information drivers, process integration and network integration.

Table 2 defines each dimension.

Table 2: Dimensions of supply chain agility

Dimension	Definition
Customer sensitivity	The capability to increase customer (i.e. mill) satisfaction/service level, or to maintain it at a high level, by reading and responding to real demand and/or using customer-based measures (instead of high levels of inventory).
Process integration	The capability to increase responsiveness, which means operating effectively and efficiently in a timely manner by having the processes properly integrated.
Information driver	The capability to access relevant information and knowledge by having accurate and frequent updates of key information, which is available to supply chain partners.
Network integration	The capability to integrate key supply chain partners in planning and execution processes by implementing and managing adequate business relationships with partners upstream and downstream of the supply chain.

To reach a standardised agility assessment among the case studies, we used an external evaluation approach rather than a survey or self-rating questionnaire. In practice, this meant that the researchers were responsible for assigning a grade from 0 to 4 (no contribution 0 – 1 – 2 – 3 – 4 extremely high contribution) for the set of enablers and practices identified in each WSC macro-process [Source, Make, Deliver (value commitment) and Deliver (secondary transport)] and their perceived contribution to the four WSC agility dimensions. Moreover, this perceived contribution was based on two questions per agility dimension (see

Table 3). To reduce subjectivity and bias in the assignment of grades, the first evaluation was made by at least two researchers together and then all evaluations were reviewed with all the researchers involved in the first evaluations.

Table 3: Guiding questions for evaluation of impact of enablers and practices on WSC agility.

Supply chain agility dimension	**Are the enablers and practices of the macro-process…**
Customer sensitivity	a) ...providing the capacity of reading and responding to real demand? b) ...allowing the identification of opportunities to increase customer value (capture emerging trends)?
Process integration	a) ...part of collaborative planning and joint strategy determination? b) ...facilitating rapid decision making between business functions?
Information driver	a) ...allowing frequent and accurate update of key information? b) ...making key information readily accessible throughout the entire supply chain?
Network integration	a) ...reinforcing trust-based relationships with customers/suppliers? b) ...minimising resistance to change and adoption of new practices?

1.1.1.Tailoring capabilities

Tailoring capabilities were firstly evaluated according to the location of the decoupling point(s) in each case studied.. But tailoring is also linked with a time dimension: the length of time a customer must wait for an order with personalised attributes. Consequently, a time metric called ‘order fulfilment cycle time’ was captured in the cases.

1.1.2.Competitiveness

Lee and Wilhelm (2010) mention that ‘‘competitiveness has been a controversial notion and few agree on a precise definition, although numerous definitions have been proposed’’. Competitiveness in this work is addressed through the competitive business strategy in the aforementioned component 2 of the framework, see also Audy et al. (2010).

2. Analysis and discussion

The analysis of the framework application to all the cases leads to different observations, which are presented and discussed in this section.

3.5 External environment

By discussing the elements of the external environment captured in the case studies, it became clear that some of them had a more direct impact on WSCs. According to Lee (2002) and Gattorna (2011), uncertainty in demand and supply drives different needs for a supply chain. Inspired by these two supply chain analyses, specific environmental characteristics in the supply and demand dimensions were identified. On the supply side of a WSC, three main characteristics were identified:

a. Raw material heterogeneity.
b. Accessibility to acquiring harvesting rights to standing timber determines how fast and simple it is to purchase or obtain harvesting rights on standing timber blocks
c. Conditions of harvesting and transportation activities: how harvesting and transportation activities are subject to variation and complexity by environmental

On the demand side, the two main characteristics identified were:

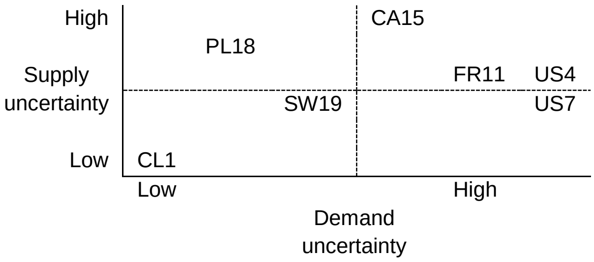
d. Length of the planning horizon in the value commitment
e. Frequency of change in the demand

From these descriptions, the context of each case was discussed and evaluated in order to be categorised in a four-quadrant matrix of supply-demand uncertainty (

Figure 66). The results show different contextual situations. The Chilean case, for instance, presented the lowest uncertainty levels, both in supply and demand. At the other extreme, we have the French and US cases, which present a medium supply uncertainty and high demand uncertainty, characterised by several short-term sales. According to Lee’s typology, this calls for a “responsive” supply chain, with mechanisms for the quick transfer of order information and transformation of the final products, with the localisation of the decoupling point being a critical decision.

The Canadian and Polish cases show a higher supply uncertainty, being both contexts of state-owned natural forests, while the Canadian case showed a higher demand uncertainty due to the frequent changes in demand, what is not so common in the Polish case. According to Lee’s typology, they should head towards a “risk-hedging” supply chain by “pooling and sharing resources so that the risks in supply disruption can also be shared, (…)

sharing safety stocks with other companies" (Lee, 2002). Finally, the Swedish case has an intermediate position, with supply and demand uncertainties not as low as in the Chilean case, not as high as in the Polish and Canadian cases for supply, and the French and US cases for demand.



Legend: Chilean case 1 (CL1); US case 4 (US4); US case 7 (US7); French case 11 (FR11); Canadian case 15 (CA15); Polish case 18 (PL18) and Swedish case 19 (SW19)

Figure 6 : Environmental uncertainty of the cases studied.

From the general assumption in the literature that an environment with high uncertainty calls for high agility capabilities, we can say that drivers for agility are higher in the cases closer to the top-right quadrant of 6. In this analysis, we consider that the level of environmental uncertainty cannot be changed while, in practice, some environmental characteristics could be changed (e.g. over-restrictive legislation on harvesting, but not the weather pattern impacting the harvesting). Thus, supply chains in the top-right quadrant should use strategies "aimed at being responsive and flexible to customer needs, while the risks of supply shortages or disruptions are hedged by pooling inventory or other capacity resources" (Lee, 2002). These recommendations support the analysis of how well the supply chain strategies, structures, enablers and practices of the cases are aligned with the environment to deliver a good performance level.

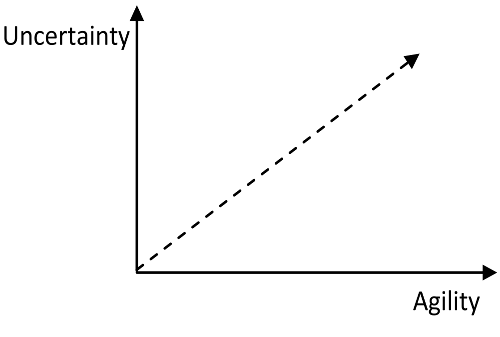


Figure 7: Uncertainty and the potential correlation with agility requirements.

This environmental analysis was conducted at a strategic and aggregated supply chain level. Further studies should focus on developing specific and more objective metrics for the environmental elements, as well as conducting an analysis by market and product segment. In this way, it will be possible to more clearly capture differences in the level of environmental uncertainty for saw wood, pulp wood and bio-fuel market segments, for instance.

3.6 Competitive business strategy and supply chain strategy

For all cases, the competitive business strategy of the main actors involved was highlighted. Among the cases, it was clearly seen that the cost-leadership strategy dominates for the cases in Canada, Chile, Poland and US. For the Swedish and French cases, the leading competitive strategy is differentiation. But, it should be noted that the strategy for different market segments (e.g. saw logs and pulp logs) can differ as different product groups are not differentiated in the cases. For instance, a competitive strategy such as cost-leadership is more suitable on a market for mass produced assortment like pulp, while differentiation is more suitable with assortments of higher and more varied product specifications. Moreover, an observation from the last section regarding Chilean case 1 is that evolving in a lower uncertainty environment justifies the adoption of a cost-leadership strategy where the primary drivers (i.e. operational excellence, high productivity, low unit cost) are more likely to be achieved.

The methodology adapted from Yee and Platts (2006) to identify the competitive business strategy and strategic implementation approach by actor was useful to highlight the different choices among the actors within the same supply chain. However, Porter's typology (i.e. cost leadership or differentiation) proved to be too generic even with the extension from Hansen et al. (2006) on the three ways to achieve differentiation. A different approach to address competitive business strategy is discussed in the conclusion.

3.7 Wood supply chain structure

3.7.1.1 Planning and execution processes

The description of the processes in each case allows 17 generic processes to be proposed for any planning and execution process at the operational level in a WSC. Three of them are associated with the procurement of standing/harvested timber, eight with harvesting, five with secondary transportation and one with the sales of harvested timber. Not all processes are used in each case and the type of actor responsible for a specific process is not always the same among the cases.

We can identify three options for the accountability of the planning and execution processes:

1) The planning and execution processes are done internally;

2) The planning processes are done internally and the execution processes are outsourced;

3) The planning processes are shared (internally and outsourced) and the execution processes are outsourced. For a complete table of main accountable in each process, se Table 6 in Audy et al.(2010).

Three basic designs of a planning system in the cases can be identified:

1) integrated sourcing and harvesting planning (Canadian case 15, Polish case 18 and Swedish case 19);

2) integrated harvesting and transportation planning (US case 4 and US case 7);

3) decoupled sourcing, harvesting and transportation planning (Chilean case 1 and French case 11).

Based on the 13 generic planning decisions, a decision matrix is proposed for each planning system design. For more information on the matrix, see table 9 in Audy at al. (2010).

The types of value commitment processes used in each case are reported in

4 All cases use at least two types, but all of them have customers with supply agreements. Even the attributes of the demand in most of these supply agreements could be modified by the wood buyer during the demand fulfilment; the supply agreement reduces planning uncertainty for the wood supplier by reducing the proportion of the total demand that is based on forecasts. Also, all cases, except Chilean case 1, maintain a spot market, mainly to dispose of their harvested volume not sold and capture interesting opportunities with volume not already committed. Finally, there are some value commitment processes that belong to more than one type of value commitment process.

Table 4: Types of value commitment processes.

	Case						
Type of value commitment process	**CL1**	**US4**	**US7**	**FR11**	**CA15**	**PL18**	**SW19**
Long term supply agreement	VC2		VC1	VC1	VC1		VC1
Medium-short term supply agreement	VC1	VC1	VC2		VC2	VC1, VC2	VC2
Continuous business without a supply agreement		VC2	VC2	VC2, VC3			
Spot order		VC2	VC2	VC2	VC2, VC3	VC2, VC3, VC4	VC2, VC3

Legend: Chilean case 1 (CL1); US case 4 (US4); US case 7 (US7); French case 11 (FR11); Canadian case 15 (CA15); Polish case 18 (PL18) and Swedish case 19 (SW19); Value commitment (VC).

2.1.1.1. Harvesting time windows

The decision of when to harvest a block is subject to different considerations, which allow harvesting time windows to be of different lengths. Longer allowed harvesting time windows provide the wood supplier with more flexibility to decide when to harvest the block. **Fehler! Verweisquelle konnte nicht gefunden werden.** 5 shows the harvesting time windows for the cases.

Table 5: Harvesting time windows in the cases.

		Harvesting time windows		
Case	**Block**	**Thinning**	**Clear-cutting**	**Purchasing agreement**
CL1	Radiata pine plantation	2-4 years	4 years	n.a.
US4	Loblolly pine plantation	3 years (1st thinning)	9 years	1-1.5 years after purchase
FR11	Maritime pine plantation	4-5 years	10-15 years	1 year after purchase
CA15	Black spruce natural stand	15 years	≥15 years	n.a.
SW19	Norwegian spruce and Scottish stand	5 years	≥15 years	2 years after purchase

2.1.2. Decoupling points

Seven decoupling points were identified in the cases: Buy block-2O, Select block-2O, Bucking-2O, Primary transport-2O, Merchandising-2O, Measuring-2O, Secondary transport-2O. The decoupling point Bucking-2O applies in the CTL method while decoupling point

Merchandising-2O applies in the FT method. The location of these decoupling points along the material flow is illustrated in **Fehler! Verweisquelle konnte nicht gefunden werden.**8. Depending on whether the material is standing timber or harvested timber in inventory before or at roadside, the seven decoupling points are located in one of the three sections along the WSC: sourcing (i.e. Buy block-2O, Select block-2O), harvesting (i.e. Bucking-2O, Primary transport-2O, Merchandising-2O) and transportation (Measuring-2O, Secondary transport-2O).

The decoupling points used in each case are reported in **Fehler! Verweisquelle konnte nicht gefunden werden.**5. More than one decoupling point is used per case and they are located within at least two of the three aforementioned sections along the WSC. **Fehler! Verweisquelle konnte nicht gefunden werden.**5 also details whether the decoupling point involves a small, medium or large part of the total demand and the value commitment to which the decoupling point is linked. Roughly half of the value commitment processes use more than one decoupling point, which means that inventories located at different steps along the WSC are used to plan the fulfilment of a confirmed demand.

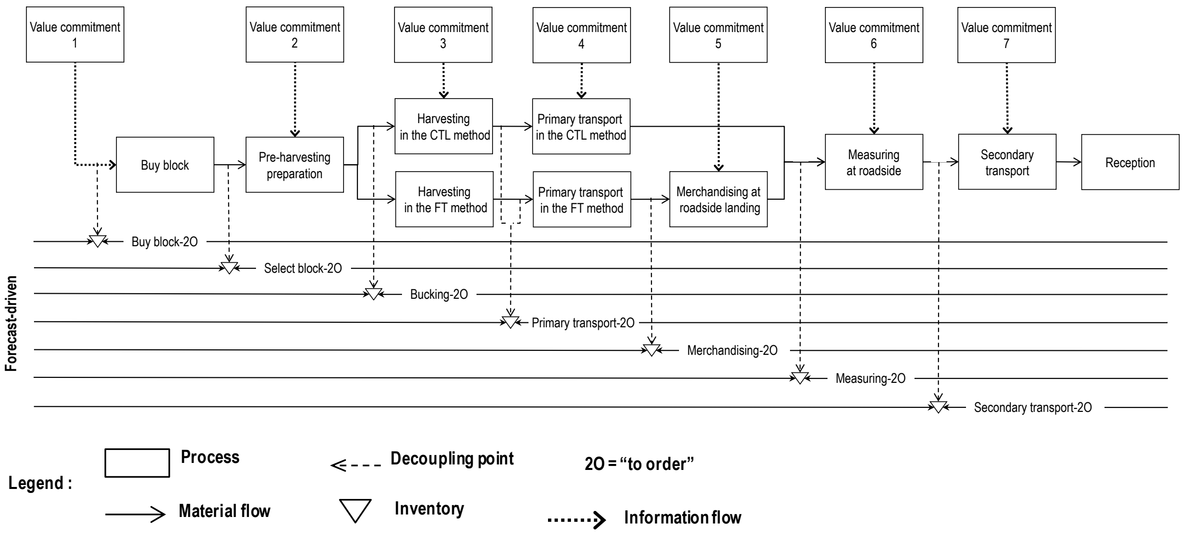


Figure 8: Localisation of the seven identified decoupling points.

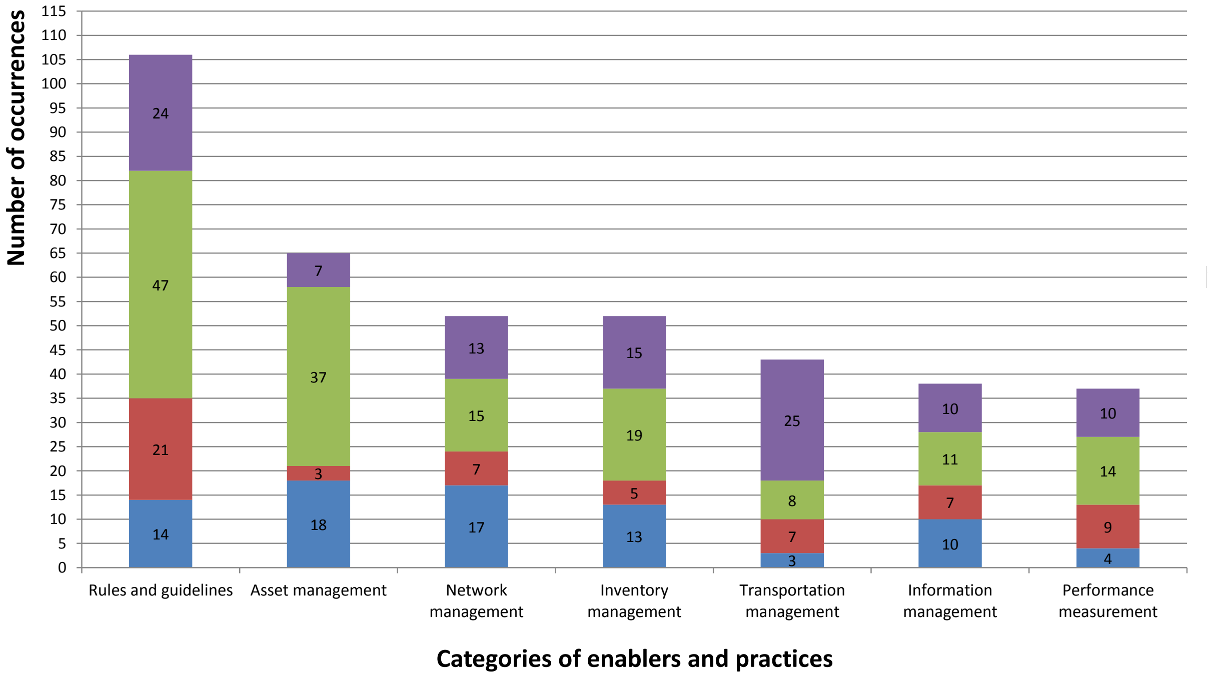
Case	VC	Sourcing		Harvesting			Transportation	
		Buy block-2O	**Select block-2O**	**Bucking-2O**	**Primary transport-2O**	**Merchandising-2O**	**Measuring-2O**	**Secondary transport-2O**
CL1	VC1		+++	+		+		
	VC2		+++					
US4	VC1	++						
	VC2	++				+		
US7	VC1		++					
	VC2		++			+		
FR11	VC1			++				
	VC2				+			++
	VC3							+
CA15	VC1		+++					
	VC2		+	++		++		
	VC3							+
PL18	VC1			+++		+++		
	VC2			++		++	+	
	VC3						+	
	VC4						+	
SW19	VC1	+	+++					
	VC2	+	+	+				
	VC3							+

Table 6: Decoupling points used in each case.

Legend: Chilean case 1 (CL1); US case 4 (US4); US case 7 (US7); French case 11 (FR11); Canadian case 15 (CA15); Polish case 18 (PL18) and Swedish case 19 (SW19); large part of the demand (+++); medium part of the part of the demand (++); small part of the demand (+); Value commitment (VC); to-order (2O)

3.8 Enablers and practices

From a global analysis of the enablers and practices identified in the cases, we can see in **Fehler! Verweisquelle konnte nicht gefunden werden.** that the categories of Rules and guidelines and Asset management had a higher number of occurrences. On the other side, the categories of Transportation management, Performance measurement and Information management had less than 45 occurrences. Along with this, the majority of these occurrences were identified in the Make process (Harvest) for all the categories, with the exception of Transportation management enablers which, for logical reasons, had more occurrences in the Deliver (secondary transport) process.



Legend: Source (blue); Make (green); Secondary transport (purple); Value commitment (Red);
Figure 9: Average agility capability by process within the dimensions.

3.9 Performance

In this component of the framework, the agility and tailoring capabilities were analysed in the cases. They are detailed in the next sections.

2.1.3. Agility capabilities

Supply chain agility capability was measured by an evaluation of the contribution of the enablers and practices identified in the four dimensions of supply chain agility (i.e. Customer sensitivity, Information driver, Process integration and Network integration) in the four macro-processes of Source, Make, Deliver (value commitment) and Deliver (secondary transport). The research team performed the evaluation based on a 0-4 scale, with 0 designating a null contribution and 4 an extremely high contribution. In **Fehler! Verweisquelle konnte nicht gefunden werden.**10, the average results of all the cases are shown by agility dimension and by macro-process. One initial observation is that no dimension showed an impressive result, all agility dimensions obtained similar average results, scoring at a medium level between 2.0 and 2.5.

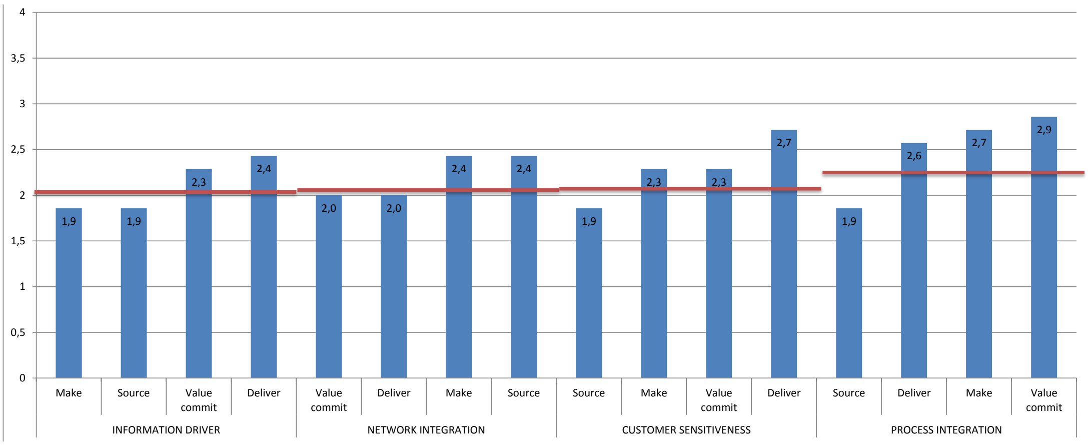


Figure 10: Average agility capability by macro-process within the dimensions.

However, exceptional cases exist, and one example can be seen in **Fehler! Verweisquelle konnte nicht gefunden werden.**10, which shows the scores of each case for the agility dimensions in the Source process. The picture below is also a way of comparing the different cases, agility dimension and macro process.

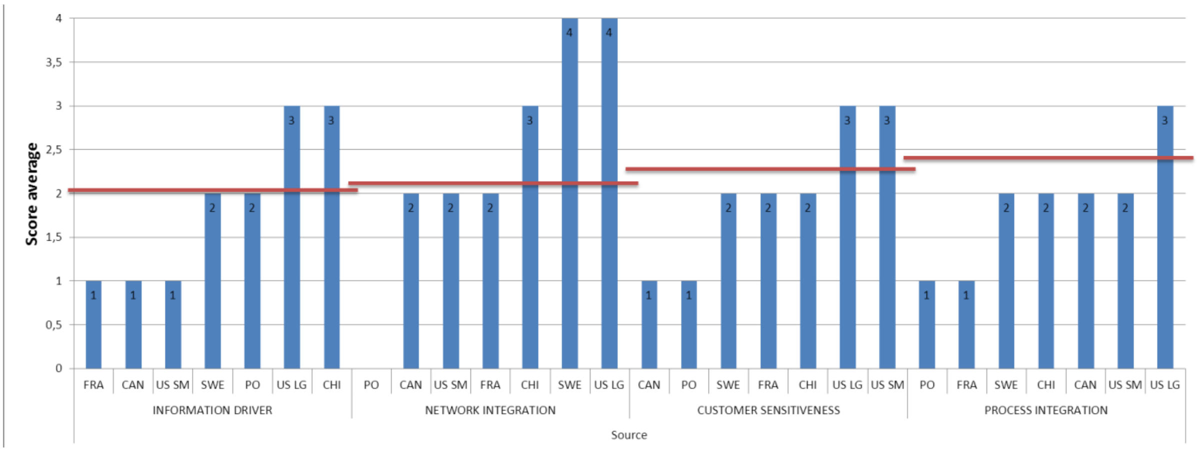


Figure 11: Agility capability by case within dimensions for the Source macro-process.

Based on the level of supply and demand uncertainty of each case (see Section 3.5), three clusters of cases can be made according to their levels of supply (Figure 12) and demand (12) uncertainty. Thus, a case aiming to improve its agility capabilities in the main processes of sourcing timber (source), harvesting (make) and/or secondary transport (deliver secondary transportation), should first review the enablers and practices of the case with higher agility capabilities in these processes that is located within the same clusters of supply uncertainty (11). The same comment applies for a case aiming to improve its agility capabilities in the main process of value commitment by searching for the same clusters of demand uncertainty (12).

According to the general assumption in the literature on supply chain agility, an environment with high uncertainty calls for a supply chain with high agility capabilities. Thus, if we compare agility capabilities evaluated in the cases and those theoretically required according to the level of uncertainty, the case studies show a case (Chilean case 1) with high agility capabilities not required by the level of uncertainty, some cases where the uncertainty level calls for higher agility capabilities (French case 11, Canadian case 15 and Polish case 18 for the supply side) and, finally, cases with agility capabilities relatively well balanced with their uncertainty level (US case 4 and Swedish case 19).

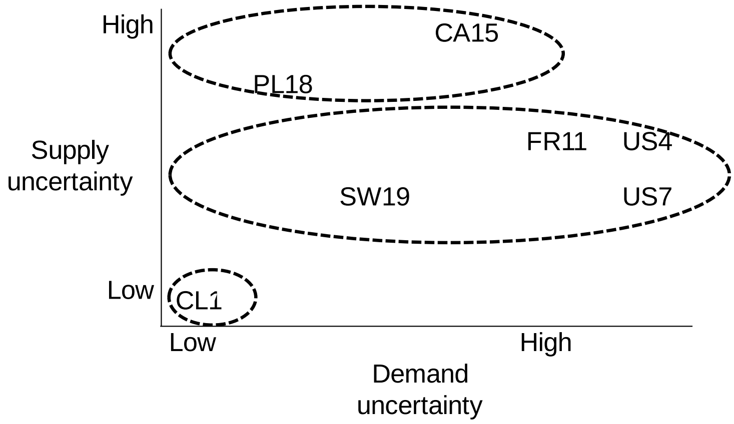


Figure 12: Clusters of cases with similar levels of supply uncertainty.

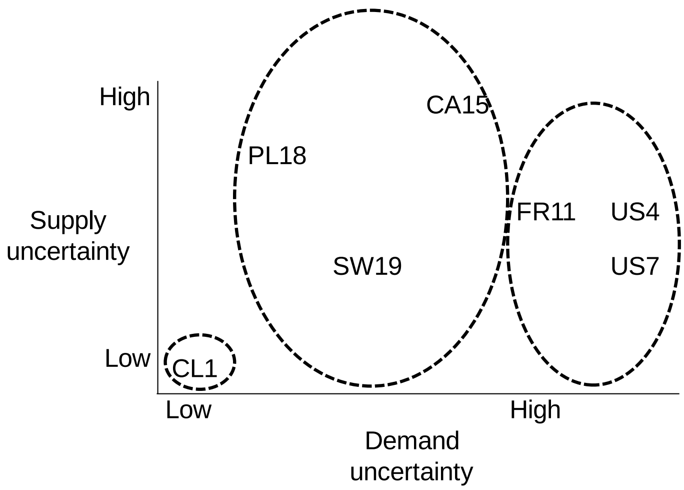


Figure 13: Clusters of cases with similar levels of demand uncertainty.

2.1.4. Tailoring capabilities

Tailoring capabilities were first evaluated based on the location of the decoupling point(s) in each case. It is assumed that the closer the decoupling point is to the sourcing of standing timber, the easier the attributes of a value proposition (i.e. a product and logistics services in a WSC) can be personalised to a customer. For the tailoring capabilities of the product specifications, a crucial process in the material flow can be identified in the cases. This process is Merchandising at roadside landing for the FT method or harvesting in the CTL method.

Indeed, the process represents the main activity along the WSC where a felled tree is processed in one (FT method) or a set (CTL method) of specific products to deliver to the mills. Specialising the work-in-progress inventory into specific end products is a process designated as product differentiation activities (PDAs) in the concept of form postponement (Forza et al., 2008). Form postponement (also termed in the literature as late customisation, delayed product differentiation, postponed manufacturing or manufacturing postponement) consists of delaying one or more PDAs along the manufacturing and distribution process (Forza et al., 2008). The potential capabilities to tailor product specifications before a PDA are superior to the tailoring capabilities after a PDA. The localisation of the two main PDAs along the WSC is illustrated in **Fehler! Verweisquelle konnte nicht gefunden werden.**14.

In the CTL method, the tailoring capabilities of the first three decoupling points (i.e. Buy block-2O, Select block-2O and Bucking-2O) in the material flow are higher to the ones in the three last decoupling points (i.e. Primary transport-2O, Measuring-2O and Secondary transport-2O). In the FT method, the tailoring capabilities of the last two decoupling points (i.e. Measuring-2O and Secondary transport-2O) are lower to the ones in the first four decoupling points (i.e. Buy block-2O, Select block-2O, Primary transport-2O and Merchandising-2O).

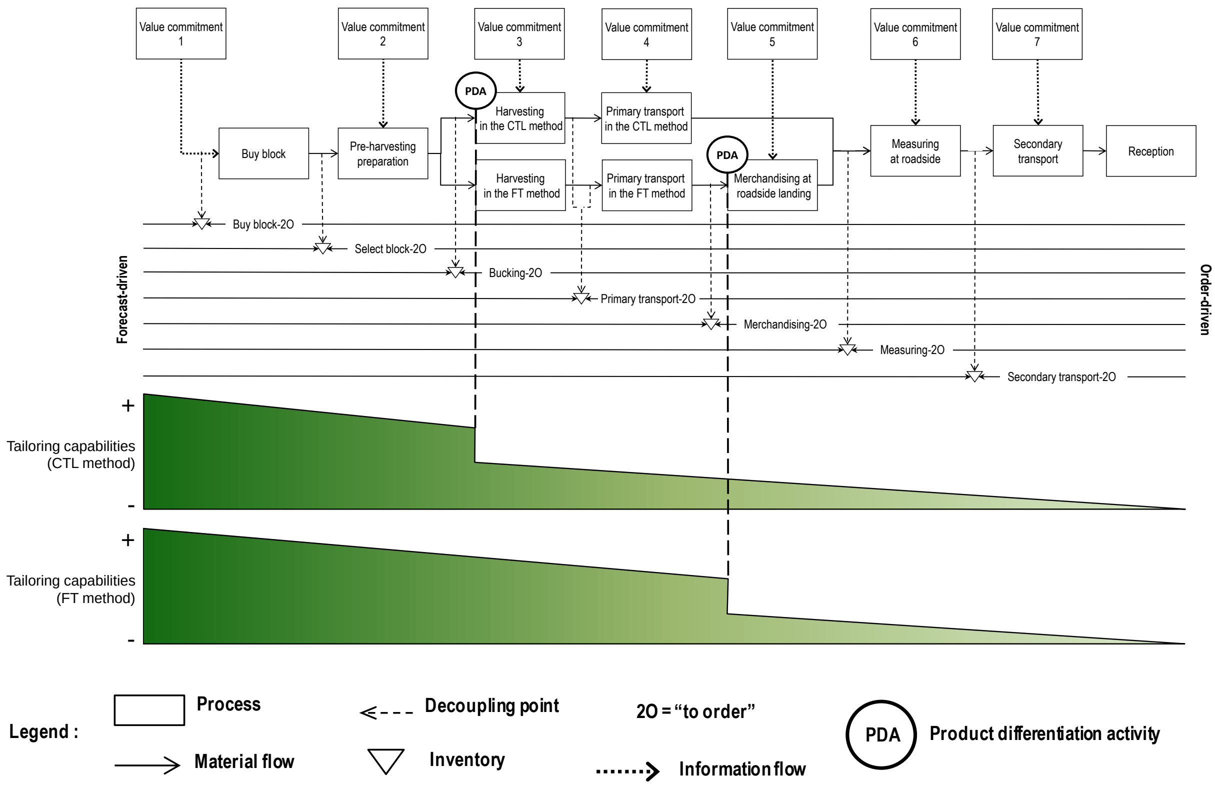


Figure 14: Location of the two main product differentiation activities.

According to the theoretical foundations of form postponement and the gains reported in the literature on case studies in different manufacturing contexts having implemented this concept, a WSC with a long order fulfilment cycle time, short term value commitment and/or short term change in the committed demand should gain from implementing form postponement. In the scope of the WSC study in this project (i.e. the scope ends at the mill yard), we observed the delaying of the PDA on a proportion of the wood flow in one case. In Chilean case 2, the bucking of a proportion of the harvested timber is performed at a bucking plant instead of at the harvesting sites. This delayed PDA is a key process in the overall procurement activities as it absorbs a large part of the production adjustments and thus avoids modification of the bucking/merchandising instructions at the harvesting sites. As a baseline for deeper investigation, the fieldwork allows a first attempt at assortment typology according to the level of tailoring (here, designated as customisation) of its product specifications: the catalogue assortment based on a general set of product specifications (low customisation of product specifications) and the niche assortment based on product specifications personalised to a customer's requirements (high customisation of product specifications). In practice, only the length can be personalised to a customer's requirements in the catalogue assortment, while the other product specifications remain common among several customers. In the niche assortment, most specifications are personalised to a customer's requirements provides additional characteristics of the catalogue and niche assortments.

Tailoring is also linked to a time dimension: how long a customer must wait for an order with personalised attributes. Order fulfilment cycle time refers to the time from the placement of an order by a customer to the fulfilment of the order by the supplier, regardless if it includes only processing time or additional time, because the order was placed well in advance by the customer (Supply Chain Council, 2008). The SCOR model splits the Order fulfilment cycle time into two parts: order fulfilment process time (OFPT) and order fulfilment dwell time (OFDT).

OFPT is defined as the time from the first process to fulfil the demand to the fulfilment of the demand by the supplier. This time includes possible 'idle time' and 'non-value-added lead time' caused by inefficiencies in the organisation.

OFDT is defined as 'any lead time during the order fulfilment process where no activity takes place, which is imposed by customer requirements' (Supply Chain Council, 2008).

6 presents the OFPT and OFDT by case (ranked from the highest to the lowest agility capabilities) and according to the three sections[2].

[2] If a case has a different OFPT (OFDT) between two decoupling points located in the same section, the mimumum and maximum OFPT (OFDT) are reported in the table.

Table 7: Order fulfilment cycle time in the cases.

		Sourcing		Harvesting		Transportation	
		OFPT	**OFDT**	**OFPT**	**OFDT**	**OFPT**	**OFDT**
+ Supply Chain Agility -	**US7**	0.5-1.5 days	A few weeks to months	0.5-1.5 days	≥1 day(s) to a few weeks	n.a.	n.a.
	CL1	10 days	A few months	10 days	A few weeks to months	n.a.	n.a.
	US4	0.5-1.5 days	1-2 weeks	0.5-1.5 days	≥1 day(s)	n.a.	n.a.
	SW19	≤1 month	A few weeks to months	<1 month	A few weeks	≤1 day	A few weeks
	CA15	3-4 weeks	Many weeks to a few months	3-4 weeks	A few weeks	≤1 day	A few weeks
	FR11	n.a.	n.a.	3.5-7 days	2-3 days to a few months	≤1 day	1-3 day(s)
	PL18	n.a.	n.a.	3-9 days	A few weeks to two months	≤1 day	≥1 day(s) to a few weeks

The three cases with the highest agility capabilities did not present a decoupling point located at the end of the WSC (transportation section), while the two cases with the lowest agility capabilities did not present a decoupling point located at the beginning of the WSC (sourcing section). For the decoupling points located in the sourcing and harvesting sections, in general the higher the agility capabilities, the shorter is the average[3] fulfilment cycle time in the section. This is due basically to shorter times in the OFPT, while higher agility capabilities do not impact the OFPT for the decoupling points located in the transportation section. These results reinforce the convergence in the literature that supply chain agility is linked to shorter lead-time.

3.10 Conclusion

We discussed the agility capabilities evaluated in the cases and those theoretically required according to the level of uncertainty in the supply and demand sides. Environments with high uncertainty require supply chains with high capabilities in agility. We did observe two cases with agility capabilities relatively well balanced with their uncertainty levels (US case 4 and Swedish case 19). The results also show a case (Chilean case 1) with high agility capabilities, while its level of uncertainty did not require it, whereas others had lower agility capabilities and experienced high uncertainty levels (French case 11, Canadian case 15 and Polish case 18 for the supply side). The evaluation of the agility capabilities in each case

[3] It is important to note that in the French and Polish cases, even if the OFPT is shorter than a more agile case, the OFDT is generally longer.

allowed us to create a database of several enablers and practices. Potential gains could be obtained in a case by the implementation of enablers and practices observed in other cases. Finally, when comparing the locations of the decoupling point, the agility capabilities and the average order fulfilment cycle time, it was possible to reinforce the results from the literature stating that supply chain agility is linked to shorter lead-time.

For the evaluation of the tailoring capabilities, two processes were identified where most of the product differentiation activities along a WSC occur: the harvesting in the CTL method and merchandising at roadside landing in the FT method. The capabilities to tailor product specifications are superior before rather than after one of these processes. Moreover, a typology of assortments according to the level of tailoring is provided as a baseline for further investigation. The financial incentive to produce a basket of assortments with a higher level of tailoring is discussed.

The framework is useful to public and private organisations interested in a describtion of their WSCs and the capacity to assess its agility and tailoring capabilities. A schematic and functional representation of the wood supply chain(s) to which an organisation belongs will make it easier to understand the constraints and objectives of each actor contributing to its processes. Moreover, such an exercise should ease the introduction of a new actor into the WSC. By assessing the tailoring and agility capabilities of a WSC, the framework can support an organisation in an exercise of self-diagnosis that leads to the identification of improvement opportunities to work on. Moreover, by assessing its WSC according to different scenarios (e.g. introduction of new technology, addition of a new value proposition for customer), an organisation can anticipate the impacts of changes.

Finally, the framework introduced a common vocabulary to be used by researchers and practitioners in different disciplines (e.g. forest engineering, management sciences, industrial engineering). It represents an original attempt to develop a reference model for future research on WSCs. Yet, to have significant impact, it needs to be further disseminated and tested within the respective communities.

We have identified several areas into which our contribution could be further developed. Eleven of those that we consider more important are presented in the extended report (Audy et al., 2010).

4. Harvesting in small private forest ownership in Europe

Set in the context of forest industry, logistic concepts are usually developed for larger entities of forest ownership or integrated forest industry. In order to cope with other property conditions, which account for a large share of the forest resource throughout Europe, it seemed appropriate to investigate specifically how small private forest ownership could be tied to these concepts.

Within Europe the situation regarding small private forest ownership is as diversified as the understanding of small-scale forest ownership itself. Due to privatization and restitution of forest land the number of private forest holdings and the area of forest land under private ownership increased in the last 20 years (Forest Europe, 2011; Hirsch et al, 2007). Currently, the share of private forest ownership in Europe is around 50 % with great variations between countries (Figure 1515).

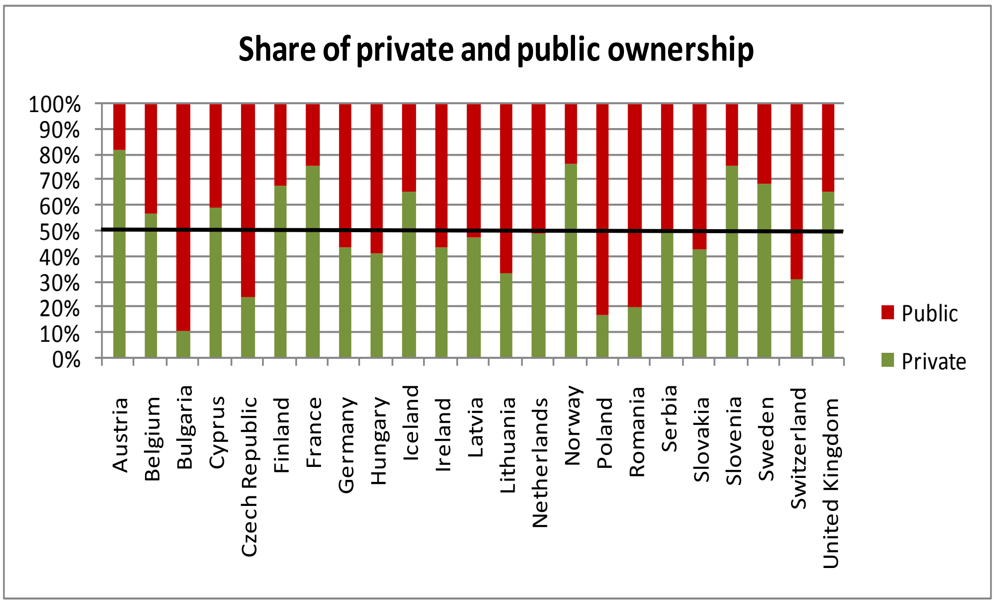


Figure 15: Share of private and public forest ownership according to total forest area in different European countries (UNECE, 2010)

It is estimated that there exist some 15 million small-scale private forest holdings with an average property size ranging from 2 to 4 ha in Belgium, France, Spain and Switzerland to 28 to 53 ha in Finland, Norway and Sweden (Wiersum et al, 2005).

Private forest institutions, particularly individual and family holdings, play an important role in wood harvesting in the private forest sector. The degree of mechanization in timber harvesting varies from country to country as well as inside countries. Apart from local availability of modern timber harvesting technology (harvester-capacity) its application depends on the particular property size since a rational operation of harvesters requires a certain minimum threshold regarding wood quantity. In addition, the layout of the forest parcels can inhibit highly mechanized harvesting. If individual forest property parcels are too small for highly mechanized harvesting, entity and ownership transcending harvesting units can be formed to create conditions for implementing fully mechanized harvesting systems. As a prerequisite, the forest owners have to accept that mechanized harvesting technologies are applied in their forests. However, this procedure requires that respective forest owners are already organized in appropriate forest owner organizations (FOO) or they have at least the readiness for implementing such an approach as it is a necessity to have the particular know-how available.

In the context of task 5200 parameters describing the situation of the private forests in the eight partner countries were collected and compiled in order to measure the possibility of an introduction of the Flexwood concept into the private forest sector due to its great importance by area and the large existing wood potential also in the small scale private forests. This resulted in individual country fact sheets, which describe the frame conditions to implement the Flexwood concept in the medium and small scale private forest holdings and permit estimation, whether Flexwood is suitable for a rational wood supply from the private forest in the individual countries respectively to identify the needed modifications for a successful implementation of Flexwood in small scale forestry.

For the compilation, the importance of the private forests in the specific countries, the actors of private forest management and private owners support, existing wood potentials, data availability, processes of the forest supply chain etc. were taken into account. The fact sheets mirror the situation of the entire countries. Additionally, within the use-case-regions (France, Germany, Poland, and Sweden) the respective regional aspects have been considered. The fact sheets, which are described more closely in chapter 4.2 are based on literature and internet researches, the analysis of existing databases and the conduction of expert interviews.

4.1 Small-scale forestry in Europe

45 % of Europe´s total land area is covered with forests amounting to 1.02 billion ha, of which 83 % are available for wood supply. The distribution of forest area within Europe is highly variable, ranging from three quarters of the land area in Finland to only 11 % of the land area in Ireland. The size of the public and the private forest area in Europe are both around 100 million ha, excluding the Russian Federation (Forest Europe, 2011).
In terms of numbers small-scale forest holdings dominate in Europe. According to a survey in 23 European countries (Schmithüsen and Hirsch, 2011), 61 % of private forest holdings have an area of less than 1 ha and 86 % belong to size classes of up to 5 ha. Only 1 % of the private forest owners (PFO) have forest units with an area beyond 50 ha. As already mentioned, the situation is very heterogeneous among countries (e.g. Wiersum et al, 2005; Nijnik et al, 2009; Hirsch et al, 2007). Since most of PFOs own relatively small properties, their share of forest land in relation to the total private forest area, as well as total forest area respectively, is quite low (see 14).

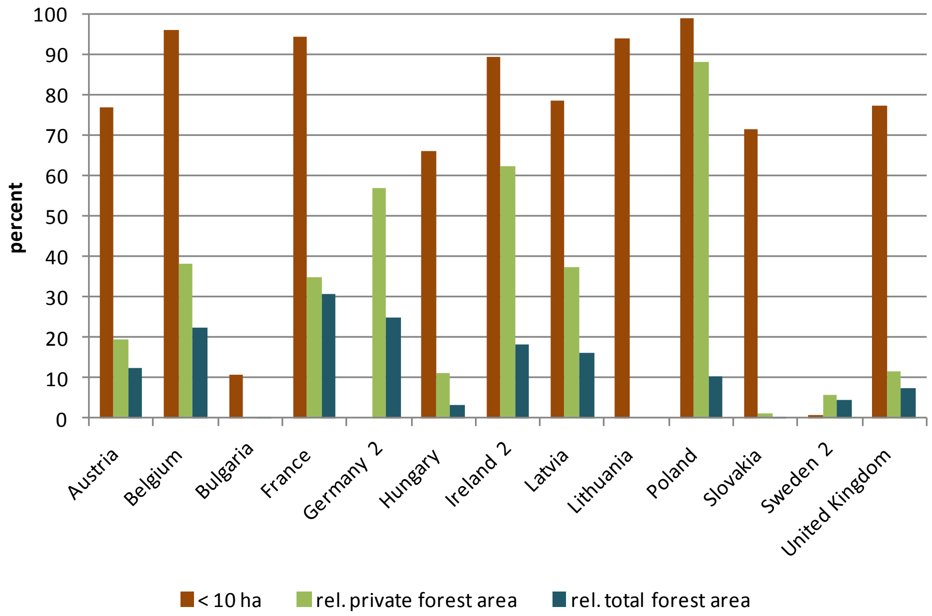


Figure 16: Share of PFOs (number) with a property size < 10 ha (² < 20 ha) and corresponding forest area in relation to total private forest area and total forest area per country (UNECE, 2010; Viergutz et al, 2011)

Apart from Bulgaria and Sweden the relative number of PFOs with a property size of less than 10 ha is mostly around 70 % and beyond. Despite there are numerous small private forest holdings, their share of forest area in relation to the total forest area in private ownership is rather low. Only in Poland, where public ownership dominates, the ratio is nearly balanced. In Germany, Ireland and Sweden data for this size class do not exist, thus these countries are reported in the next one (< 20 ha). It is estimated that there are approximately 2 million private forest holdings in Germany. As the share of PFOs with larger properties than 50 ha is below 1 %, owning 35 % of the private forest land, it is obvious that most individuals belong to the size class < 10 ha (Viergutz et al, 2011). In Sweden, on the other hand, the relevance of PFOs with a forest area < 10 ha seems to be negligible.

4.2 The situation in the Flexwood partner countries

The possibilities for implementing the Flexwood concept in the private forests depend on the situation and circumstances of private forests in the partner countries and in particular in the use-case regions. Apart from the question, whether and in which form remote sensing and inventory data of the private forests are available, it must be clarified, whether it is possible to deploy modern timber harvesting methods in these forests. On the basis of specific country fact sheets on private forestry, conducted within the project, a detailed overview of the situation in the eight partner countries has been elaborated in task 5200.

As already discussed on a European level, the situation regarding private forest ownership in the partner countries is significantly different too. The share of private forests (for detail see Fig. 1 above) in the entire forest area ranges from 17 % in Poland to 81 % in Austria. In terms of numbers the private forest area exhibits as follows (see Table 8).

Table 8. Total forest area (ha) and total private forest area (ha) in the partner countries (Viergutz et al, 2011)

Country	Total forest area (ha)	Total private forest area (ha)
Austria	3 609 856	2 912 918
Finland	22 156 000	15 168 000
France	14 802 000	11 037 000
Germany	11 084 799	4 832 722
Ireland	668 000	278 000
Norway	9 683 000	8 321 000
Poland	9 200.000	1 590 000
Sweden	22 543 000	16 999 000

Respective national circumstances the importance of private forest ownership in each country proves to be highly variable. Despite this, their relevance in relation to wood mobilization and the supply of wood processing industries on a European level cannot be neglected.

The ratio between annual increment and felling is commonly used to characterize the potentials of domestic wood supply. In the European region, approximately 40 percent of the increment is utilized (Forest Europe, 2011). In all countries where data is available (i.e. except Ireland and Poland), the ratio between gross annual increment and fellings (i.e. utilization rate) is well balanced in accordance to this sustainability paradigm. Nevertheless, there exist notable differences between countries. A comparison of the utilization rate in European countries showed similar results (Schmithüsen and Hirsch, 2010). In general, the utilization rate in public forests is higher than in private forests.

In the northern European countries (Finland, Norway and Sweden) timber harvesting in private forests is done fully mechanized predominantly, by harvester and forwarder. The situation is completely different in Poland and also in Austria where motor-manual harvesting methods, e.g. by chainsaw and skidder, dominate (BMLFUW, 2010). In France and Germany the distribution of both systems, fully mechanized or motor-manually, is nearly balanced. The use of modern harvesting technologies is not only restricted to regional availability of the technology itself. Minimum thresholds regarding the degree of capacity utilization with regard to economic aspects, forest parceling and numerous aspects according to specific regional structures (e.g. topology, labor force, degree of organization, individual know-how) may be limiting factors for the use of this technology. Beside this it is highly dependent from the forest owner´s willingness to deploy highly-mechanized harvesting technologies. Attitudes towards risk and respective management behavior of private forest owners may differ significantly due to a shift in the dependence on forest resources, existing values towards their own forests and increasing mobility throughout small-sized European private forest ownership (e.g. Andersson, 2012; Schraml et al, 2004; Lidestav and Ekström, 2000). The degree of organization and thus declared intention to participate in the marketing of forest resources may be used to indicate the prospect of success of the integration of small forest holdings in novel logistic concepts.

As described by Weiss et al (2011) forest owner organizations (FOO) are understood as forest owner associations (FOA) and forest owner cooperatives (FOC) and are based on non-state and non-industrial private forestry. Within the partner countries the share of PFOs in FOCs ranges between 3 % in France and 45 % in Sweden. The number of cooperatives per country ranges widely; with e.g. up to 4550 in Germany.

4.3 Wood supply from small non-industrial private forests

The importance of private forest owners in the context of wood mobilization due to increasing wood demand in the next decades, as indicated in different studies (e.g. UNECE, 2011), raises awareness to decision makers for integrating these stakeholder groups into novel systems like the Flexwood approach. The situation regarding small privately owned forest within Europe is highly variable with substantial differences within regions, countries and even intra-national. This divergence is reflected in the countries where the demonstration cases are implemented as well. A brief overview of the situation in the specific regions is given below (see table 9). As there is no private forest in the Polish Use Case region this partner country is not incorporated.

Table 9. Overview of typical wood supply from small non-industrial private forests in the use cases per country (Vuillermoz et al, 2011)

Country	Property size [ha]	Sale type	Sale volume/ PFO [m³]	Logging type	Customer
France	> 15	Standing timber	500	Fully-mechanized	Regional
Germany	4.5	Roadside	40	Motor-manually	Local
Sweden	20 - 50	Standing timber	50 - 1000	Fully-mechanized	Regional

4.4 Integrating private forest ownership into novel logistic concepts

The divergence regarding small private forest ownership throughout Europe is high, not only due to variable definitions of small-scale forestry within European countries (Wiersum et al, 2005). Thus regional circumstances need to be considered and have to be scrutinized case by case to see how small non-industrial private forest ownership can be integrated in advanced harvesting and logistic concepts such as Flexwood. This relates to the widely discussed topic of wood mobilization and constraints in private ownership, which arises amongst others from the fact that for instance in Austria and Germany the ratio between increment and felling is significantly higher in small private forests than in larger properties.

Novel logistic concept are particularly attractive where forest function and ecosystem services are segregated from each other (e.g. plantations) and in timber-oriented, highly mechanized forestry regimes with high levels of accessibility and infrastructure. Furthermore up-to-date inventory and mechanized harvesting systems are prerequisites for advanced data acquisition and transfer, while small holdings lack detailed inventory data and restrict the use of mechanized harvesting systems for various reasons. This may inhibit their participation in advanced wood supply chain systems and may restrict their market access

However, there remain other possibilities. Cooperatives can play an important role as providers for the required knowledge, services and technology. In addition, the modules of Flexwood separately offer large potential for the wood mobilization from small private forests. This is for example the case for the application of novel technologies for forest inventory and the web-based platform approach. These can furthermore be possible tools visualize the potential benefit of the utilization of their forest resource and stimulate forest owners to consider harvesting. This may be especially well-suited to address younger generations of forest owners, which will be an increasingly important aspect in the next years, but is certainly not limited to that.

5. Allocation procedures

With its main objective of illustrating procedures and processes for the allocation of forest raw material to the industry, this chapter builds the link between industry and forestry. Starting from the industrial requirements it follows the concept of demand-driven wood procurement and relates these back to forest inventory. Therefore it describes and structures the data on industry requirements towards forest raw material on the one hand and of the forest resource from novel inventory technology on the other. As not all resource parameters, which are required for a pre-harvest allocation to the industry, can be derived from the data acquired by these technologies directly, special attention is given to the deduction of missing data.
Technically different inventory concepts have been alternatively developed in the Flexwood project and are applied in the different use cases. Therefore the matching procedure may (technically) differ from case to case. Here, the "Central European Case" is presented in detail as an example model case to describe the conceptual procedure. In addition, the "Nordic perspective" is presented hereafter.

The allocation of forest raw material to industry based on remote sensing technology requires and has been accomplished according to the following main steps:

5.1 Identification of industrial requirements

Information about industry requirements in the procurement of raw material has been collected together with WP3000 through inquiries and expert interviews. Specific requirements tables have been created based on standards as well as numerous interviews and roundwood procurement specifications from several companies in Germany, Poland, Finland, Sweden and France. The results show, that industrial requirements are based and expressed towards the intake product, which can be either single logs or batches of logs with average or specified distribution of requirements, depending on the industry or the final product.

5.2 Structuring of industrial requirements

From the enquiries in collaboration with WP3000 and WP6000 three hierarchical levels could be distinguished for the description of industry requirements. These levels are in descending order

- Category,
- Parameter and
- Value

Three main requirement categories can be differentiated: Species, dimension and quality. For each of these categories, the parameter and their respective specific minimum or maximum threshold values may differ between species, product or industry types and companies as a consequence of market differentiation and mill size. The sawmilling industry has been chosen to serve as an example to describe the industrial requirements in the following chapters as it has the most specific demands, whereas the pulp paper and fiber industry as well as the energy industry follow the same concept, but with a lower grade of complexity and with less detailed parameters.

5.2.1.1 Species

Defined tree species is one of the major requirements of the industry (cf. Flexwood Deliverable D 3.1). Different tree species show different properties regarding processing and use and thus industrial requirements may differ between species. In some cases, industry forms species groups with similar raw material characteristics regarding their product. These are e.g. white softwood (Spruce/ White Fir) versus colored softwood (Pine / Douglas Fir / Larch).

5.2.1.2 Dimensional requirements related to logs

The log dimension requirements of sawmills depend on the sawing technology and the product to be produced from the roundwood. However, sawmills usually specify their requirements regarding accepted log dimensions either by indicating a defined value, a value range or minimum or maximum values for the following dimensional parameters:

- log length (fixed or range of values)
- diameter (range of accepted small end, large end or mid diameter values)
- taper (maximum values)

All dimensional requirements have in common that they are quantifiable and measurable. In addition they can be assessed on the exterior both pre-harvest on standing timber and on logs after harvest.

Table 10Example of saw log dimension requirements (PNSY, Germany)

parameter (e.g. diameter, knottiness, taper, moisture content,…)	description of parameter	reference unit	specific values (min, mean, max,…) type		required data type (e.g. measured, predicted, direct, indirect, …)	required level (e.g. stand level, tree level, batch level, …)
			type	type		
			min	max		
diameter	top diameter	centimeters [cm] over bark	13	55	measured	log level
diameter	butt diameter	centimeters [cm] over bark		55	measured	log level
length	log length	decimeters [dm] including cross cut allowance	31	44	measured	log level
taper		millimetres per linear meter [mm/m]	0	20	measured	log level

Fehler! Verweisquelle konnte nicht gefunden werden.**9** gives an example of German saw log dimension requirement parameters and the related values for Pine (PNSY) specifying an accepted range of top diameters by indicating both minimum and maximum top diameter, the maximum butt diameter, the accepted log lengths and the maximum taper.

5.2.1.3 Quality requirements

The quality of the product (sawn timber) to be processed depends on the interior quality of the log. As this interior quality of the wood can ultimately only be determined in the mill after sawing, exterior parameters are assessed to derive it at an earlier stage. Therefore the third category of industrial roundwood requirements are those related to the quality of the roundwood (logs). This refers to the knottiness, sweep, shakes, damages and so forth. An example of a set of quality parameters and the related values is given in

11 for German Pine (PNSY) saw log quality requirements.

Table 11 Example of saw log quality requirements (PNSY, Germany)

parameter (e.g. diameter, knottiness, taper, moisture content,…)	description of parameter	reference unit	specific values (min, mean, max,…)		required data type (e.g. measured, predicted, direct, indirect, …)	required level (e.g. stand level, tree level, batch level, …)
			type	type		
			min	max		
sweep	smooth sweep of log	millimetres per linear meter [mm/m]		30	visually estimated	log level
sound knot	size of knot	millimetres [mm]		80	visually estimated	log level
dead knot	size of knot	millimetres [mm]		70	visually estimated	log level
rotten knot	size of knot	millimetres [mm]		40	visually estimated	log level
rot		allowed / not allowed		0	visually estimated	log level
ring shake		% of log top diameter		25	visually estimated	log level
star shake	size of shake	% of log top diameter		50	visually estimated	log level
crook		allowed / not allowed		0	visually estimated	log level
insect damages		allowed / not allowed		0	visually estimated	log level
discoloration		allowed / not allowed		0	visually estimated	log level

Quality requirements include parameters assessable on either the exterior of the logs or trees (e.g. sweep, knots, damages) or only on the cross-cut face of logs (e.g. rot, shakes discoloration). As a consequence, only those parameters assessable on the exterior can be used directly for the assessment of the quality of standing timber. Knots are among the most important quality parameters of the sawmill requirements and together with sweep, taper and scars they are the only ones that are measurable and quantifiable on the exterior of the roundwood. Enquiries showed that most mills' requirements are based on and very much in line with the EU Standard EN 1927 allowing e.g. regarding knottiness certain maximum values of knot diameters in different roundwood quality classes.

5.3 Acquisition of forest resource information with remote sensing technology

In contrast to the industry requirements on roundwood, which are usually stated on log or batch level, forest resource information is typically on stand (= population of trees with average or specified distribution of attributes) or sample tree level. Forest resource information therefore needs to be expressed according to the same categories species, dimension and quality as a prerequisite for the matching with industry requirement. The various technologies applied in FlexWood each are useful to assess a certain set of parameters. A comprehensive table listing numerous parameters for the description of the forest resource has been compiled in order to investigate together with WP 4000 which inventory based information is available or could potentially be made available from which data source in the use cases. From this list it is possible to identify those parameters which are required or useful to support the matching with industry (i.e. sawmill) requirements.

Forest resource information from the uneven-aged forests of the Central European use case with a species mix of dominantly Scots Pine (PNSY) and European Beech (FASY) serves as example.

Table 12Source of origin and availability of information on forest resource (Central European Use Case)

Category	Parameter	Terrestrial inventory	ALS	TLS
		Sample plot	Full area	Sample plot
Species	Species	**X**[1)]	(X)	(X)
Dimension	Tree height	(X)	**X**	-
	Crown base height	(X)	**X**	X
	Crown radius/ diameter	(X)	**X**	(X)
	Diameter at breast height (dbh)	X	-	**X**
	Diameter at height 7m (D7)	X	-	**X**
Quality	Taper	-	-	**X**
	Sweep	-	-	**X**
	Branch height	-	-	X
	Branch base diameter	-	-	X

[1)] Primarily used for calibration and validation

Fehler! Verweisquelle konnte nicht gefunden werden.12 illustrates, that the additional value of the laserscanning technologies applied in FlexWood for the forest resource assessment results from the combination of the acquired data, which can replace or support traditional terrestrial inventory methods. Species represents the only parameter not assessable from laserscanning, at least in mixed stands. However, differentiation between species groups, more precisely between coniferous and deciduous trees, can be achieved already today also from ALS data analysis. The use of hyperspectral imagery as well as the future development of bark structure detection from TLS may further reduce this current limitation. The combination of ALS and TLS derived information requires substantial pre-processing and is realized by fusion of the data on a tree by tree basis, which is described in the Deliverables D4.1 and D5.2 as well as 8.1 for the Central European Use Case.
Information on the two categories ‘species’ and ‘dimension’ are very important for an efficient roundwood allocation to industry, but they offer only a limited possibility for improvement if not accompanied by information on ‘quality’. Sweep, taper and most importantly branchiness/knottiness are the most important quality parameters accounting for a large proportion of the reasons for downgrading logs. In addition, they are assessable externally, on standing timber as well as on logs.
Sweep and taper are quantifiable log quality parameters, which are derived from dimensional data and directly measurable in the TLS point cloud. They can be derived automatically, e.g. using the algorithms applied in the AutoStem software.
Knottiness, a key wood quality parameter (Sauter et al. 2009), cannot be assessed or derived fully automatically from TLS data. However, it is feasible to retrieve this tree quality information from TLS at the sample plot level. Here, the most important parameter for an external quality assessment is branchiness.

A first step in deriving branchiness data from ALS/TLS datasets has been achieved by manually measuring branches on a tree by tree basis from visualization of the TLS data-generated point cloud with automated colour marking of the main stem, branches and live crown (**Fehler! Verweisquelle konnte nicht gefunden werden.**17).

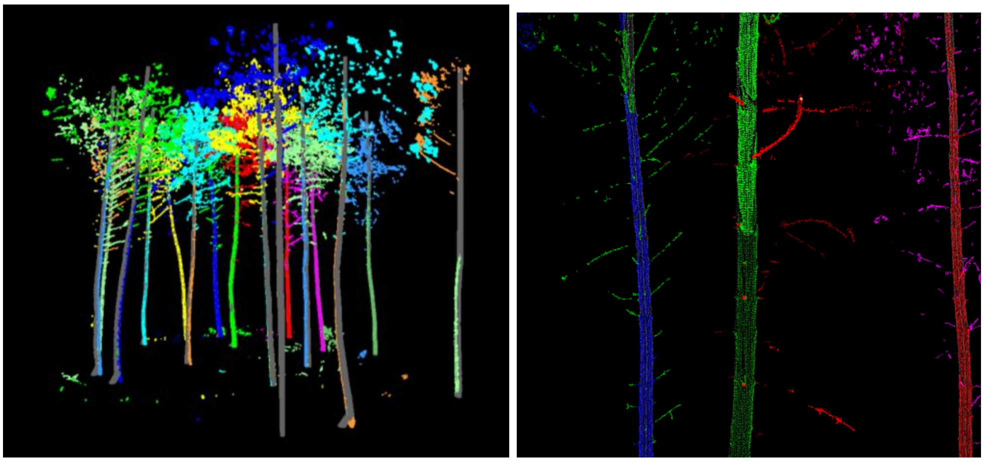


Figure 17. TLS images of a sample plot with colour marking of stem and branches (left). Branches are clearly detectable and measurable in the TLS point cloud (right).

For each visible branch, data on its diameter at the base and its position and angle in relation to the horizontal plane can be recorded for each tree in a sample plot. For these data, allometric functions can be used to predict roundwood quality parameters. Further programming efforts are necessary to establish a fully automated branch detection procedure.

Figure 18. Example of allometric functions: Branch diameter over bark at different distances from the branch base (left) closely related to the knot diameter of the log (right), relevant for grading (Graphics: R. Seipp 2012).

As one important prerequisite for the branch diameter prediction an allometric relationship has been established for spruce as an example between diameters at different distances along the branch from the branch base (which can be detected and measured with TLS) and the knot diameter on roundwood logs, which is relevant for log grading (Figure 18).

5.4 Matching of forest resource information with industrial requirements

After derivation of quality parameters and fusion of data sources the generation of tree lists is the next step. Tree lists compile and translate all relevant forest resource information into a format which corresponds to industry standards of raw material requirements. The forest resource data including those parameters, which are relevant to the industry in these lists is formally structured. **Fehler! Verweisquelle konnte nicht gefunden werden.**2 shows an example of such a tree list.

Table 13. Example of a tree list

Tree # #	Geo coord. x [m]	Geo coord. y [m]	Dia bh [cm]	D 7m [cm]	Height top [m]	Length crown [m]	Height cr.Base [m]	Species code #	Length stem [m]	Dob mid [cm]	Dub mid [cm]	Dub top [cm]	Vol sub [m³]
1	3458005,55	5435405,39	23,3	20,5	19,20	6,67	12,53	PNSY	12,67	20,92	19,74	14,25	0,36
2	3458009,40	5435406,33	20,7	15,9	19,62	12,39	7,23	PNSY	8,53	17,60	15,96	14,15	0,19
3	3458013,16	5435404,82	29,0	24,6	22,39	4,90	17,49	PNSY	16,41	23,77	22,43	14,25	0,63
4	3458012,39	5435396,40	23,0	20,7	21,69	10,56	11,13	PNSY	14,19	20,65	19,48	14,25	0,40
5	3458007,32	5435396,73	29,0	24,6	21,82	4,20	17,62	PNSY	15,69	23,58	22,25	14,25	0,76
6	3458003,37	5435394,24	28,5	23,1	20,55	9,69	10,86	PNSY	14,61	22,87	21,58	14,25	0,53
10	3457991,42	5435402,00	26,3	21,0	19,34	10,87	8,47	PNSY	12,98	21,38	20,17	14,25	0,41
12	3457994,14	5435408,88	27,2	23,4	19,73	5,77	13,96	PNSY	14,20	23,33	22,01	14,25	0,51
13	3458000,73	5435404,15	22,9	19,6	19,64	9,04	10,60	PNSY	12,37	20,10	18,96	14,25	0,33
14	3457998,28	5435408,52	26,2	19,6	19,40	4,02	15,38	PNSY	12,21	20,28	19,14	14,25	0,37
15	3458001,73	5435408,53	31,5	25,0	20,59	10,47	10,12	PNSY	15,24	24,47	23,09	14,25	0,64
1	3456404,02	5433007,51	53,2	35,6	26,19	4,06	22,13	FASY	24,10	32,14	30,96	9,42	2,07
2	3456412,14	5432998,29	50,9	44,1	28,13	7,84	20,29	FASY	26,26	39,83	38,42	9,42	2,86
5	3456401,42	5433005,30	59,4	52,4	27,00	4,03	22,97	FASY	19,25	50,70	49,00	36,55	3,63

The allocation of the right harvestable stand for a given demand, where the requirements on the categories species, dimension and quality are best met, requires a matching procedure. In this procedure information on industry requirements is compared to the information on the available forest resources.

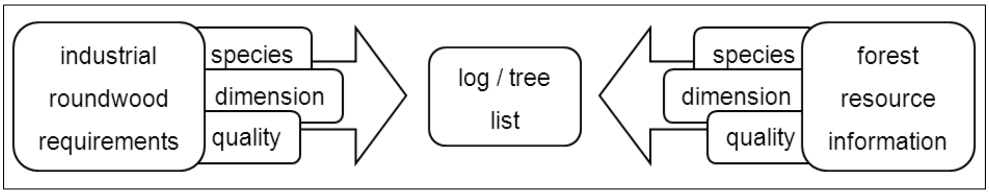


Figure 19: Matching procedure

Figure 19 illustrates this matching procedures: forest resource data are sorted according to the same structure as the industrial requirements, which results in tree lists for each harvestable stand. Each tree list is converted into log lists, containing the logs that comply with the roundwood requirements of the industry. This conversion can be performed by existing simulation software (bucking simulation). In the Central European Use Case, *Holzernte* software is used, as it has been developed specifically for the prevailing forest and market conditions of southwest Germany. **Fehler! Verweisquelle konnte nicht gefunden werden.**14 shows an example of such a log list with a selection of the parameters and the resulting quality grade.

Table 14. Example of a log list

Log #	Species code	length [m]	allow. [m]	mid Dub [cm]	top Dub [cm]	Vol sub [m³]	Taper [mm/m]	Quality	Grade
1	FASY	25,8	0	38,44	10,50	3,00	21,64	Ind	Ind
4	FASY	9,3	0	32,22	10,50	0,76	34,76	Ind	Ind
3	FASY	18,3	0	29,63	10,50	1,26	12,42	Ind	Top log
1	FASY	5,1	0,2	54,09	51,83	1,17	8,87	Saw B	Butt log
2	FASY	5,1	0,2	50,09	48,27	1,01	6,98	Saw B	Top log
1	FASY	5,1	0,2	43,85	37,04	0,77	26,72	Saw C	Butt log
3	FASY	5,1	0,2	45,94	43,00	0,85	10,34	Saw C	Top log
2	FASY	2,5	0,2	34,72	33,26	0,24	15,09	Saw C	Top log
4	PNSY	3	0	13,30	11,26	0,04	12,89	Ind	Ind
4	PNSY	3	0	14,27	11,51	0,05	17,30	Ind	Ind
4	PNSY	2	0	13,06	11,45	0,03	15,84	Ind	Ind
3	PNSY	2	0	13,64	13,00	0,03	6,42	Ind	Ind
4	PNSY	2	0	12,28	11,47	0,02	7,63	Ind	Ind
4	PNSY	2	0	14,10	12,37	0,03	17,01	Ind	Ind
4	PNSY	2	0	12,73	10,79	0,03	18,94	Ind	Ind
4	PNSY	2	0	12,28	10,77	0,02	14,83	Ind	Ind
4	PNSY	2	0	12,63	11,13	0,03	14,51	Ind	Ind
4	PNSY	2	0	13,75	11,63	0,03	20,67	Ind	Ind
1	PNSY	5	0,1	25,41	23,68	0,25	6,90	Saw B	Butt log
1	PNSY	5	0,1	20,65	19,71	0,17	3,77	Saw B	Butt log
1	PNSY	5	0,1	25,45	23,70	0,25	6,98	Saw B	Butt log
1	PNSY	5	0,1	24,53	22,40	0,24	8,51	Saw B	Butt log
1	PNSY	5	0,1	20,18	18,84	0,16	5,36	Saw B	Butt log
1	PNSY	5	0,1	26,91	24,36	0,28	10,20	Saw B	Butt log
1	PNSY	4	0,1	21,05	20,20	0,14	4,24	Saw B	Butt log
1	PNSY	4	0,1	17,72	16,00	0,10	8,58	Saw B	Butt log
1	PNSY	4	0,1	22,40	20,01	0,16	11,96	Saw B	Butt log
2	PNSY	5	0,1	22,69	20,93	0,20	5,50	Saw B	Top log
2	PNSY	5	0,1	22,68	20,83	0,20	5,75	Saw B	Top log
2	PNSY	5	0,1	21,22	19,23	0,18	6,34	Saw B	Top log
2	PNSY	4	0,1	19,76	18,48	0,12	4,30	Saw B	Top log
3	PNSY	4	0,1	16,73	14,61	0,09	9,67	Saw B	Top log
2	PNSY	4	0,1	15,39	14,28	0,07	4,30	Saw B	Top log
2	PNSY	4	0,1	19,38	18,27	0,12	3,61	Saw B	Top log
3	PNSY	4	0,1	16,80	15,13	0,09	7,86	Saw B	Top log
1	PNSY	5	0,2	22,48	20,40	0,20	8,31	Saw C	Butt log
1	PNSY	5	0,1	24,14	22,58	0,23	6,22	Saw C	Butt log
3	PNSY	5	0,1	18,61	15,77	0,14	10,32	Saw C	Top log
2	PNSY	5	0,1	21,50	19,34	0,18	6,48	Saw C	Top log
2	PNSY	5	0,1	18,01	16,18	0,13	5,31	Saw C	Top log
2	PNSY	5	0,1	22,95	20,77	0,21	7,17	Saw C	Top log
2	PNSY	4,5	0,2	19,35	17,55	0,13	6,34	Saw C	Top log
3	PNSY	4,5	0,2	15,10	11,68	0,08	13,06	Saw C	Top log
3	PNSY	4	0,1	18,88	16,70	0,11	10,33	Saw C	Top log
3	PNSY	4	0,1	17,31	14,58	0,09	11,64	Saw C	Top log
2	PNSY	4	0,1	19,00	17,56	0,11	6,12	Saw C	Top log
3	PNSY	4	0,1	15,91	14,03	0,08	8,82	Saw C	Top log
3	PNSY	4	0,1	18,73	15,76	0,11	12,52	Saw C	Top log
3	PNSY	2,4	0,1	17,90	16,51	0,06	11,82	Saw D	Top log
4	PNSY	2,4	0,1	14,43	12,16	0,04	18,10	Saw D	Top log
3	PNSY	2,4	0,1	14,97	13,73	0,04	10,22	Saw D	Top log

The logs can subsequently be sorted according to actual demand which allows the right products to be allocated to the right mills depending on the respective requirements.

5.5 Allocation procedures from a Nordic perspective

A lot of the information given above is relevant for the Nordic perspective as well. Though it is of decisive importance to keep in mind that wood allocation possibilities are based on a market. Below some basic statements concerning the market impact and possibilities to make it more efficient are presented.

In principle allocation of wood is judged by agreements between buyers and sellers, i.e. market operators at regional markets. Integrated forest and industry companies may put internal priority on allocation of their own forest resources but integrated or non-integrated forest companies as well as private forest owners are always dependent on their competitiveness at the market. Buyers judgments of competitive and effective price offers regarding different stands, trees, assortments, log dimensions and grades are important components. Beside the wood pricing, different costs for transportation to industry but also differences in cost for the purchasing and harvesting processes will affect the competitiveness of different offers and sellers willingness to sell.

The technical development of tools that can help market operators to get a better picture of their own as well as potential sellers are important parts of the Flexwood concept. Laser scanning, standardized (e.g. StanForD2010) production files from previous harvesting operations of similar stands, stem banks, conventional inventory methods and national forest inventories are all sources that may be used when considering allocation preferences from different market operators point of view (industry companies, forest companies, forest owners or logistics providers), The more accurate information of the stand the lower cost for operational inefficiency and risk has to be calculated. In principle improved information accuracy will add total value to the sum of value chains, more value to share between the operators at the market and opportunities to reduce environmental load. The strength of this concept will be dependent on:

- the market situation and existing industrial competitors and co-operators in a region
- the present knowledge concerning existing and potential interrelationship between forestry and industry, i.e. possible integration
- the information quality concerning the variables needed to utilize knowledge.
- the market operators ability to exploit present knowledge and develop their business in the most efficient ways
- further development of knowledge and action

Different parts of this concept are presented in deliverables D3.1 (Bajric et al 2010), D4.1 (Vauhkonen et al. 2012), D5.3 (Opferkuch et al. 2012), D6.4 (Usenius et al 2012) and in other chapters in this deliverable. The technical parts concerning improved production control in harvesters including bucking and fleet management facilitated by new standards are presented in detail in chapter 4, Work package 5400. Some other possibilities to improve tools to improve market driven allocation are presented as bullet points in

15.

Part of the suggestions can be introduced soon while most will need the improved knowledge stated above concerning the actual industrial values from improved characterisation of logs at harvesting at the individual industry level today and in a context of developed production techniques, product manufacturing, business concepts and so forth.

Tree pricing per diameter class is one interesting concept including quality indices based on relationship between existing quality grades of species and tree age at breast height. This concept is now used for buying wood by some Swedish forest companies, e.g. Sveaskog and Södra. The idea is to show an easily understandable price offer to forest owners, providing full flexibility in bucking and faster payment by quality certified harvester measurements. This concept may be further developed with a more agile and rapid index expressing different wood material preferences based on measured and objectively predicted log characteristics to improve the interface between logistics providers and their industry customers. The results from WP 4000, Task 5300 as well as Task 8100 show that the possibilities to improve valuation of stands and flow of wood prior to

harvesting by means of ALS and retrospective statistics from harvester production files in combination. Regardless of the pricing method used the system for bucking control of harvesters is a crucial part of the Cut-To-Length system.

Table 15 Suggested outlines of improved market driven allocation forestry to industry in a Cut-To-Length context aiming for gain optimization of parallel value chains

1. Wide comparisons (e.g. rough cost/benefit analyses including harvesting and haulage cost and emissions) of different offers/price lists should be supported. Objective: Strategic analyses of differences in existing and potential chains gain from a larger number of operational and potential alternatives. Support ambitions to optimize gain with respect to economy and environmental load.
2. Restricted analyses. Operationally, assisted by wider comparisons (1), a limited number already agreed and/or operationally feasible alternatives will be identified, selected and used when setting up operative bucking instructions and planning of harvesting and haulage (logistic concept). Objective: Basis for optimizing gain with respect to benefits, costs, productivity and risk from a restricted number of operational alternatives also including respect to environmental load.
3. Different assortments are defined by minimum requirements (threshold values) only when threshold values are clearly motivated. Examples: log dimensions (min/max diameters and log lengths), acceptable apportionment intervals (see below) and unacceptable faults, damage. Objective: Required properties should be restricted to really unacceptable, while desired and undesired properties may be expressed by price based on their impact on production economy. This can be performed by index values (e.g. calculated as deviations from reference/average values) or price matrices (e.g. diameter vs. length).
4. Properties (within assortments) e.g. diameter, length, crooks and partial faults all impacting yield may be calculated as a yield indices (independent of product quality). Objective: To meet customers process-specific conditions in the most economical way (price is adjusted to predicted impact of log properties on yield).
5. Properties (diameter, length, distance from ground, basic density, knot structures (type, sizes, numbers, distances between whorls etc.), heartwood, number of rings from pith to bark, earlywood/latewood, block distances from pith/bark etc. all impacting product recovery may be expressed as value indices. Objective: To meet customers product-specific conditions in the most economical way (price is adjusted with respect to predicted impact of log properties on product types/product quality classes etc.).
6. Demands of different sawmills are calculated (by sawmills) from their expected yields (yield indices) and product values (value indices). Objective: Decide the demanded minimum volume of sawlogs to be delivered by predicted yield and product recovery (from 4 and 5 above). Calculate the consequences of positive or negative impact from sawlogs on total production capacity and plan for the most economic actions (full utilization of production capacity, detected ability to increase production, or a necessity to reduce production).

6. Work Package 5400

6.1 Background

6.1.1.1 Today

CTL-harvesters using bucking optimization are controlled by apt-files according to StanForD (http://www.skogforsk.se/en/About-skogforsk/Collaboration-groups/StanForD/). The apt-files include price matrices usually expressed as different prices per cubic meter for different tree species length and diameter combinations of logs. The bucking control also normally includes matrices for desired length distribution per diameter class . There are also quality restrictions, manually decided or calculated by the harvester (butt log allowed/not allowed, sound knot quality etc).

Today, all these control parameters are not adjusted more than monthly or normally more seldom. When a change is made it is normally in connection with the movement to next harvesting object. One reason to not update the control parameters on-line or at least each stand is that very few organizations/ companies have good estimates of the stands previous to harvesting. Furthermore they commonly have a poor estimate of logs which has not been used at the industries (stored along the forest to industry chain). Another reason is that the present structure is inflexible when it comes to changes of the control during an ongoing operation within a harvesting site as a consequence of the structure of the standardized control and production file system.

6.1.1.2 Future

Bucking optimization should be controlled in relation to specific industrial demands (WP 3000, WP 6000) and the improved information on the standing trees (WP3000, 4000 & 5400). Ideally, the bucking process should be a fully integrated, efficient part of each industry. As the wood flow becomes controlled by advanced logistic tools, it becomes increasingly important to support the system with an efficient bucking control, including description of the logs by individual characteristics and predictions of total product yield as indicated in chapter 3.5. To achieve the objectives of a novel logistic concept, the system need new tools for automatic and more flexible bucking control, with respect to alternative customers' and pricelists in question for specific harvesting objects

6.2 Aim

Further develop and test of a system for flexible automatic bucking control based on different customers' demands. The model shall be possible to use in future simulation programs and in future harvester bucking control. The work shall be strongly connected to harvester manufacturers development and StanForD 2010.

Further develop and test of a new "individual log production message" including log characteristics as a base for use in the Flexwood optimization system.

6.3 Project goals

The project goals were to:

- Support the Flexwood scheduling optimization module with adapted production data in a standardized format according to StanForD 2010
- Adapt and test the control messages to control the harvester with production instruction according to the needs calculated in the novel Logistic Flexwood scheduling optimization tool. The control messages shall follow StanForD 2010.

This means that the goals of WP5400 were primarily to improve two parts of the "Novel logistics" chain:

1. bucking simulations that generates improved detailed production data (figure 20, step 2) that can be used in the logging scheduling optimization.
2. Controlling production at individual sites through a significantly more flexible bucking (figure 20, step 5).

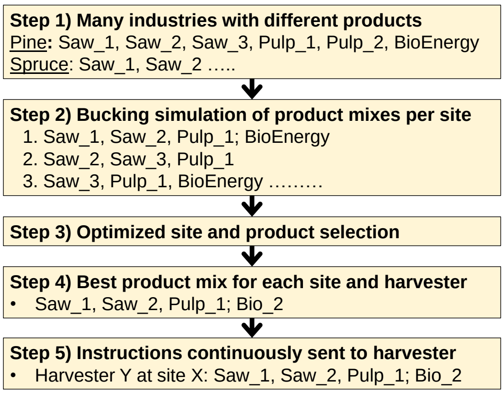


Figure 20.Flow chart illustrating the "novel logistics" chain.

6.4 Flexible bucking

6.4.1 Description of flexible bucking

The present standard for communicating with forest machines, StanForD, does not support the possibility to update or modify product instructions in the harvester in a very flexible way. The work in WP5400 has therefore partly been to develop a concept for a more flexible bucking control which has been used when implementing a totally new standard version, StanForD2010. The new StanForD2010 standard thus supports a more flexible bucking.

What does "flexible bucking" mean? The basic objective is to make it possible to update all active harvesters at once (on-line) when product requirements from one or more industry customers have changed. It might be that the prices of a certain product has been increased or that the required length distribution is changing etc. (figure 21).

1. Updated prices (+1,5€/m3)
2. New length requirements
3. Changing quality demands

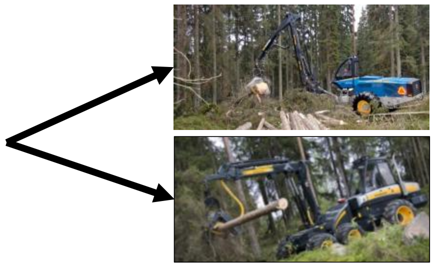


Figure 21 Examples of changes in product instructions.

The most significant characteristic of flexible bucking is that it should be possible to send updated object (oin) and product (pin) instructions to all relevant harvesters at any time before or during production at a specific harvesting object in order to for example activate a certain product or change the distribution matrix of an already existing product. It shall be possible to momentarily start using these instructions in the harvesters.

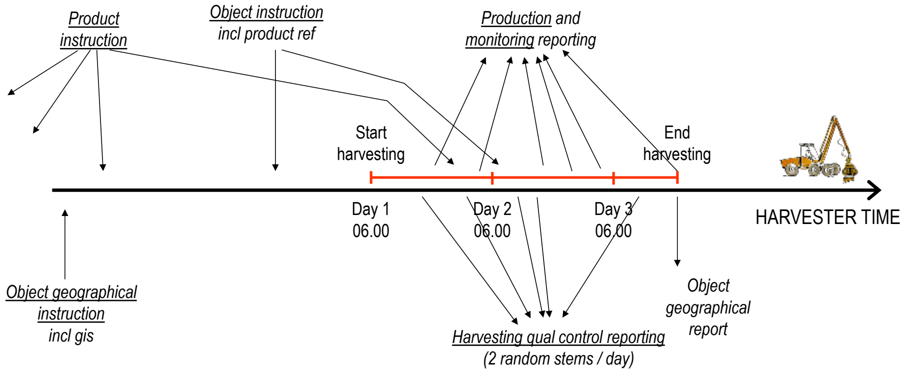


Figure 22 Illustration of flexible bucking where product instructions can be modified at any time during harvesting.

6.4.2 Example flexible bucking

Below follows a practice example of how to administrate product and object instructions sent to the harvester. Observe that ProductUserID is an important element where the identity of the product is included and ObjectUserID is used for including the identity of the harvesting object (site).

6.4.2.1 Step 1.

Product instruction (pin) including four products is sent to harvester

ProductName	PineSaw	PinePulp	SpruceSaw	SprucePulp
ProdUserId	0110	1010	0120	1020
ModificationDate	10-01-18	10-01-18	10-01-18	10-01-18
LengthClasses	34, 40, 46, 49	38, 40, 45	37, 43, 46, 49	37, 41, 44
DiameterClasses	18,22,24,30	5,10,15,18	18,22,24,30	5,10,15,18
PriceMatrix	45 €/m3 …	20 €/m3 …	42 €/m3 …	25 €/m3 …

6.4.2.2 Step 2.

New object instruction (oin) sent to harvester

ObjectUserId	ModificationDate	Product references
PinkForest_1380	10-01-19	PineSaw (0110), PinePulp (1010), SprucePulp (1020)

6.4.2.3 Step 3.

New harvesting object started with the following products according to oin message

ObjectKey	ObjectUserId	Products used
38	PinkForest_1380	PineSaw (0110), PinePulp (1010), SprucePulp (1020)

6.4.2.4 Step 4.

New product instruction for “PineSaw” (new diameter classes and increased price) sent to harvester during harvesting at “PinkForest_1380”

ProductName	PineSaw
ProdUserId	0110
ModificationDate	10-02-01
LengthClasses	34, 40, 46, 49, 55
DiameterClasses	18,22,24,26,30,32
PriceMatrix	51 €/m3 …

Operator is asked: Replace old PineSaw with new?

Answer: Yes!

New object instruction (oin) including product “SpruceSaw” sent to harvester during harvesting at “PinkForest_1380”

ObjectUserId	ModificationDate	Product references
PinkForest_1380	10-02-01	PineSaw (0110), PinePulp (1010), SpruceSaw (0120), SprucePulp (1020)

Operator is asked: Update present object or start a new object?

Answer: Update present object!

6.4.2.5 Step 5.

Harvesting at object "PinkForest_1380" is continued with updated product "PineSaw" and new product "SpruceSaw"

ObjectKey	ObjectUserId	Products used
38	PinkForest_1380	PineSaw (0110), PinePulp (1010), SpruceSaw (0120), SprucePulp (1020)

6.5 Implementation in harvester

The *Flexible bucking* needs a database for administrating the instructions in the harvester (figure 23). In that case data can be communicated from the database to the bucking application at any time, also during operation at a harvesting object.

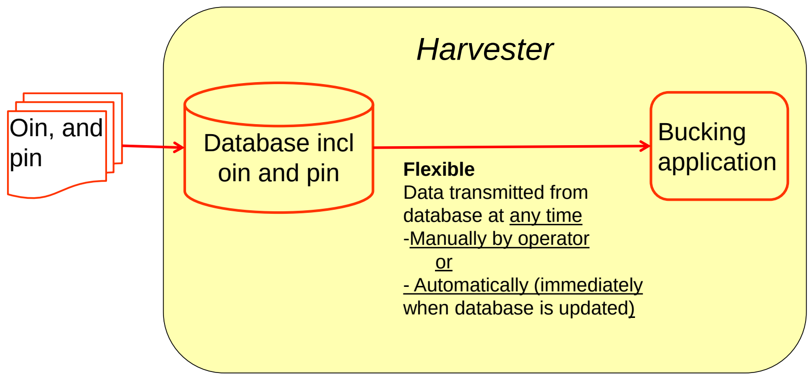


Figure 23. Illustration of how a database can be used in order to administrate different product instructions (pin) in the harvester.

The *Flexible* system could be manual and/or automatic. The first step is to make the system manual which means that the operator manually decides when to import a new or updated product instruction (pin) from the database to the bucking application. The same applies to harvesting object instruction (oin). The manual flexible system is the first base level that is strongly recommended to implement. In an automatic system an updated or new product will be automatically imported into the bucking application. The table below describes four different events where pin and oin files are received by the harvester and added to the database.

File recieved	Flexible - manual	Flexible - automatic
New oin	Used when starting at new object.	Used when starting at new object.
New pin	Used instantly if manually imported by operator.	Used instantly if ProductUserId is included in active oin, automatically imported by bucking application.
Updated oin	Used instantly if ObjUserId is same as in active oin, manually imported by operator.	Used instantly if ObjUserId is same as in active oin, automatically imported by bucking application.
Updated pin	Used instantly, manually imported by operator.	Used instantly if ProductUserId is included in active oin, automatically imported by bucking application.

Observe that it is strongly recommended to the harvester manufacturers that the harvester system is Flexible - manual . To also include automatic functionality is optional.

Also observe that it should always be possible for operator to edit products and species groups during production if attribute modificationRestricted is false. A special id-element (ProductKey) must be updated if product is modified in any way.

6.6 Test of flexible bucking

The first complete version of StanForD2010 standard supporting “Flexible bucking” was finalized in November 2011. Four out of six manufacturers of cut to length harvesters had implemented StanForD2010 during the spring of 2012. Skogforsk then carried out a test of these four different manufacturers.

The following table gives a summary of the test results.

Harvesters	Log Max	John Deere	Ponsse	Komatsu
Read all relevant bucking instructions (oin, pin, spi)	X	X	X	X
Add new product (pin) during harvesting at an object	X	X		X
Update all relevant bucking instructions (pin and spi), during harvesting at an object	X			X
Start object with new object instruction (oin), using product and species isntructions (pin and spi) already sent to and registered in machine	X	X	X	X
Read xml envelope including all relevant instructions (oin,pin, spi)	X	X[3]	?	X[3]
Create a new sub-object	X	X		X

The results indicate that all machines can utilize the new StanForD2010 messages while there are still some limitations regarding changing and updating products during operations at a harvesting object. Ponsse cannot add a totally

new product within a harvesting object, this means you have to wait until the next object or you have to do a "restart" which takes some work. Both John Deere and Ponsse have a limitation which means that they cannot add a modified existing product within a harvesting object, this means you have to wait until the next object or you have to do a "restart".

Observe that there are two major manufacturers of harvester software systems who have not yet implemented the new standard fully. These two manufacturers are Dasa and Parker (Motomit), but have both stated that they will have system solutions ready to test during the second half of 2012.

6.7 Harvested production

Historically the most common format for reporting harvested production has been prd. This format has a major drawback due to the fact that it only includes aggregated data, for example a log matrix where the total number of logs per length and diameter class is registered. No exact information about each individual log is included. A file format called pri was therefore introduced around year 2000 where data per log was included. However this format has never come into wide use and it has some limitations concerning the possibility to include company or country specific information.

The message structure for *harvested production* in StanFord2010 could be described as an extension of the present pri format.

The new data structure for production reporting will make it possible to:

- Identify multiple occurrences of identical stems (using combination of *MachineKey* and *StmKey*)
- Identify missing stems (*StemNumber* a running stem number per object needed)
- Identify location (object & sub-object) of a stem
- Identify objects for a specific machine if data from several machines are included in one message.
  Example:
  Data from harvesters A and B harvesting object XX is merged into one message. It must be possible to separate Object-data (for example start and end date) for the two harvesters.
- Easily extend the message with presently non-standardized data, for example log characteristics like estimated green density or fiber dimensions.

A structure similar to the present pri-file will be used (figure 24). Using this structure will make it possible to register data from several machines and harvesting objects in one single message. The abbreviation GUID means Globally Unique Identity. Observe that the combination of *MachineKey*, *StmKey* and *LogKey* must be totally unique for each and every log.

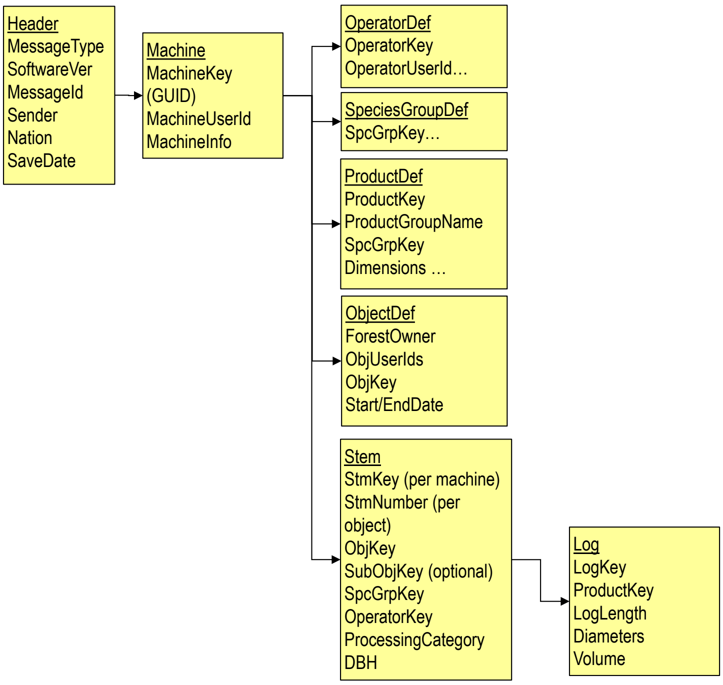


Figure 24. General layout of message including harvester production data. Diagram also describes how sub-objects may be used. Observe that MultiTreeProcessing is not included.

A more detailed description of harvested production data is included in figure 25. The element "Extension" can be used in order to include any relevant information about e.g. logs or stems that are not yet standardized.

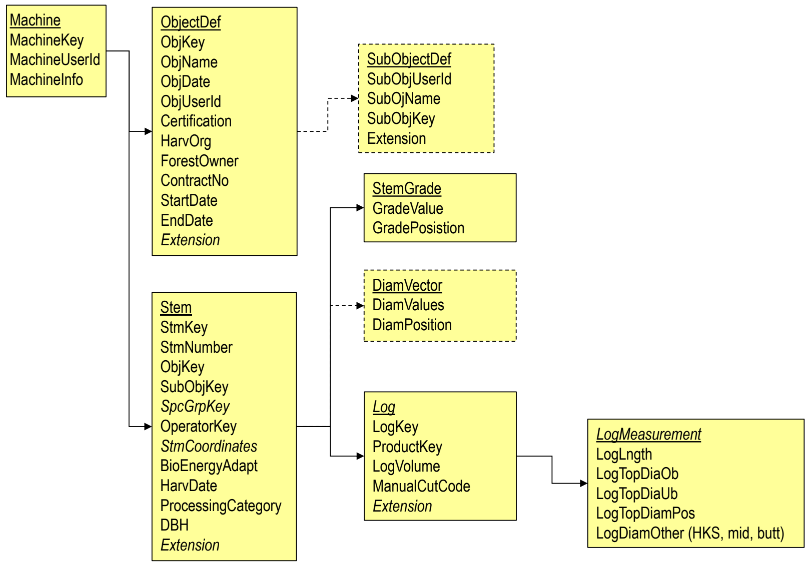


Figure 25. Diagram describing detailed harvesting data.

6.7.1.1 Example

Below is an example of stem and log data registered according to StanForD2010 (hpr format


```
<Stem>
  <StemKey>1001</StemKey>
  <ObjectKey>1</ObjectKey>
  <SpeciesGroupKey>2</SpeciesGroupKey>
  <OperatorKey>1</OperatorKey>
  <HarvestDate>2010-12-22T11:01:18.348+01:00</HarvestDate>
  <BioEnergyAdaption>None</BioEnergyAdaption>
  <StemNumber>1001</StemNumber>
  <ProcessingCategory>SingleTreeProcessing</ProcessingCategory>
  <StemCoordinates receiverPosition="Base machine position" coordinateReferenceSystem="WGS84">
    <Latitude latitudeCategory="North">60.17924</Latitude>
    <Longitude longitudeCategory="East">17.90278</Longitude>
    <Altitude>39</Altitude>
  </StemCoordinates>
  <Extension>
    <HPRCMResults>
      <Biomass Title="BranchesTops Dry weight" Unit="kgDM">11.613</Biomass>
      <Biomass Title="BranchesTops Fresh weight" Unit="kgFM">23.226</Biomass>
      <Biomass Title="BranchesTops Energy dry" Unit="kWh(dry)">61.936</Biomass>
      <Biomass Title="BranchesTops Energy fresh" Unit="kWh(fresh)">54.033</Biomass>
      <Biomass Title="BranchesTops Solid volume" Unit="m3solid">0.02834</Biomass>
      <Biomass Title="Stump Dry Weight" Unit="kgDM">7.885</Biomass>
      <Biomass Title="Stump Fresh weight" Unit="kgFM">15.77</Biomass>
      <Biomass Title="Stump Energy dry" Unit="kWh(dry)">42.054</Biomass>
      <Biomass Title="Stump Energy fresh" Unit="kWh(fresh)">36.688</Biomass>
      <Biomass Title="Stump Solid volume" Unit="m3solid">0.01877</Biomass>
      <StemInfo>
        <TreeHeight Unit="cm">828.8</TreeHeight>
        <DominantHeight Unit="m">G26</DominantHeight>
        <HeightToCrown Unit="cm">255.6</HeightToCrown>
        <EstimatedTop Unit="m3sobEstimated">0.00603</EstimatedTop>
      </StemInfo>
    </HPRCMResults>
  </Extension>
```

```
    <SingleTreeProcessedStem>
      <DBH>102</DBH>
      <ReferenceDiameter referenceDiameterHeight="120">102</ReferenceDiameter>
      <StemGrade>
        <GradeValue gradeStartPosition="0">0</GradeValue>
      </StemGrade>
      <Log>
        <LogKey>1</LogKey>
        <ProductKey>26</ProductKey>
        <LogVolume logVolumeCategory="m3 (price)" logMeasurementCategory="Machine">0.02300</LogVolume>
        <LogVolume logVolumeCategory="m3sob" logMeasurementCategory="Machine">0.02600</LogVolume>
        <LogVolume logVolumeCategory="m3sub" logMeasurementCategory="Machine">0.02300</LogVolume>
        <CuttingCategory>
          <CuttingReason>Automatic</CuttingReason>
        </CuttingCategory>
        <LogMeasurement logMeasurementCategory="Machine">
          <LogDiameter logDiameterCategory="Top ob">72</LogDiameter>
          <LogDiameter logDiameterCategory="Top ub">66</LogDiameter>
          <LogDiameter logDiameterCategory="Mid ob">93</LogDiameter>
          <LogDiameter logDiameterCategory="Mid ub">86</LogDiameter>
          <LogLength>373</LogLength>
        </LogMeasurement>
        <Extension>
          <CalculatedLogInfo>
            <BasicDensity Unit="kg/m3sub">728.8</ BasicDensity >
          </CalculatedLogInfo>
        </Extension>
      </Log>
    </SingleTreeProcessedStem>
  </Stem>
```


6.8 Working plan

The work will be divided into different parts as follow:

1) Description and demands
   a. Description of the situation today.
      Describe the situation of how the control of bucking optimization works today. Describe the problem and the possibilities with the system.

   b. Description of developed model for bucking instruction system.
      Describe the future needs of bucking control and put up the demand of how the control of the simulation and harvester bucking shall work in the future according to the flexwood model. The system shall be adapted to fulfill the advanced industry demands. For example it should be easier to change bucking instruction and to control different harvesters on-line with standardized messages.

   c. Description of new individual log production message.
      Describe the future needs of production data from a simulation or a cut object to fulfill the needs in the flexwood system.
      The needs shall be specified down to log characteristic level. It shall also include the needs of geographical information and identities.
      There shall be a description of how different log characteristic data shall be measured or calculated and included in the message.

2) Development of messages and simulation.
   a. Adaptation of messages and instruction for bucking control. The demand of the flexwood model shall be used as a base for further development of the standardized control messages for harvesters and simulation programs.

b. Adaptation of messages for production message.
The demand of the flexwood model shall be used as a base for further development of the standardized production messages for harvesters and simulation programs.

c. Simulation and practical test using new messages and instructions.
The last part of the project is to test the new ideas in novel logistic tools. Test the developed production control model in simulation and create new individual production messages including log characteristics. Eventually there may also be a practical test with some harvester manufacturers which have implemented StanForD 2010.

3) Documentation of result and recommendation.
   a. The result is to describe how the new system with harvester and simulation control shall work in the future.
   b. A second result is a documentation of the flexwood demand of future control and production message for simulation tools and harvester.
   c. Adapted control and production message from harvesters and simulation program for use in the novel logistic tools.

7. Work Package 5500

7.1 Background

Planning the activities of harvest teams (harvesting and forwarding) and transportation is critical for the efficiency of the procurement of roundwood from forests to the mills. In addition, there are many integrated decisions to make. These decisions consider both spatial and temporal aspects. The spatial aspect concern which area to harvest, which machine team to use, to which mill the timber should be allocated and where to store. The temporal aspect concerns when to harvest, and when to transport from area to mill in order to meet specific demand at mills and when to store. Associated to both aspects is also how the trees should be bucked. With the temporal decisions, it follows to determine in detail a schedule for each harvest team. This is complicated by the fact that harvest team has different home bases, different machine systems with their own performance description and capacities. The decisions are highly dependent upon the demand for round wood at mills and the supply in the forest. Accurate information about both supply and demand are of great importance to the success of the planning process. Demand is often more easy to estimate based on historical data and annual budget plans. However, this is not the case for the supply where, for example, volume and proportions of assortments are known only within some bounds.

The planning process of scheduling harvest teams is normally executed in a manual or semi-manual way with a small amount of decision support. Maps are used to view the spatial extent of the planning and some tools to support the calculation of yield. However, very few systems today include optimization models to support the planning process. Also, the background data is rather often poor with lack of information and/or low quality of the information. This is also true for information around machine capacity and team performance in different environments. It is very time consuming to make a complete plan from scratch. Moreover, when there is a need to revise a plan due to unplanned events, there is often a lack of time.

The overall plan we are searching for should be efficient and resilient. Efficiency can be measured through a cost function. Resilience is more difficult to evaluate but it means that the solution should be easy to change as more information becomes available. An important concept is anticipation. This means that we split decisions variables in a model into business decisions which are to be implemented, and anticipation decisions which are a response in the future given the business decisions. Business decisions can be those decisions which are taken place within the next weeks and anticipation decisions that are several months in the future. For example, the schedule of harvest areas for the next month is a business decision whereas the transportation flow is an anticipation decision. All flows are later planned using routes for logging trucks on a daily or weekly basis for business decisions to be used. Using anticipation means that we can balance long term objective and restrictions with the short term operational decisions. For example, by using anticipation in the future, we can ensure a balance in thinning/final felling, keep the average distance from areas to mills within some limits and make sure that all harvest teams have a fair allocation of the available areas. Resilient solutions need less re-planning, and have reduced risk to be stuck with a difficult position which requires expensive corrective actions, and less emergency management i.e. only solve urgent problems as they appear. All this together leads to reduced costs, increased flexibility, increased fairness and last but not least, decreased negative environmental impact.

An optimization model, with the objective to create a harvesting schedule on an operational and tactical level, minimizing costs and/or maximizing revenues, could significantly improve the solution quality and make the planning process more simple and fast. This is helping the manager not only to a better work flow, but also to more cost effective overall roundwood procurement. Such a tool can also enable the analysis of “what if” scenarios. For example, what happens if another team is included or if a team is replacing an old machine system? Other scenarios can support questions like: what happens if the demand from industry x increase 10% or what happens if the volume of spruce is 15% less than expected in some areas? The overall planning problem is an integrated allocation, transportation and scheduling/routing problem. This is known to be difficult to solve even for small instances. In order to meet the limited solution time, special care must be used when developing a Decision Support System (DSS).

Within FlexWood work package 5500 the aim was to develop a DSS that could be used to make a complete plan and a number of different scenario analyses within a short computational time. The DSS is developed to be an independent module of the VSOP planning system used by Korsnas. For that reason, we also need to develop the communication and interface between the two systems. The DSS require a solution approach and we have developed one aimed to schedule harvesting resources (i.e. harvester, forwarder and harwarder) in combination with the selection of stands to be harvested under restriction of fulfilling demand from industry and minimizing the overall logistic cost. The purpose is to create an operational plan on which stands are to be harvested when in time and by which harvesting machine team. The logistic cost includes costs for harvesting, transportation of round wood from forest to mill and moving machines between stands. The outcome of the harvested stands (volume per assortment) will be matched with the demand from pulp-mills, sawmills and CHP-plants. In order to get the right outcome from the stands the solution approach can also suggest which apt file that should be used for each stand.

7.2 Literature review

Supply Chain (SC) planning in the forest products industry encompasses a wide range of operations and decisions, from strategic to operational. SC in the forest industry has been discussed in several papers, and a recent survey is found in D'Amours *et al.* (2008). Many Decision Support Systems (DSS) have been developed for different planning problems in the forest SC. These are often integrated into application-specific databases holding all the information needed for the models and the Geographical Information System (GIS) used to visualize the input data and results. In addition, many DSS include Operations Research (OR) models to support the planning. Rönnqvist (2003) presented a series of typical planning problems found in the forest products industry, with comments about the time available for solving each of these problems. Rönnqvist (2012) discuss a number of issues that may appear when solving industrial problems. One conclusion of the paper is that it is important to model the problem faced by the problem owner and a second is that the data quality is essential for the usefulness of the solution.

Our problem belongs to the class of tactical problems or medium term planning problem. These are problems where the overall planning horizon extends a number of months. We should however notice that the business decisions taken may be just for the next week. There are many problems and DSS systems developed for these problems. The Forestry Research Institute of Sweden has developed several tactical tools. We will limit our survey to literature that deals with the Swedish situation. Karlsson *et al.* (2004) study the problem of harvest planning for one year. In this problem there is no consideration taken for scheduling or movement of teams between harvest areas. The model is formulated into a large scale mixed integer programming (MIP) model. Also, there is no detailed information given about neither the harvest areas nor the teams. A short term harvest scheduling is studied in

Karlsson *et al.* (2003). In this paper, they suggest a heuristic to generate feasible schedules for each of the harvest teams. Another tactical problem is road maintenance. Olsson (2004) and Henningsson *et al.* (2007) have presented MIP models that include decisions about restoring existing forest roads and transportation in order to provide access to available harvest areas during the spring thaw, when only certain roads are practicable. The model used by Henningsson *et al.* (2007) is the basis for the decision support system, RoadOpt (Frisk *et al.* 2006), developed by the Forestry Research Institute of Sweden. Epstein *et al.* (2007) consider forest where some short term harvest operations are planned. Transportation is an important part of forest operations, and Forsberg *et al.* (2005) propose a model which includes several transportation modes. This is the first description of the DSS system FlowOpt. A number of articles with specific developments follow up on this. In Carlsson and Rönnqvist (2008), the models and solution methods for backhauling is outlined and several case studies are described. FlowOpt was used after the storm Gudrun where more than 80 million cubic meters of wood was wind-felled (Broman *et al.* 2009). FlowOpt was used for the company Sveaskog to support their logistic planning with terminal location and distribution planning using trucks, trains and ships. There is often a large potential to make wood-bartering between companies as their supply and demand locations cover each other. In Frisk *et al.* (2010) they propose a game theoretic model to make a fair cost allocation of the joint logistic costs between eight participating companies. Operational routing is also an important but short term planning problem. There are several papers describing different solution approaches and DSS systems, see Weintraub *et al.* (1996), a DSS for logging trucks, which received the Franz Edelman Award in 1998. This DSS which exploits a simulation-based heuristic to produce a one-day schedule, is currently used by several forest companies in Chile and other South American countries. The Swedish system RuttOpt (Andersson *et al.* 2008) establishes detailed routes for several days and integrates a GIS with a road database, using a combination of tabu search and an LP model. Test performed on this system has shown cost reductions of between 5% and 20% compared to manual solutions.

The article that is the closest to our problem is described in Bredström *et al.* (2010). In this article, the authors study an annual harvesting problem for SCA, a large Swedish forest company. The decisions are to allocate harvest teams to areas and then make a feasible route. The objective is to find a plan for a fixed number of areas to be harvested during one year. The authors propose a two phase heuristic. In the first phase an allocation of areas are done against the teams. In the second phase, each team is given a route for the areas allocated. In the model formulation, there is no demand given. Instead all areas must be harvested. There is a detailed description given for teams as well as for areas. Also, the time periods is given in months. This is not possible in our case as the planning periods during the business period must be as short as one day in order to provide a detailed short term schedule. The idea to use a multi-phase heuristic to balance of the difficulty of a full model is used in developing our proposed solution approach.

7.3 Problem formulation

To formulate an OR model, we need decision variables, objective function and constraints. The plan or schedule is supposed to be detailed (daily) for about one month. However, this short term plan needs to be balanced against the long term use of the resources. Otherwise, we may get stuck in a bad situation with very high costs. A simple example is if we harvest the closest (to mills) harvest areas first (as this has the lowest cost for the transportation). As we get closer to the end of the year, we have a very difficult situation with stands far away and not enough transport capacity and/or long equipment moving.

Which machine team that will be assigned to which stand is determined by several factors. Consideration should be given first and foremost to the machine type and whether it is allowed in the current stand (a machine for final felling is not allowed e.g. small thinning). In addition, there are restrictions on how far from home base a machine is allowed to operate. In order to compute how much time it takes to harvest each site the machines are described with a performance which is dependent on the average log (harvesters) and forwarding distance (forwarders). The performance of the machines is not only dependent on the average log and forwarding distance, but also on the cutting type (clear cutting, thinning and harvesting seed trees). The decision of when a particular area is to be harvested is determined partly by its bearing capacity. In VSOP the bearing capacity is defined as a combination of road and terrain accessibility together with ground conditions. The time of logging can also be controlled explicitly by the user to specify when a specific stand should be harvested. In addition, stands can be forced to become a priority so that they are harvested within a fixed set of months after the purchase (in the case when Korsnäs purchase harvesting rights from Bergvik).

Demand is described as a target volume of all specified assortments in a given time period (calendar week) for a particular mill. Also, it should be possible to require a balanced distribution of deliveries between the days of the week (5, 6 or 7 days). Deviation from the target volume is allowed by a specific percentage (both up and down) per week and per month. Tolerance of weekly level is typically greater than the permissible deviation of a monthly level. Demand is complemented with information about the price the recipient pays for the respective assortment. The model can also maximize the impact by choosing the most convenient apt-file and decide which mill the volume is aimed for. The company's delivery requirements based on agreements between the forest company and the industry company must be met. The exception is if there is insufficient amount of volume of a specific assortment. In such case, the model is able to purchase these volumes from an external source at a given cost.

Before we can formulate any model, we need detailed data. Below, we outline which data is required and available. Input is retrieved from various systems/subsystems but is defined in the same way before it is sent to the optimization.

7.3.1 Harvest areas

As a basis for the annual planning, there is a set of harvest areas (or stands) available for final felling, thinning operations or other types of harvesting. These areas are selected from an earlier and more long-term strategic planning. The areas may be owned by the forest company or by an external organization or private owner. The forest assets for all stands available are described with one or more sets of yield depending on the used apt-file (price list). Assets are described with an id number for the stand, names of apt-file and volume per assortment. This can be described in one file, or in multiple files (one file per apt-file). For each stand it is required (except for the volume and value outcome) information about the properties that are relevant for the selection of harvesting machine type, the duration of harvesting and choice of harvesting point of time. These properties are total volume, average log diameter, forwarding distance, bearing capacity, felling form (clear cutting, thinning, and seed tree felling or other), and any performance reduction. Furthermore, the coordinates of the stand as well as information about if it is own forest or purchased from private forest owner.

7.3.2 Demand at industries

The demand is described for each mill with volume per assortment and time period. Volume per week will probably be the most common. The mills must also be described individually by name, id and coordinates. The demand is described by one target level and one minimum and one maximum demand level.

7.3.3 Machine systems

There are two main machine types; harvester and forwarder. The cutting operation is supported with on-board optimization routines to find the best possible cutting pattern given a price list of log values. The outcome is given by the apt-files. The on-board system also creates information about the trees harvested and a detailed description of each log. This information also includes GPS coordinates for the log piles. The log piles are picked up by forwarders and moved to piles adjacent to the forest road. The forwarders must follow in the tracks of the harvesters to avoid additional damage to the ground. They can also use the information provided by the harvesters, e.g. the GPS coordinates, to find efficient routes for the forwarding operations. Over the last few years, a machine called a harwarder that can perform both harvesting and forwarding operations has been introduced. This machine can be more cost efficient in some types of harvesting areas, in particular, in thinning operations. The description of harvesting machines is associated with the description of harvesting teams. Each machine is described with id, which team the machine belongs to, machine type (harvesters, forwarders or harwarders), size (large, medium, small), available capacity per time period and the cost per hour.

7.3.4 Harvesting teams

A harvest team is generally made up of one harvester and one forwarder. This is also the general grouping when a contract is negotiated between a forest company and a contractor. Other setups are possible. A harvest team has a home base, typically a town or village where the operators live. To limit traveling, each team has a maximum operational radius, measured as the distance from the home base to the harvest area. A team may have different focuses with their operations and these may be defined in a contract. A team may be primarily concerned with either final felling or thinning operations, depending on their skills and size of machine. The teams are described with id, type (own or contractor), home base, radius of action (max allowed distance between home base and stand), the minimum and maximum time that the team can work each time period and possibly the minimum working time if there is any. For each home base, name and coordinates are required.

7.3.5 Performance functions

To compute the time it takes for a machine to harvest or forward a harvest area, we need to consider machine characteristics and harvest area properties. This is done with so-called *performance functions*. Each function provides how many cubic meters are harvested/forwarded per standard hour. There are many possibilities for such functions but most companies use straightforward and simple functions as they are easy to use. The performance function for the machines can be expressed as

$$p_{harvester} = a_{s0}x^2 + b_{s0}\mathrm{x} + c_{s0}$$

$$p_{forwarder} = d_{s0}y^2 + be_{s0}\mathrm{y} + f_{s0}$$

$$p_{harwarder} = {g_{s0}}/{h_{s0}} + {i_{s0}}/{x} + j_{s0}y$$

Here *x* is average tree size m^3sub (solid under bark), *y* the forwarding distance, and *s* indicating the size (small, medium, large or very large). All coefficients are company specific and are measured through many tests on machines operating under different conditions and areas.

In Figure 26, we illustrate typical performance functions for harvesters in final felling operations.

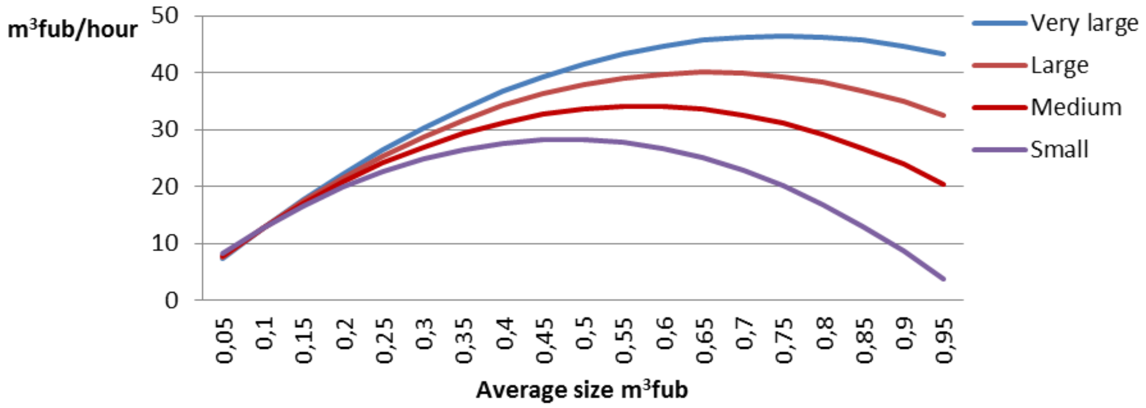


Figure 26. Performance curves for different sized harvesters in final felling operations.

7.3.6 Cost coefficients

The objective is made up of six main cost components. The first is the production cost. This is the combined cost of harvesting and forwarding each harvest area. Given the volume in each area, the performance function and the hourly cost for each machine, we can compute the overall production cost. Included in the production time (and cost) is also the time it takes to clean the harvest area before moving to the next. Note that our production time is based on the slower of the two machines (harvester and forwarder) in the team for each harvest area. The second cost is the traveling for teams between their home bases and harvesting areas. For each harvest area, we can compute the number of times they need to travel back and forward. The third is the moving cost which is the cost to move machines between harvest areas. If the distance is over a certain limit, a trailer must be used to move the machines, otherwise, the machines can be driven (on wheels) directly to the next area. There are specific parameters which describe the maximum distance, average speed (to get the moving time) and costs for the moving. The fourth is the transportation cost to move the logs from harvest areas to mills. The fifth is the inventory cost and the sixth is a cost based on the deviation from the target demand levels. Additional information needed to compute some cost coefficients are the distances between areas, mills and home bases. This is computed using the Swedish National Road Database (Selander *et al.* 2012).

7.4 Solution approach and models

It is possible to formulate the overall problem into one model. However, this model would be too large and not possible to solve in reasonable time. Instead we apply a decomposition scheme where a sequence of models is solved based on a hierarchical structure. With this final solution, we have a detailed schedule for the operational planning. This can then be resolved in a rolling horizon type approach i.e. resolved as things are changed. The result, in the form of a scheduled harvesting plan, is to be presented both as a Gantt chart and in a map. The results will also be shown in tables and diagrams (costs for harvest and transportation, harvested volumes, etc.).

The model is working on both a short and long term horizon. The short term is based on short time periods, say 30 one day periods, and the remaining long term on longer timer period, say 11 one-month periods. This provides a detailed planning of the first month and a coarser planning for the remaining 11 months. The first time period is linked to a specific date in order to have control over current operations and inventories, what times various areas are available and when different machine teams can work (holidays, planned maintenance stops, etc.). In addition, there must be a calendar that determines when different accessibility periods occur as well as an availability calendar for all machine resources.

The solution approach works in several main steps, even if the user does not notice of more than one. These steps are described in detail below. Moving costs can be specified directly even if, as in this case, Korsnäs has this cost embodied in the cubic meters price to the contractor. However, it is possible to limit the number of moves per year for a machine. If this number is exceeded, a penalty fee will fall out. It is also possible to add an additional cost that falls out for each stand (e.g. clean-up compensation to the hauler). If multiple areas can be clustered only one cost for the entire cluster is applied. It is also possible to force a particular harvesting team to harvest a specific stand, for example, if there are special requests from the landowner.

The solution approach is based on solving one *Master* problem. This Master problem includes the main decision variables for allocating teams to stands, time to harvest stands, flows between stands and industries, inventories and apt instructions. The main interest is to decide an operational short term plan but include long term planning to balance capacities and supplies. To include this, we divide the planning horizon as discussed earlier into *business* periods (detailed short term) and *anticipation* periods (aggregated long term). Examples are daily periods for the first month and monthly periods for the remaining part of the year. It is important to note that the business decisions provide the operational decisions and the anticipation decisions provide possible plans in the future. This Master problem will be extremely large in our application and it is not possible to solve directly. Instead, we need to apply some decomposition and aggregation techniques to stepwise solve the full Master problem. The overall solution approach is described below.

Algorithm 1 Overall solution approach

Phase 1: Assumptions: All periods (business and anticipation) are aggregated into one period.
  Solve Problem P1 (Simplified allocation problem)
  Output: Initial allocation of stands to teams.
Phase 2: Assumptions: Teams aggregated into one final felling team and one thinning team, all business periods aggregated into one, original anticipation periods
  Solve Problem P2 (aggregated Master problem)
  Output: Allocation of stands to aggregated business period
Phase 3: Assumptions: Selected stands to business periods.
  Solve Problem P3 (Master problem with business periods only)
  Output: Allocation of stands to teams and starting harvesting times in business periods i.e. initial schedule in business periods
Phase 4: Assumptions: Generation of many detailed schedules based on initial stand-team allocation
  Solve Problem P4 (Detailed scheduling)
  Output: Detailed schedule in business periods
Phase 5: Assumptions: Detailed schedule in business periods
  Solve Problem P5 (Full Master problem fixed schedule (not flows and inventories) in business periods)
  Output: Full plan in business periods and anticipation periods including all flows and inventories.

Below, we discuss each of the problems. Complete models can be found in the FlexWood report "Optimization model for scheduling of harvest resources" (Delivery No 5.3 WP 5000).

Problem P1: The objective with problem P1 is to allocate harvest areas to teams. There is only one time period. The purpose is to support problem P2 to make sure that the spread of areas to home bases is balanced i.e. we need to set some restrictions on P2. There are no flows included in this problem.

Problem P2: We use two aggregated teams to make sure that the proportion of final felling and thinning stands are balanced. We use all anticipation periods together with one aggregated business period. Based on the solution from P1, we make sure that there is balance of harvest areas close to the home bases (and the related teams). The purpose of problem P2 is to allocate areas to the aggregated business period. In this model we include inventory and flows between stands and industry.

Problem P3: From P2, we know which stands that will be harvested in the business periods. Note that now we have a quality balance between business and anticipation periods. This coordination is done by solving P1 and P2. We now want to solve the full model but only for the business periods. The purpose is to allocate areas to teams and an initial sequence in how they will be harvested. The sequencing part is an approximation as we allow only one area to be harvested in each business period. In this model we include inventory and flows between areas and industry.

Problem P4: Given that we know which areas that are allocated to each team and an initial approximate sequence the first month we generate many detailed schedules. These detailed schedules include exact costs for moving equipment and how much is produced in each business period. The next problem is a set partitioning type problem where each team is to select one detailed schedule while all together satisfies demand restrictions and minimize logistic costs. A schedule may also include a detailed description of apt instruction for each area. In this model we include inventory and flows between areas and industry.

Problem P5: Given the detailed schedule for the business periods, we can solve the remaining full problem to allocate areas to teams for the anticipation periods. In this model we include inventory and flows between areas and industry. This will provide the final solution to be presented.

The problems/models are solved using either the commercial solver CPLEX or the open source software glpk and CBC. The models are defined through the modeling language AMPL which easily is linked to the different solvers.

7.5 DSS design

The models and solution approach will be implemented and used as a standalone module for VSOP, an application for operational harvest planning created by Logica[4] and used by several Swedish forest companies. This implementation is also discussed within FlexWood 8100 - The Swedish use case. The models use information about the yield per stand, which can be generated at an earlier stage by the VSOP system. Data for each stand consists of one or more yields depending on how many different apt-files that are used. The model in this stage is developed and tested within a Nordic context with cut to length systems with

[4] Logica, now a part of CGI (www.cgi.com).

harvester and forwarders as logging devices. It is important to point out that the model is general and usable for any logging- and transportation systems.

The solution approach is implemented in a web service and should work fully automatically. It is called from the FlexWood platform, see Figure 27. The web service, which is allocated to a server at Skogforsk, consists of a function to receive input files and a model that optimizes the harvesting resources and match assets with demand. The result is sent back to the FlexWood platform to be illustrated graphically together with reports to the user.

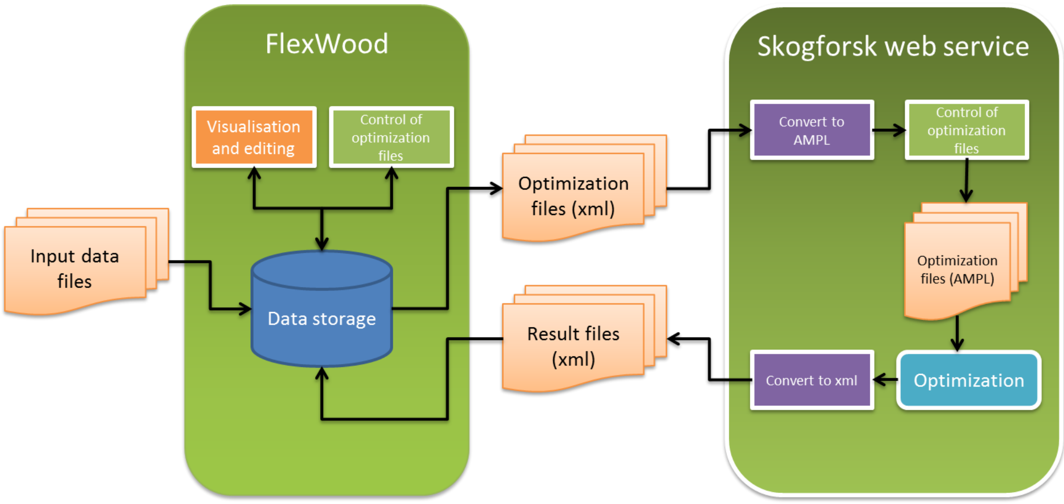


Figure 27. Illustration of the connection between FlexWood and the Skogforsk web service.

The model is scalable, i.e., it will allow optimization with a smaller data set if not all data is available. The optimization provides possibilities for having various factors weighted depending on the organization objectives. Factors that can be weighted are revenue, transportation cost, harvesting cost and moving costs. By default all the factors will be given the weight one, i.e., all the factors are equally important. The optimization also takes into account other harvesting objectives, in particular the percentage volume in thinning versus clear cutting and also the proportion of volumes harvested in own forests versus purchase from private forest owners.

The overall information flow process is described in Figure 26. First the data files are converted into a standard optimization format. In our case we use the modelling language AMPL and hence the files are converted into an AMPL format. With this data, we perform a number of controls to make sure that the data satisfy some basic rules. In case any error is detected, an error output is generated. We then apply a solution approach by solving a number of models as described above. Once the solutions are generated they are produced in AMPL format. This needs to be converted back into a general XML format and then sent back to the user.

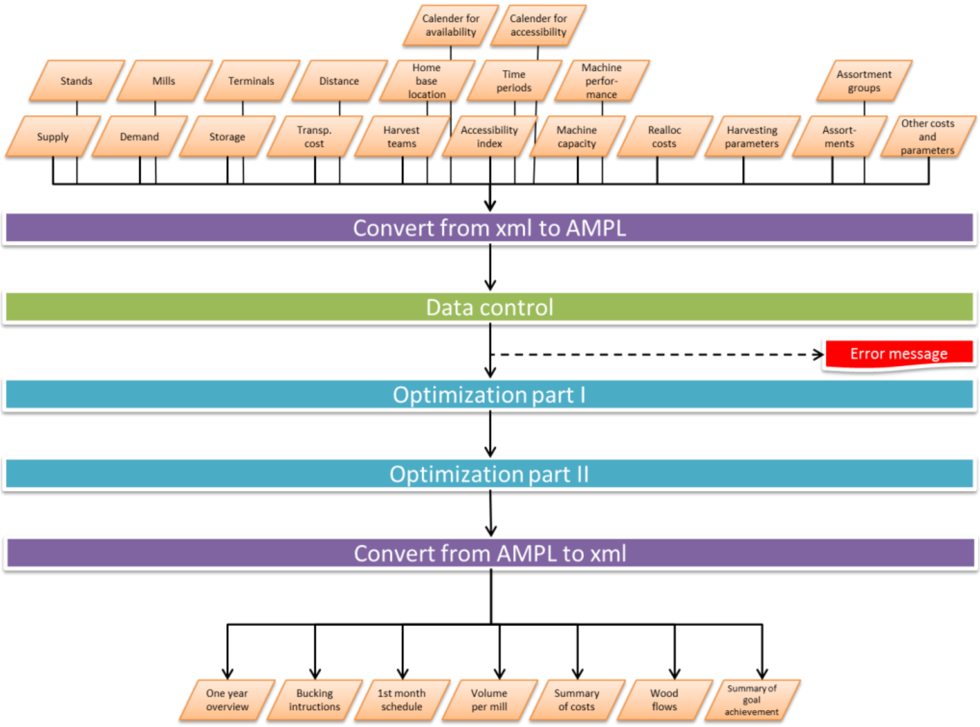


Figure 28. Overall description of the process with data, solution approach, and result handling.

The results are integrated into VSOP and can be visualized in different reports. One important output is a Gantt chart; see an example in Figure 29. The harvesting sequence for the teams can also be illustrated with maps. This will be illustrated in the next section.

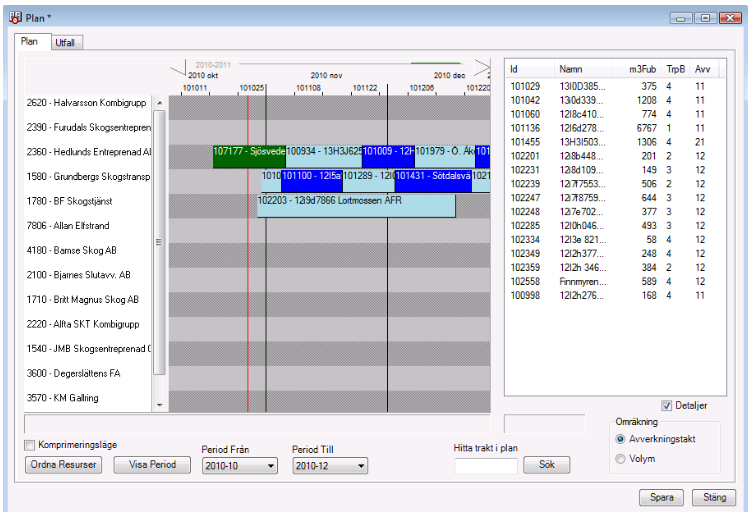


Figure 29. An example with a Gantt chart in VSOP.

7.6 Case study

Evaluation of the optimization model is done by testing its functionality in a case study together with Korsnäs. Data about industrial demand on a weekly basis, harvest team information, stand information and forecasts of product recovery, costs, etc. is extracted from the VSOP system. The case study area covers an area of X km2 where all the stands and location of delivery timber is located in the south east part of the area, northeast of the city of Uppsala. The case study comprised 257 harvesting sites, 52 location with delivery logs, 19 mills and 21 harvesting teams (Figure 30). The overall demand for four months was 318,502 m3fub divided into 6 assortments (pine and spruce timber, pine, spruce and birch pulp wood and fuel wood). The total available volume representing about a half of a year was 373,176 m3fub. The planning horizon was divided into 34 periods, one period for each of the first 31 days and then one for each of the following 3 months.

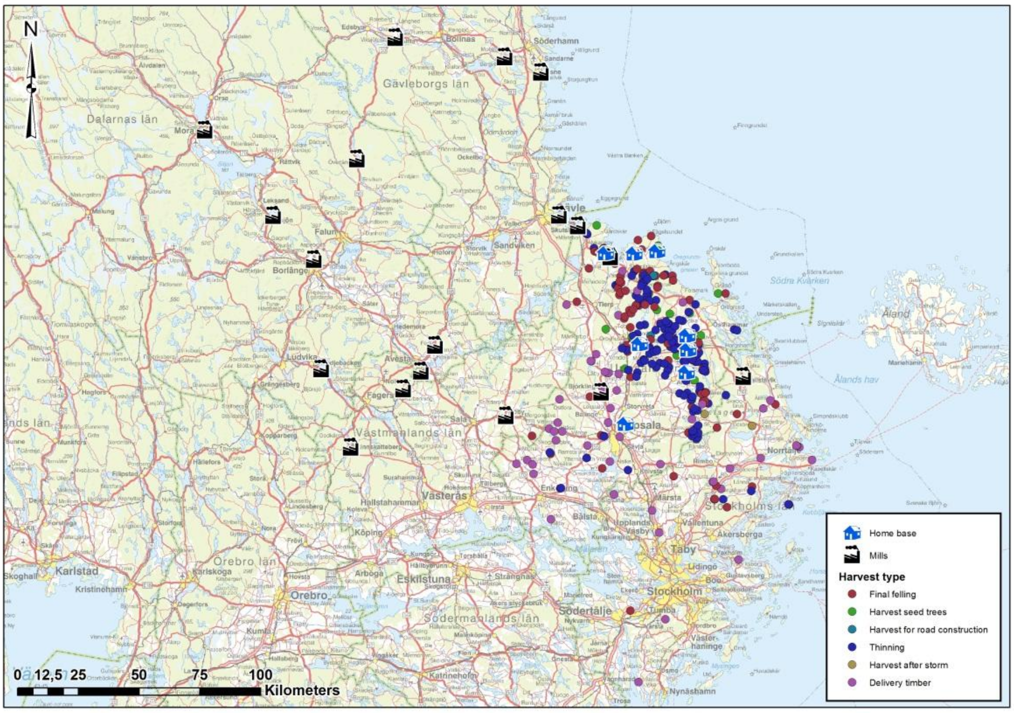


Figure 30. The spatial extent of the test area showing harvesting sites, mills and home bases for harvest teams.

The number of available areas, size and volume are given in Table 16. The availability of different assortments and the demand is given in Table 17. Based on the volume it is possible to satisfy the lower limit of the demand. There is only one aptan file associated with each harvest area.

Table 16. Information on the harvest areas.

Harvest type	Number	Area (ha)	Volume
Harvest seed trees	19	62.78	4,042
Harvest after storm	2	1.34	43
Harvest for road construction	2	11.29	135
Final felling	93	1,138.46	285,205
Thinning	141	1,634.25	72,965
Delivery timber	52	0	10,787
	309	**2,848.12**	**373,177**

Table 17. Information on the supply and industrial demand for each assortment.

Assortment	Abbreviation	Available volume	Target Demand	Lower limit demand
Pine Timber	TT	127,831	113,819	91,055
Spruce Timber	GT	73,285	62,400	49,920
birch pulp wood	LM	18,996	17,183	13,747
Pine & Spruce pulp wood	BM	83,320	74,400	59,520
Spruce pulp wood	GM	60,035	43,300	34,640
Fuel wood	BV	9,709	7,400	5,920
	Total	373,176		

7.7 Results

The results will be described in several headings. We start to describe general results but with a focus on harvesting and transported volume. Next we describe the flows and catchment areas for industries and assortments. Then we describe some short term solutions; this is the scheduling and movements of teams. We end to describe the optimization processes and the solution time and model size for the different subproblems.

7.7.1 Harvesting, transportation and costs

Table 18 gives information on the harvested volume for each month divided into final felling, thinning and other operations. The harvested volume is stable over the first three months and decreases for the last month. The reason is that the demand is lower in the last period and also that more harvesting is done in prior periods and stored to the last period waiting to be transported.

Table 18. Information on harvested volumes for each month.

Month	Final felling	Other	Thinning	Total
September	57,418	396	13,549	71,363
October	56,223	230	12,404	68,857
November	58,661	0	11,842	70,504
December	39,883	565	6,162	46,609
Not harvested	53,940	3,029	27,751	84,719

Table 19 gives a detailed description of the harvested volumes (for different harvest alternatives i.e. final felling, thinning and other operations) for each of the assortments and months. In the table, we also provide the delivered volumes to industries together with the minimum demand and targets. From the results it is clear that the solution satisfies all demand constraints but that the delivered volumes are on the lower limit. This is natural as there is no incentive to harvest or deliver more as it would incur a higher cost. In order to deliver more to the industries there is a need to have a high penalty to deviate from the target values. As an alternative, we could include a “value” of already having the supply available at the customers. This can be implemented using a high inventory cost in the last period. Also in this table we can see that the harvested volume decreases for December, the last time period, especially for the assortments pine pulp wood, fuel wood and pine timber.

Table 19. Detailed information on harvesting and delivered volumes.

		harvested volumes				delivered volumes		accumulated		
	Assort.	final felling	other	thinning	total	harvested	delivery timber	delivered	min demand	goal level
September	BM	10,016	80	4,597	14,693	13,358	482	13,840	13,840	17,300
October	BM	11,460	11	5,730	17,202	16,469	0	30,309	29,120	36,400
November	BM	14,352	0	5,449	19,801	19,191	0	49,500	45,120	56,400
December	BM	7,472	53	2,908	10,434	10,020	0	59,520	59,520	74,400
Total	BM	43,301	144	18,685	62,130	59,038	482			
September	BV	1,653	0	51	1,704	1,360	0	1,360	1,280	1,600
October	BV	1,658	10	80	1,748	1,974	4	3,338	2,960	3,700
November	BV	1,503	0	20	1,522	1,413	183	4,934	4,640	5,800
December	BV	956	0	4	961	934	52	5,920	5,920	7,400
Total	BV	5,770	10	155	5,936	5,681	239			
September	GM	4,778	10	4,877	9,665	9,164	2,116	11,280	11,280	14,100
October	GM	6,257	20	3,271	9,548	8,283	0	19,563	19,280	24,100
November	GM	6,985	0	3,608	10,592	9,726	0	29,289	27,360	34,200
December	GM	5,132	0	743	5,875	5,341	10	34,640	34,640	43,300
Total	GM	23,152	30	12,497	35,680	32,514	2,126			
September	GT	13,389	10	1,264	14,663	13,613	327	13,940	12,880	16,100
October	GT	11,346	108	732	12,187	13,168	210	27,318	26,640	33,300
November	GT	9,960	0	755	10,715	10,785	1,097	39,200	39,200	49,000
December	GT	11,776	0	170	11,946	10,720	0	49,920	49,920	62,400
Total	GT	46,472	118	2,921	49,511	48,286	1,634			
September	LM	2,259	0	942	3,201	3,193	1,113	4,306	3,869	4,836
October	LM	1,891	68	1,344	3,303	3,277	0	7,582	7,057	8,822
November	LM	2,227	0	755	2,982	2,788	0	10,371	10,371	12,964
December	LM	1,694	218	1,575	3,488	3,376	0	13,747	13,747	17,183
Total	LM	8,071	287	4,615	12,973	12,634	1,113			
September	TT	25,322	296	1,818	27,437	22,735	585	23,320	22,720	28,400
October	TT	23,611	12	1,247	24,870	27,713	0	51,033	45,496	56,870
November	TT	23,634	0	1,257	24,891	24,917	0	75,950	68,112	85,140
December	TT	12,852	293	762	13,906	15,060	45	91,055	91,055	113,819
Total	TT	85,419	602	5,083	91,104	90,425	630			

Table 20 gives information on different cost aspects such as transportation cost and harvesting costs for different operations. The table also gives other important measures such as average transportation distance, average moving distance, etc. From the table, we can see that the average transportation distance is kept on a good level. It is hence no “creaming” of the close stands in the early months. The average travelling distance between home bases and harvesting sites are also short and stable, clearly below the maximum limit of 70 km defined in the input data. The average travelling cost represents the average traveling cost per day and team.

The average moving costs represents the cost for moving between harvesting sites and is the average cost for moving teams from one harvesting site to another and includes two parts; one fixed cost and one variable cost depending on the moving distance.

The average transportation cost is 56 SEK/m3fub and represents the cost for transporting timber from forest to mill. The total transportation cost is over 14 million SEK which corresponds to about 38 % of the total costs in the case study.

The total number of harvested areas is 142 but the number of moves between areas is only 121. This is possible since some of the areas are neighbors and there is no distance for moving the machines.

The cost for harvesting is 23 million SEK which corresponds to 62 % of the total costs.

At the end of the planning period there is also some ending inventory kept in the forest. The volumes are given in Table 20. The reason for the inventory is that in order to be able to fulfill the demand of all assortments some volumes of other assortments has to be harvested. It is not possible only to harvest one or two assortments in a stand, all assortments must be harvested. Another reason is that it in some occasions is better to harvest volumes close to the mills and leave some of the already harvested volumes that are far away from the mills. In those cases it is a balance between harvesting costs and transportation costs.

Table 20. Detailed information on harvesting and delivered volumes. Costs are described in SEK, volumes in m3 and distances in km.

	September	October	November	December	Average/Total
# areas harvested (started)	66	34	28	14	142
Volume harvested	71,363	68,673	70,374	46,410	256,820
Average travel distance (home)	41	50	45	30	41
Average travel cost (home)	126	155	139	94	128
# moves between areas	45	34	28	14	121
Average moving distance	17	33	29	27	27
Average moving cost	2,129	2,336	2,217	2,174	2,164
Transported volumes	68,046	71,097	70,101	45,559	63,700
Average transported distance	69	61	60	65	64
Average transportation cost	58	54	54	56	56
Total transportation cost (MSEK)	3.965	3.867	3.769	2.556	14.157
Harvesting cost final felling (MSEK)	4.114	3.841	4.095	2.809	14.859
Harvesting cost other (MSEK)	0.044	0.028	0	0.048	0.120
Harvesting cost thinning (MSEK)	2.357	2.350	2.255	1.209	8.170
Total cost (MSEK)	10.556	10.663	10.167	6.645	38.031

Table 21. Ending inventory kept in the forest of the assortments.

Assortment	inventory after the planning horizon (m3)
BM	3,092
BV	254
GM	3,166
GT	1,225
LM	339
TT	679

7.7.2 Transportation flows

The results given in the previous section does not provide any spatial information. To provide some insights for the catchment areas for industries and assortments, we use Google Earth. By generating a set of Google Earth .kml files, we can view different results and some of these are given in this section. The case study area given in Figure 30 can also be illustrated in Google Earth in Figure 31. The allocation of harvesting areas and delivery timber are illustrated with colored dots in the map while industries and home bases are illustrated with black and blue illustrations.

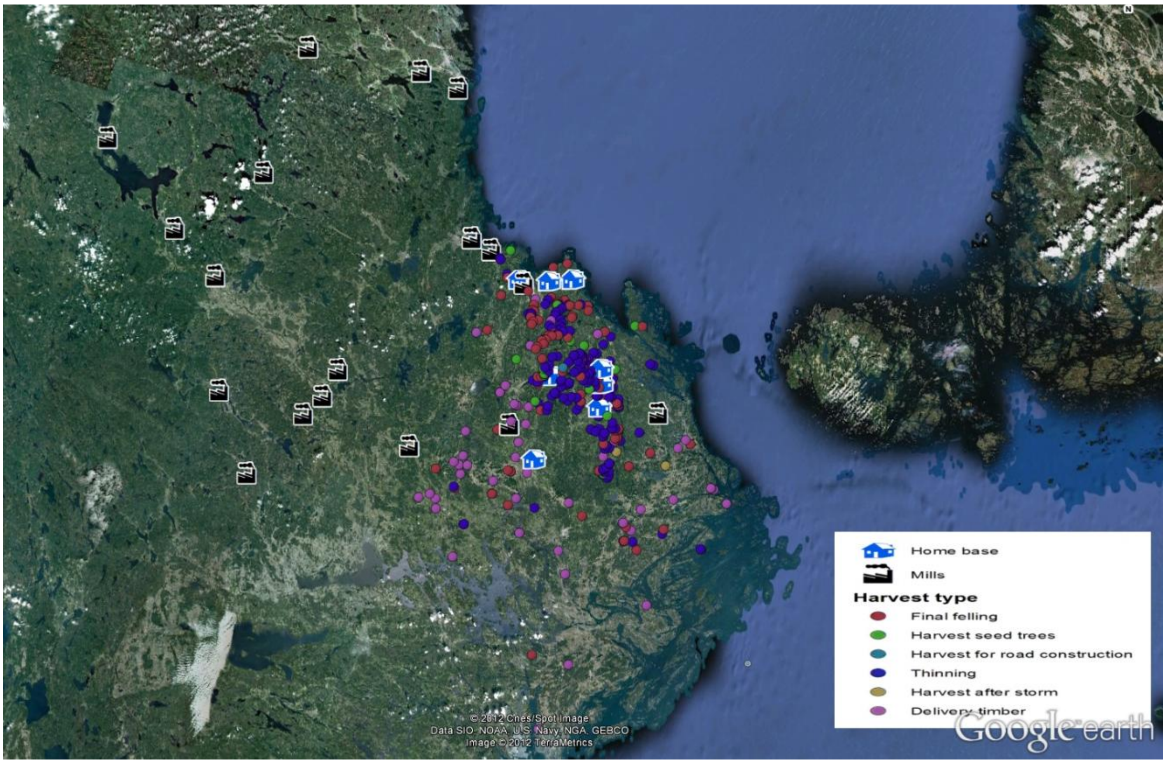


Figure 31. The spatial extent of the case study in Google Earth.

In Figures 32-33-34, we give the transportation flows and the catchment areas for each of the assortments. Note that the maps do not have the same scale. They are scaled to provide the most detailed level for each assortment.

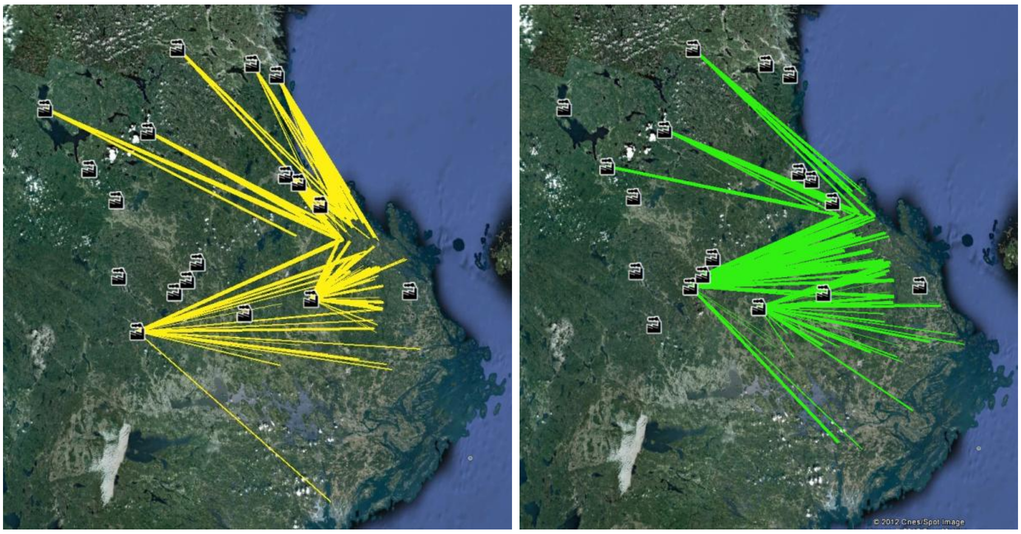


Figure 32. Transportation flows of pine timber TT (left) and spruce timber GT (right).

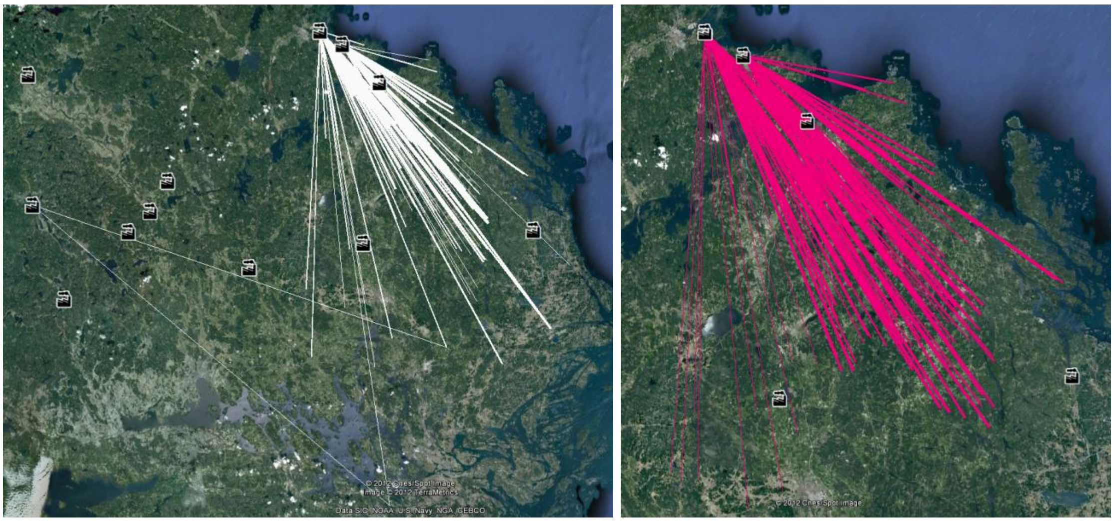


Figure 33. Transportation flows of Birch pulp wood LM (left) and spruce and pine pulp wood BM (right).

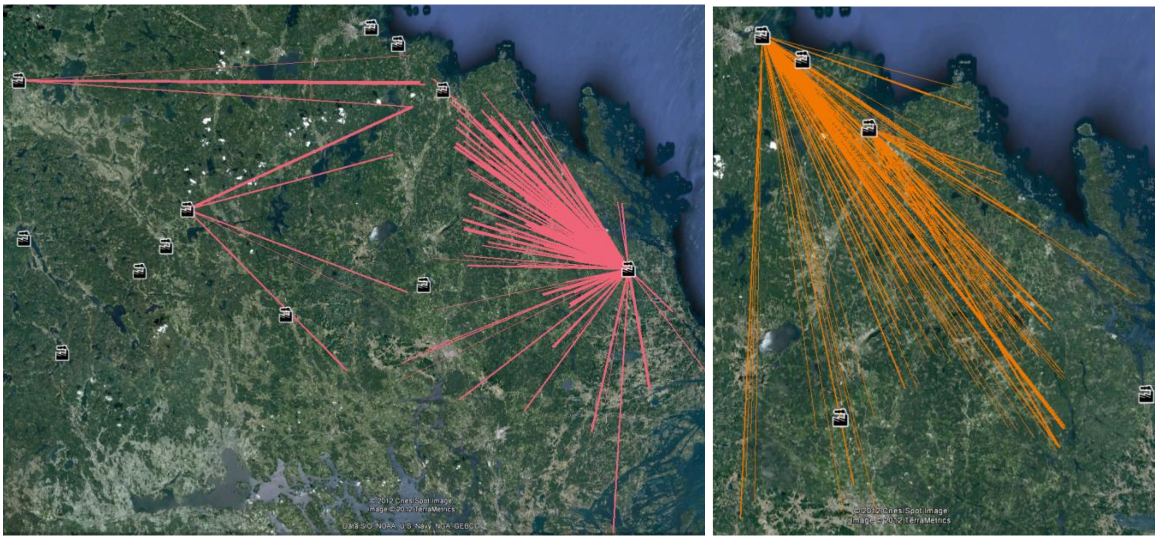


Figure 34. Transportation flows of Spruce pulp wood GM (left) and fuel wood BV (right).

By looking at the maps for those assortments with more than one receiving industry it is clear the model aims to minimize transportation distance and costs. This way of viewing the results gives a very fast understanding of the results regarding transported volumes. It is clear that for Korsnäs many of the industries are far away and it would certainly be profitable if there were more industries close to the harvesting sites.

7.7.3 Scheduling

The schedule for each harvest team can be illustrated in several ways. Figure 35 gives a Gantt chart for all teams. The daily time periods during September (2012) are indicated by 1-30 and the subsequent three months in October-November-December (2012-10, 2012-11, 2012-12). It is clear that the spread of size is large. This Gantt chart can be used as the business decisions to implement. The underlying solution for the production of different assortments is already feasible. Some harvest areas need 1-2 days and some several months due to difference in size. Between each harvest part in the chart there is time for moving the machines to the next harvest site. However, the schedule can also be illustrated in maps. Figure 36 shows two examples where the schedule is illustrated by routes for two of the harvest teams during one part of the planning horizon. The routes are viewed in Google Earth together with the team´s home bases. The planning period starts at the home base and the sequence for moving from one harvesting site to another is illustrated in the maps. When viewing the results from the optimization this way it is very easy to see any kind of incorrectness in the suggested plan. This is also true for the transportation flows as any wrongly information about location or distance will be very clear.

Figure 35. Gantt chart for all teams. The green areas are harvesting time and red are moving times between harvest areas.

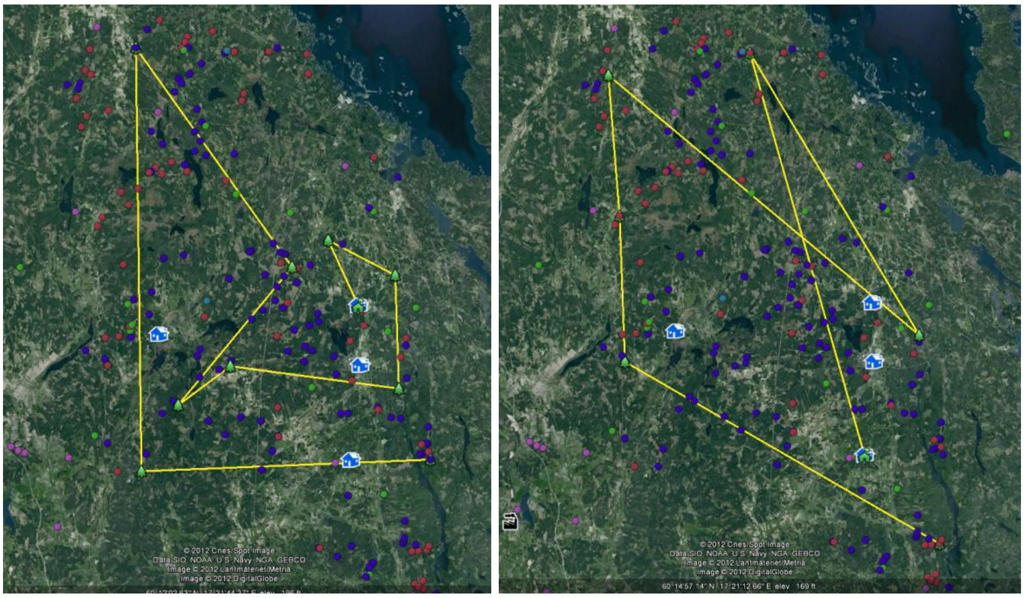


Figure 36. An example of a route (illustrated in Google Earth) for two harvest teams.

7.7.4 Optimization

The evaluation test showed that the optimization model worked properly. It is not possible to solve the full model directly. This is the reason why we developed the multi-phase solution methodology where we solve a sequence of optimization problems. The first phase is to solve a resource allocation problem where it is decided which team that will harvest a particular harvest area. In this model we consider the resources (supply, harvesting capacity, transportation capacity etc.) available. In the next stage, we solve a scheduling problem in which each team is given a sequence of harvest areas. This includes a detailed description of start and end times and different costs including moving costs. It also includes flows between harvest areas and industries. In Table 22, we provide information on the optimization approach. Here, we give the size of each of the subproblems together with the solution time. The maximum time for any subproblem is given as 1800 seconds. If this time is reached, the optimality gap for the MIP problem is given. This is the case for Phase 3. We can also note that a solution within 0.03% was found after less than 60 seconds. The number of variables and constraints given in the table are once AMPL presolve process is completed. Given the size of the problems, we can generate high quality solution within a practical time limit.

Table 22. Information about the optimization models and solution times.

	Solution time (sec)	# Binary Variables	# Continuous Variables	#Constraints
Phase 1	6	2,943	279	279
Phase 2	543	2,520	110,206	10,489
Phase 3	1,800 (0.02%)	30,256	165,974	34,298
Phase 4	95	518	417,582	28,974
Phase 5	420	13,842	317,062	52,148

7.8 Concluding remarks

With high accuracy supply data, provided by ALS of the forest, and a data management system like VSOP, it is possible to build an advanced decision support system for scheduling harvest activities. The optimization model and method is a key component in order to create an efficient harvest schedule for a number of harvesting teams while considering detailed industrial demand, forest supply and transportation capacity. The suggested schedule generates less expensive harvesting and transportation activities for any forest company than possible with manual planning. The improved possibilities to allocate adapted products according to the industry demand will probably provide more revenues and more satisfied industrial customers than manual planning. All this is typical for models that have a global overview of all activities and constraints.

The optimization model requires a large amount of detailed data and it is very important to controlling the accuracy of the data. Such controls can also be used to identify likely erroneous data and hence improve the quality. If the quality of the data is low, so will also the quality of the solution; “garbage in – garbage out” is very true in this sense. When solving the model, it is also possible to identify errors in the data, for example wrong demand information, by identifying infeasibilities. This is also a valuable control mechanism.

The solution time for the optimization is less than one hour for the case study at Korsnäs. In order to make the model suitable for practical use, the optimization time should be decreased to a maximum of 15 minutes. The current solution method is by no means optimized for speed and we are convinced, from our experience from similar implementations, that such lower solution times can be met.

8. Discussion

The outcome of task 5100 shows clearly that each wood supply chain is unique but can be described, analysed and compared with one common framework.

The logistic solutions to build efficient wood supply chains must be unique for each situation but there are core modules that a novel logistic model should consist of.

The results from the five tasks in work package 5000 shows examples on core modules building a novel logistic model for efficient wood supply integrating forestry with industry.

These core modules can already now be used to build novel logistic models. The results from work package 5000 and 4000 have within the FlexWood project been used to build novel logistic systems.

In the Swedish use case, task 8100, both the agile bucking control (task 5400), optimized scheduling (task 5500) and improved description of the forest stand via areal laser scanning (work package 4000) have been tested and built in to a commercial software developed by Logica (VSOP).

Both bucking instructions (task 5400) and scheduling (task 5500) together with terrestrial laser scanning (work package 4000) have been used in the webservice developed in work package 7000. The webservice shows the possibilities to use different core modules to build novel logistic models adaptive in different wood supply chain contexts all over Europe.

To be able to buld novel logistic solutions standards and common ways to describe industrial demand and forest wood supplies are essential. The work in task 5300 is an example of how to describe demand and supply in a general form possible to use

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