Era-Net Transport – Sustainable logistics and supply chains (ENT III FLAGSHIP 2015 CALL)

MultiStrat final report

Multimodal strategies for greener

and more resilient wood supply



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Multimodal strategies for greener and more resilient wood supply

1. Key findings

The objective of MultiStrat was to establish an integrated framework for testing multimodal strategies for greener and more resilient wood supply, delivered as a supply chain simulation model for participatory evaluation and implementation of results. The work was structured in 3 work packages: WP1 Supply chain mapping, WP2 Supply operations analysis and WP3 Supply chain modeling and evaluation. The project spanned 3 climate zones; continental (Austria with rail transport), sub-arctic (Sweden with rail transport) and oceanic (Norway with sea transport) and therefore started with the development of common frameworks to enable comparative cataloguing of regional challenges, capacities and solutions.

WP1 Supply chain mapping – In a supply chain context, resilience represents the ability to sustain supply in the face of disruptions. This work package started therefore with mapping of disruptions (event, impact and frequency) for all three regional cases as well as the management processes which respond to these (annual, intermediate and monthly/weekly cycle). In all three cases, the most critical risks are found on the supply side and related to weather events (Austria; wind storms, Sweden; varying terrain and road bearing capacity, Norway; bearing capacity and occasional wind storms). The agility required of the organization to meet disruptions typical for the region was generally reflected by the frequency of control and planning cycles and their time horizons. The Swedish case forest owner association, for example, relied on a rolling monthly re-planning cycle for updating the following 3-months (sharp plan for the first month, prognosis for the following 2 months). The Norwegian forest owner association had 4 re-planning cycles per half-year with a sharp plan for the upcoming period and updated prognoses for the following periods. In contrast, the Austrian organization (with its own forest) could allocate 60 % of monthly harvesting at the beginning of the annual cycle, leaving 40 % in reserve to meet disturbances. At the operational level (weekly, daily) the greatest need for coordination was between truck arrivals and multimodal departures. A general process framework was drafted to capture the typical sequence of management activities used in forecasting, planning, execution and control of wood supply (7 processes, 22 activities with categories for time horizon and flow resolution).

WP2 –*Supply operations analysis* – Given the variation in conditions between regions, this work package started with developing a common framework for analysis of organization-level variation in harvesting production and multimodal transport, as well as the driving factors behind this variation. The framework enables presentation of multi-year time series with relative weekly production and transport pace (% of annual average) with the corresponding weekly temperature, precipitation and snowdepth. Using this framework, the effects of driving factors for variation in production and transport pace could be more clearly seen and compared between regions. The three regions demonstrate contrasting seasonal patterns of supply pace. The most fundamental difference is that the snowpack in the Austrian case often represents an extra cost or direct hinder for wood supply, while in the Swedish and Norwegian cases snow enables access to wood supply for areas of low bearing capacity. In the present data weather parameters could explain up to 50 % of variation in weekly production and transport pace. The region-specific differences between production and

transport pace determine the time spent in roadside stock before delivery to mill or multimodal terminal. The typical lead times for the respective regions varied therefore accordingly. The highest proportion of roundwood transported with multimodal solutions was highest in the Austrian case and lowest in the Swedish case. In the Austrian case, direct loading from truck to block-train solutions (up to 9 –wagons) caused a maximum 5 day prolongation of the lead time between harvesting and mill. In the Norwegian case, the time for vessel cargo accumulation (2500-5000 m3) caused an 2,4 weeks prolongation of lead time, on average. The quantitative analysis of weather parameters was useful for structuring the effects of weather on supply challenges. The driving factor for variations, however, starts with roundwood prices and the forest owner's willingness to sell wood. This study has focused more on quantifying the residual short-term variations in wood supply within a given market situation.

WP3 Supply chain modeling and evaluation. This work package focused on developing supply chain simulation models for testing multimodal innovations and enabling participatory evaluation of strategies to counter supply chain risks. The respective researchers focused on key aspects for the regional cases. The Austrian work continued with a simulation study for quantifying the effect of fixed levels of multimodal transport (0, 50 %, 100 % of volume via block-train solution) on system KPIs (three typical scenarios: business as usual, high snowfall levels and windstorm salvage). The Swedish work focused on further simulation studies of lead times for direct and multimodal transport (system-train solution) in order to test the simulation approach and compare values with those empirically mapped in WP2. The Norwegian work focused on development of two demonstration modules for testing management alternatives for entire supply systems over the whole supply organization. The first (supply chain demo I) provides weekly visualization of the geographical distribution of production, truck and vessel transport. The second (supply chain demo II) provided an optimization tool based on the same graphical interface, used for testing and visualizing the effect of multimodal strategies (cargo volume class and terminal capacity as well as load collection practices) within the seasonal trends mapped in WP2.

Compared to truck transport alone, the Austrian results showed a 6 % reduction of CO_2 emissions and 29 % reduction of lead times from forest to mill for the current block-train solution. The reduction of lead times for multimodal solutions increased further to 54 % for the increased wood flows after wind storms. The Swedish results show that the simulated lead times for truck transport varied between 11-43 days, in contrast to the annual median of 37 days resulting from the methods used in WP2. The simulated values for lead time from forest to pulpmill via the system-train solution increased to 50 days. Regarding tools for working at the organization-level, the Norwegian results provided optimal truck/vessel solutions for pulpwood deliveries during 12 balance periods (4-5 weeks) throughout the yearly cycle. The optimal proportion of vessel use followed the same seasonal pattern as provided by transport statistics in WP2, but with a slightly lower overall level. The optimal solutions enabled access to a wide variety of geographies with minimal variation in sum transport system costs, providing a good demonstration of the structural flexibility enabled by multimodal solutions.

Synthesis. In all three regions, multimodal system provides a robust base level of transport capacity to ensure stable deliveries from terminal stocks regardless of varying operating conditions. However, WP2 showed variation in production pace was greater than for transport pace, and that the bottleneck for improved supply chain performance was therefore production. The simulated re-

scheduling of production based on weather-based modeling of weekly bearing capacity presented a plausible alternative for evening out production from the head of the value chain. The experiment provided a simple demonstration of the potential for improved resilience to operating conditions through an adaptive management response enabled by weather-based modeling of site availability. Following this direction of development enables further exploitation of the structural flexibility inherent to multimodal solutions. The improved supply chain coordination between production and transport is synonymous with higher capacity utilization and shorter lead times. For the forest sector, better control over lead times ensures higher roundwood freshness and reduced deterioration/degradation. This translates directly to lower costs and higher product value; with direct impacts for competitive advantage.

2. Project progress and deliveries

The project had an allotted time frame from June 1, 2016 to Sept 29, 2018. The original time frame extended to 29.June 2018, and a 3-month extension was granted due to low initial progress during data collection. All three work packages were completed by the final date. Final reporting was done in Oct 2018.

The project had 5 milestones marking progress from common understanding of supply chain challenges (MS1) with a draft model architecture (MS2) before completion of supply operations analysis (MS3) for validation of regional models (MS4) and final analysis (MS5). Work packages 1 and 2 were dependent on developing common frameworks to enable direct comparison between the regional cases. This work proved to be more time consuming than expected, because of the need for consensus between countries with varying data availability and resolutions. The approach helped to better identify the relevant supply chain challenges.

	MS1	MS2	MS3	MS4	MS5
WP1 - Supply chain mapping	Common understanding of challenges achieved				
WP2 - Supply operations analysis			Harvesting and transport analysis complete		
WP3 - Supply chain modeling and evaluation		Model architecture drafted		Models validated	Final analysis complete
MS reached	Q2/2017	Q2/2017	Q2/2018	Q3/2018	Q3/2018

 Table 1. MultiStrat project milestones.

In the course of working through towards MS1 (WP1) and MS3 (WP2) supply chain challenges became clearer. Regarding solutions, managerial response should ideally handle an entire supply organization, with the full selection of terminals used by management to balance supply pace and demand. The results of this was the branching of WP3 into 3 models: i) the originally drafted single-terminal simulation model providing an advanced management cockpit interface (Austria), ii) a single-terminal simulation model focusing on the consequences of seasonality for lead times (Sweden) and iii) a multi-terminal tactical model providing geographic interface for visualization and

analysis for a whole supply organization (Norway). The resulting documentation of planned deliverables is indexed below.

Deliverable	Name	Documentation index
1.1	Catalogue of typical risk scenarios	WP1 report: 3.1
1.2	Common definitions and resolutions for risk, disruptions, scenarios	
1.3	Catalogue of system elements and manager business processes	WP1 report: 3.2, 4.1
2.1	Variation in organization-level variation in production pace and driving factors	WP2 report: 3.2, 3.5, 3.6
2.2	Variation in organization-level variation in transport pace and driving factors	
3.1	Final model architectures (revised after original draft)	WP3 report: 3.3, 5.3
3.2	Validated regional supply chain simulations models with manager-generated multimodal strategy options implemented.	
3.3	Quantitative analysis of the effect of multimodal strategies on supply chain resilience and sustainability.	WP3 report: 3.4, 5.4

 Table 2. MultiStrat deliverables and WP-report documentation index.

Participatory evaluation of the multimodal strategies was run in the Austrian case (WP3 report: 6). Participatory evaluation of production strategies and resultant modeling of potential for rescheduling of production were run in the Norwegian case (WP3 report: 5.5). Additional content outside of the planned deliverables include development and testing of methods for analysis of lead-times (WP3 report: 4.3, 4.4).

3. Achievement of objectives

The objective of MultiStrat was to establish an integrated framework for testing multimodal strategies for greener and more resilient wood supply, delivered as a supply chain simulation model. The objective regarding integrated frameworks were fulfilled via the common frameworks from work packages 1 and 2 and the corresponding analysis. The objective regarding delivery as supply chain simulation models was based on the original ambition in work package 3 for a "one-size-fits-all" simulation model. This ambition had to be re-worked to meet the challenges which arose in WP1 and 2. The resulting spatial scale of the WP3 supply chain models increased considerably from the Austrian (1-terminal) to Norwegian (10-terminal) models, with a corresponding progression from simulation to optimization to handle the increased complexity. The increased focus on lead-time analysis provided by the Swedish simulation model was not envisioned at the time of project initiation, but added during the work with WP3. The Norwegian workshop for testing production management strategies, while not in the original plan, was straightforward. The Austrian participatory evaluation of multimodal strategies was done according to plan. The Norwegian followup study of the potential for production re-scheduling was enabled by a prototype developed in a parallel project. In conclusion; the original objectives were fulfilled, and additional ambitions which arose underway were also reached.

The project work has two noteworthy aspects. The first concerns the structure of the project work content. The progression from risk/management process mapping to quantitative supply chain operations analysis provided a launch pad for the analysis approaches which were finally developed and used. The second concerns advance beyond state-of-the-art. The project constitutes the first international comparison of seasonal variation in wood supply chain operations, driving factors and

resulting lead times. In hindsight, it may seem obvious that this was the correct path to follow, reaching consensus on common frameworks proved to be a time-consuming iterative process, which in the end paid off in terms of increased insight. Compared to monthly-level statistics typically used for such analysis, weekly aggregation of daily data gave more consistent trends, and the possibility to correlate these with weather data. Initially, the choice of regions (continental, sub-arctic, oceanic) may also seem extreme but this selection served to capture sufficient variation in operating conditions to provide contrasting seasonal trends.

Regarding internal research team interactions, the integrated framework was enabled by the portfolio of competencies brought into the project by the respective partners. Examples include: Norwegian and Austrian supply chain mapping experience and syntax in WP1, Swedish data reporting and operations analysis in WP2, and comprehensive simulation and optimization experience from all parts in WP3.

4. Recommendations

In general, multimodal solutions are known to provide both reduced emissions and transport costs. In this context environmental goals go hand-in-hand with economic efficiency. However, the capability which multimodal systems provide to reduce system shock after both minor and major disturbances is important for sector resilience. The structural flexibility to both re-source and reroute wood flows with limited extra costs is a key to development of new collaborative approaches in wood supply.

While often considered the realm of company strategy and investment, investment in terminal networks increases sector resilience forg both existing and new industries in the growing bioeconomy. The optimal design of such bio-economy networks varies between regions. Optimal design should be analyzed further to provide decision-makers, both public and private, with a better foundation for investment decisions.

Regarding the continuation of research work, an important result was the reduced lead times provided by multimodal solutions after major natural events such as windstorms. This reduces the subsequent risk for raw material deterioration, however further insight and development requires concurrent modeling of raw material value based on seasonal weather. A project proposal for further work on lead-times and wood value (GreenLane), has been submitted to the upcoming Era-Net Forest Value call. The GreenLane proposal builds on the MultiStrat frameworks and modeling approaches.

5. Project evaluation

As noted under point 3, the original project objectives were fulfilled. Additional ambitions which arose underway were also reached. With such a small research team, project management was kept informal, and enabled flexibility to react to regional challenges. However, the project time plan was optimistic for work packages 1 and 2. More unified progress in work package 3 would have been aided by an industrial steering committee.

6. Dissemination

Publications, presentations

- Asmoarp, V, Davidsson, A, Jönsson, P ; (2017): Prediction model for variations in harvester production. Precision Forestry 2017 Producing more from less: towards optimizing value in the bio-economy from data driven decisions. Stellenbosch Feb 28-Mar 2, 2017. Proceedings
- Asmoarp, V, Davidsson, A ; (2017): Prognosemodeller för att förutse volymutfall I virkesforsörjning. Skogforsk arbetsrapport 958-2017.
- Fjeld, D; (2017): R&D in the production-transport supply chain: status, ongoing work, future paths. Steering committee ARENA SKOG Infrastruktur. Presentation 17-08-11.
- Fjeld, D; (2018): Transport lead times in Trøndelag how can we optimize these? ARENA SKOG Timber Logistics Seminar. Presentation 18-01-18.
- Fjeld, D; (2018): Wood supply strategies Scandinavian trends and highlights. Symposium: Operations Management in Wood Products Industries, 17.5.2018, Vienna, AUSTRIA. Presentation.
- Fjeld, D; (2018): Seasonality of truck transport lead-times in coastal Norway. Proceedings of the Nordic-Baltic workshop Cost modeling approaches and latest news from the front. Oslo 11-12th Sept, 2018. Proceedings.
- Fjeld, D; (2018): Seasonality of wood supply operations in coastal Norway. FORMEC 2018 Madrid 24-28th Sept, 2018. Proceedings.
- Fjeld, D, Westlund, K, Rauch, P ; (2018): MultiStrat veier til mer robust virkesforsyning. Norsk Skogbruk Nr. 10 2018.
- Kogler, C; Rauch, P (2017): Multimodal strategies for greener and more resilient wood supply in Austria. Symposium on Systems Analysis in Forest Resources, AUG 27-30, Seattle, USA. Presentation.
- Kogler, C; Rauch, P (2018): Wood Procurement in Austria. Symposium: Operations Management in Wood Products Industries, 17.5.2018, Vienna, AUSTRIA. Presentation
- Kogler, C; Rauch, P (2018): Workshop zu multimodalen Strategien für eine nachhaltige und resiliente Holzlieferkette bei den Österreichischen Bundesforsten. Workshop Österreichische Bundesforste, 5.7.2018, Purkersdorf
- Kogler, C; Rauch, P (2018): Workshop zum Aufzeigen von multimodalen Strategien für eine nachhaltige und resiliente Holzlieferkette bei den Österreichischen Bundesforsten. Workshop Österreichische Bundesforste, 28.09.2018, Purkersdorf
- Kogler, C; Rauch, P (2018): Discrete event simulation of multimodal and unimodal transportation in the wood supply chain: a literature review (accepted Silva Fennica).
- Rauch, P Kogler, C; (2018): Forstlogistik 4.0. Österreichische Forstzeitung, 08/18, 6-8. (Forest Logistics 4.4, Austrian Forestnewspaper).

- Rauch, P; (2018): Finding robust strategies to overcome biomass supply risks . [Poster] [EUBCE 2018 European Biomass Cinference & Exhibition, Kopenhagen, MAY 14-18, 2018]
- Rauch, P; (2018): Finding robust strategies to overcome biomass supply risks .Abstract In: ETA-Florence Renewable Energies, Proceedings of the 26th European Biomass Conference and Exhibition
- Rauch P; (2018): Multimodal wood supply chain simulation. Presentation, [8th Edition of the International Symposium FOREST AND DEVELOPMENT, Brasov, OCT 25-27, 2018]
- Rauch, P; Kogler, Ch (2017): Simulating multimodal wood supply chains including risks agents. Abstract In: INFORMS, INFORMS Annual Meeting 2017 Houston – Proceedings
- Rauch, P; (2017): Simulating multimodal wood supply chains including risks agents. [INFORMS Annual Meeting 2017, Houston, TEXAS, OCT, 22-25, 2017] Presentation.
- Steininger B., Gronalt M. (2017): Strategien zur robusteren Holzlieferkette. Holzkurier, S5. Article in forest based industry sector newspaper.

Project reports

- Fjeld, D, Davidsson, A, Kogler, C, Rauch, P, Westlund, K ; (2017): MultiStrat interim work report for WP1 Supply chain mapping. Era-Net Transport 39 pp.
- Westlund, K, Jönsson, P, Fjeld, D, Kogler, C, Rauch, P ; (2018): MultiStrat interim report for WP2 Supply chain operations analysis. Era-Net transport 36 pp.
- Kogler, C, Rauch, P, Westlund, K, Jönsson, P, Fjeld, D; (2018): MultiStrat interim work report for WP3 Supply chain modeling. Era-Net transport 39 pp.

Pending submissions

18th Symposium on Systems Analysis in Forest Resources (SSAFR) Mar 3-7th 2019, Chile:

- Fjeld, D, Davidsson, A, Kogler, C, Rauch P, Westlund, K. A common framework for comparison of system risks and management processes in multimodal wood supply report from ERA-NET project MULTISTRAT (WP1).
- Westlund, K, Jönsson, P, Fjeld, D, Rauch, P, Kogler, C. A common framework for analyzing seasonal and weather effects on wood procurement in the forest supply chain report from Era-Net project MULTISTRAT (WP2).
- Fjeld, D. Managing seasonality of wood supply with multimodal systems in coastal Norway.
- Kogler, C; Rauch, P. Evaluation of resilient and sustainable strategies based on scenario analyses of a discrete event simulation model for the wood supply chain in Austria
- Rauch, P; Kogler, C. Testing multimodal wood transport options with discrete-even simulation.

Winter Simulation Conference (WSC) 2018, Dec 8-12th 2018, Gothenburg, Sweden:

Kogler, C (2018): A discrete event simulation model to test multimodal strategies for a greener and more resilient wood supply in Austria

MultiStrat interim work report for WP1 (Supply chain mapping)



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Synopsis

WP1 is the forum for establishing a common understanding of sector challenges in the respective regions (MS1). The work package mapped and compared supply chain risks and disturbances (**D1.1**, **D1.2**) typical for each region within a common framework (Tables 5a, b, c). The relevant system functions are catalogued (Tables 3a, b, c) with their corresponding supply chain coordination processes (**D1.3**) for planning and control (Tables 4a, b, c). These are explored in more detail for annual cycles (Figures 2a, b, c), intermediate cycles (Figures 3a, b, c) and monthly, weekly, daily cycles (Figures 4a, b, c). The report concludes with a general framework of wood supply management processes (Table 6).

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1. Introduction

Work package 1 *Supply chain mapping* was the forum for establishing a common understanding of sector challenges in the respective regions. The goal of the first task (T1.1) was to complete an initial mapping of supply- and demand-related risks and disturbance patterns. The goal of the second task (T1.2) was to map the possibilities to mitigate risks and disturbances through supply management processes.

The study compared three wood supply organizations operating in continental, sub-arctic and maritime conditions. The common frameworks for data collection and comparison were developed by the project group during the initial stage of WP1. The mapping of risks and management processes is based on personal interviews with the relevant functions of the organizations. The emphasis of the mapping is on coordination between functions in roundwood supply leading up to and including multimodal transport to the mill customer.

The results of the mapping are presented in 3 parts:

- an overview of operating conditions and management functions
- frameworks for cross-functional coordination and risks
- the management processes used to mitigate risks and disturbances

The syntax used for representation of business processes is Business Process Management Notation (BPMN2.0). The final chapter consists of a brief comparison of the three organizations within these frameworks before presenting a general framework of business processes in wood supply.

2. Overview of participating organizations

The MultiStrat project spans three wood supply organizations supplying sawlogs, pulpwood and energy assortments. The Austrian case is consists on a selected portion of the Austrian Federal Forests who operate as a limited stock company with the Austrian state as the sole stock holder. The Swedish and Norwegian organizations operate as limited stock forest owners associations with their members as stock owners. The annual harvesting volumes range from one to two million m³ per organization and the harvest intensity ranges from two to four m³ per year and hectare. All three use contracted services for harvesting and transport, but the Austrian organization also retains their own harvesting personnel for 30 % of their volumes.

Regarding multimodal transport systems, all three organizations use the services of 50-100 logging trucks for transport to forest to terminal or mill (Table 1). In the Austrian case, roundwood for multimodal transport are transferred to their own rail terminals for single-wagon transport to their mill customers (1-5 wagons per transport). In the Swedish case, roundwood for multimodal transport are transferred to the customers' terminals for system-train transport to their mills (24 wagons/train). In the Norwegian case, the logs for multimodal transport are delivered to timber docks at the nominated ports-of-lading (PoL) for transfer to own chartered vessels for domestic cargoes or customer-chartered vessels for export cargoes.

	Austria	Sweden	Norway
Type of organization	Stock company	Forest owners	Forest owners
		association	association
No. of employees	1096	152	77
Harvesting personnel	110 AFF-employed	49 contracted	39 contracted
	logging workers	harvester-forwarder	harvester-forwarder
		teams	teams
Logging trucks	90	95	45
No. of external suppliers	0	17 000	7 727
Annual turnover (€/yr)	231 000 000	138 366 500	86 444 000
Annual supply volume (m ³)	1 527 000	2 027 000	1 170 000
Forest area (ha)	339 000	1 102 000	536 000
Harvesting intensity (m ³ /ha/yr)	4,5	1,8	2,2
Volume per employee	1 393	13 335	15 194
(m ³ /yr/person)			
Annual turnover per employee	211 000	910 305	1 123 000
(€/yr/person)			

Table 1. Key numbers for the participating organizations.

2.1 Operating conditions

The three cases are situated in geographies of varying topography (Figure 1) between the humid continental climate of central Europe (Austria) the sub-arctic climate of Nordic Lapland (Sweden) and the maritime climate of the North Sea (Norway).



Figure 1. Location of participating wood supply organizations.

Regarding harvesting conditions (Table 2), the Austrian case has the most challenging topography with over half of the area steeper than 33 %, followed by the Norwegian (25 %) and Swedish cases (10 %). Average extraction distances are shortest in Austria (approx. 100 m) followed by Sweden (400 m) and Norway (600 m).

Regarding transport conditions, the truck transport distances are shortest in the Austrian case (60-70 km) and longest in the Swedish case (115-120 km). Truck sizes (GVW) are smallest in Austria (40-50 t) and largest in Sweden (60-64 t). Average multimodal transport distances to domestic customers are similar in Austria (rail, 170 km) and Norway (vessel, 200 km) and longer for Sweden (rail) and for Norwegian export customers (vessel). The proportion of annual volume handled by the multimodal system is highest for the Norwegian case (approx. 30 %) and lowest in the Swedish case (approx. 10 %)

	·	·	Typical values or avera	age (range where applicab	ole)
			Austria	Sweden	Norway
Forest	Standing volume	e (m3/ha)	337	106	120
	Area (%)	0-33 % slope	44	90	75
		> 33 % slope	56	10	25
Transport	Extraction	Ground-based	90	400	600
	distance (iii)	Cable harvesting	120	n/a	250
	Truck	Sawlogs	60	118	67
	transport distance (km)	Pulpwood	70	115	74
	Truck gross vehicle weight (t) Multimodal transport distance (km)		40-50	60-64	50-60
			170	250	200 (domestic) 600 (export)
	Multimodal tran	sport cargoes	1-5 wagons	24 wagons/train	1500 m3 (domestic) 5000 m3 (export)
Climate	Temperature	Winter	-1 (-21; 18)	-12 (-14; -11)	-2 (-11; 6)
(monthly	(°C)	Spring	7 (-11;26)	0 (-6; 6)	4 (-7; 25)
values)		Summer	16 (2; 34)	12 (11; 14)	14 (-8; 19)
		Autumn	7 (-9; 25)	1 (-6; 7)	6 (-6; 13)
	Precipitation	Winter	55 (19; 174)	33 (26; 42)	73 (1; 227)
	(mm)	Spring	76 (36; 224)	30 (28; 33)	59 (2; 158)
		Summer	127 (54; 272)	67 (55; 80)	81 (3; 191)
		Autumn	80 (33; 219)	55 (52; 61)	93 (3; 236)
	Snowpack (cm)	Winter	38 (10; 468)	50 (30; 70)	20 (0; 74)
		Spring	18 (1; 705)	50 (15; 75)	7 (0; 60)

Table 2. Typical operating conditions per enterprise.

The comparison of climatic conditions in Table 2 frames the seasonal variation in operating conditions between cases. Average monthly temperatures were lowest for all seasons in northern Sweden (-12 to 12 °C) and highest in Austria (-1 to 16 °C). The greatest range in monthly temperatures was in Austria (-21 to 34 °C). The average monthly precipitation was lowest in northern Sweden for all seasons (30-68 mm), highest during spring and summer for Austria (76-127 mm) and highest during winter and autumn for Norway (73-93 mm). Average winter and spring snowpack depths were deepest in Sweden (50 cm) and thinnest in Norway (7-20 cm), while the range was widest in Austria (1-468 cm).

2.2 Functions per organization

2.2.1 Austria

The Austrian federal forests (AFF) consist of twelve forest management units (geographical regions) which are divided into 121 forest districts. The relevant process owners along the wood supply chain include the different functions/divisions of the AFF as well as external enterprises involved in harvesting and forwarding (according to tendering procedures for harvesting projects), truck transport, train transport and industrial customers (according to supply contracts). While strategic decisions of the AFF are developed either directly by the management board or the supporting wood division management, forest management units (regions) are mainly responsible for tactical tasks. The district management entities as well as the wood harvesting division (121 workers for harvesting and forwarding, responsible for approx. one third of the harvesting volumes) deal primarily with operational tasks.

The main functions are concentrated around market management, transport management (including terminal operations) and harvesting management. The market function is responsible for contracting sales to industry for the respective AFF managers over a larger geography. The transport function plans and coordinates both truck and multimodal operations. The responsibility of the responsible AFF actors and their carriers are restricted to specific geographies. The planning of harvesting and forwarding operations (harvesting packages) is initiated by the AFF managers on a national level and progresses step-by-step down the hierarchy to the district level. Harvesting operations are performed either by AFF or by external harvesting enterprises who have won the tendered harvesting packages.

Function	Process owner	Duties	Geographical responsibility
Market	Industry	Negotiate supply contracts, receive logs at the stockyard.	Organization
	Wood Division Management	Negotiate demand contracts.	Organization
	Forest Region Management	Charge delivery.	Regions
Transport Forest District Management		Plan transport, compile transport packages, manage freight orders, control terminal operations.	Terminal, Forest districts
	Truck Carrier	Transport logs from forest to industry or terminal, manage terminal operations. Terminal, Forest districts	
	Rail Cargo Austria	Plan rail transport, coordinate with carrier, deliver logs to industry.	Terminal
Harvesting	Management board and Wood Division Management	Plan wood harvest, define budget targets and harvesting areas.	Organization
	Forest Region Management	Compile and assign harvest packages/projects.	Regions
	Forest District Management	Coordinate wood harvest.	Forest districts
	AFF Harvesting Division	Harvest and forward wood to roadside.	Local harvesting project area (one or more sites) in a forest district
	I naivesting company		

Table 3a. Austria - Functions and process owners with primary duties and geographical responsibility.

2.2.2 Sweden

The Swedish organization has central market, logistics and production functions with responsibility for operations in eight wood supply regions (VOs) with 27 forestry districts (SBOs). The market function's goals include obtaining the best return on forest products from the association's own sawmills, securing wood supply to the internal sawmills and negotiating the delivery contracts with external mill customers as well as ensuring sales of member round wood. The market function balances and follows-up total supply and demand for forecasted and actual volumes per assortment. The key duty of the market function is to assign the main volume targets and distribute these throughout the organization.

The logistic function, e.g. the logistic manager, plans the annual round wood deliveries to customers. Their key duty is to procure cost-effective transport solutions and ensure timely delivery of agreed volumes to customers. The annual delivery plan is divided in monthly and weekly quotas per assortment with follow-up (monitoring) for the respective periods. The transport plans and delivery rates are followed-up by both production managers and truck associations to ensure coordination of the transport plan with road-side inventories and deliveries to mill customers.

The truck associations are contracted by the logistic function and in turn, contract individual truck enterprises (owner/operators). The associations collect information on disturbances (risks, events and exceptions) and forwards this information to the production manager. Each truck enterprise (owner/operator), typically responsible for a specific geography, also reports disturbances to the regional production managers who aggregate this information for subsequent re-planning of the delivery plan and quotas.

The chief production manager's main duty is to plan and coordinate production between regions (VO or wood supply area), compile the total production and maintain close contact to the logistic manager for re-balancing production and transport resources. The chief manager maintains control of the production and deliveries according to the annual delivery plans, distributed over months, and delegates responsibilities for fulfilling monthly quotas to region managers. Each regional manager (eight in all) plans the production for that region and allocates harvesting resources. This includes delegating roundwood purchase, managing the harvesting resources, updating production and delivery quotas and managing the local transport enterprises. The manager follows-up (monitors) production and deliveries continuously (monthly, weekly and daily). The chief production plans. In case of sudden events, the regional managers are the first to handle the situation and re-plan harvesting and transport resources, since they are closest to the event and its effects on roundwood flows. Local solutions are therefore considered most effective, since they build on experience and more knowledge of typical risks and events.

The district managers of the 27 forestry districts (SBOs) are responsible for reaching the target volumes per assortment through contracting of member harvesting contracts. Their directives or missions are based primarily on information from the regional managers but also on demand forecasts from the market department.

Function	Process owner	Duties	Geographical responsibility
Market	Market manager	Ensure sales of member volumes, secure roundwood supply to internal mills and deliveries to external mill customers.	Organization
Logistics	Logistics manager	Plan roundwood deliveries annually and weekly (with production managers and truck entrepreneurs). Negotiate and procure logistic resources time, follow up round wood inventories in forest, at landings and mill yards.	Organization
Truck association	Manager for the truck association	Report risks, events and exceptions to regional production manager. Re-plan quotas according to information from logistic manager	Organization
and enterprise	Truck enterprise (owner/operator)	Report risks, events and exceptions to regional production managers. Re-plan delivery quotas according to information from logistic manager and regional production manager.	Region
Harvesting	Production manager	Plan annual production, harvesting resources and plan the production at the regions. Follow-up production and delivered volumes. Inform regional production managers and logistics manager about updated production plans.	Organization
	Regional manager	Plan harvesting teams and transport resources at regional level and time period. Re-plan resources after sudden events and exceptions. Monthly meetings with truck companies and logistics manager.	Region
	District manager	Purchase members' round wood.	District
	Harvesting teams	Follow the harvesting plan and stand priority with respect to volumes and assortments.	District

Table 3b Sweden - Functions, process owners, primary duties and geographical responsibility.

2.2.3 Norway

The Norwegian organization is divided into three regions (North, Mid, South) and 30 districts. The main functions include market, road transport and harvesting. The overall responsibility for development of supply coordination processes belongs to the market manager. Within the market function the management of sales to customer mills belongs to the sales manager with responsibility for setting market goals, negotiating volumes/prices, developing delivery plans, monitoring deliveries and updating delivery plans.

The organization charters their own shipping capacity for domestic deliveries and the responsibility for managing this capacity is assigned to the sales manager. Responsibility for managing truck transport belongs to a daughter company with one chief transport manager and 4 area managers. The daughter company acts as a transport association and contracts individual trucking enterprises. The chief transport manager contracts transport capacity, develops transport plans and updates these after monitoring deliveries. The area transport managers manage the deliveries to mills and terminals by the contracted truck enterprises.

The harvesting function is led by the three regional production managers who forecast regional wood purchases, contract harvesting capacity, develop harvesting plans (goals) and allocate harvesting capacity to the 30 district managers. The 30 district managers are responsible for purchasing harvesting volumes from the association members and planning/managing the harvesting operations.

Function	Process owner	Duties	Geographical
			responsibility
Market	Sales manager	Set market goals	Organization
		Negotiate volumes and develop delivery plans	
		Monitor deliveries and update delivery plans.	
	Vessel	Adjust vessel capacity	Organization
	management	Develop and update vessel plans	
		Coordinate vessel plans with truck transport and customers.	
Road	Chief manager	Adjust truck transport capacity	Organization
transport		Develop truck transport plans	
		Monitor deliveries and update truck transport plans.	
	Area manager	Manage area deliveries to mills and terminals	Region
Harvesting	Region manager	Forecast regional wood purchase	Region
		Adjust and allocate regional harvesting capacity	
		Develop harvesting budget	
		Monitor and adjust harvesting budgets/plans.	
	District	Purchase area harvesting volumes and manage harvesting	District
	manager	operations.	

Table 3c. Norway - Functions, process owners, primary duties and geographical responsibility.

3. Results

3.1 Cross-functional coordination and risks

3.1.1 Austria

The general framework of the AFF planning process (Table 4a) is divided into three time horizons. Longterm plans for wood harvesting and transport are developed for a time horizon of ten years with annual adjustment, in contrast to long term market planning which does not exceed a time horizon of one year. On the 10-year horizon there is therefore limited coordination between the functions.

Based on the long-term plans and actual supply contracts, harvest volumes and stands for the upcoming year (medium term) are defined and the AFF Forest Management Unit compiles these in harvesting "packages". These are assigned either to the internal AFF harvesting division (30 %) or, after a tendering procedure, on the open market to external harvesting companies (70 %). This enables the initiation of transport capacity and storage planning, where coordination with market and harvesting functions is implemented through monitoring and adjusting.

The short-term planning concentrates on coordination and control of activities of the wood supply chain (harvesting, forwarding, truck transport, terminal operations, train transport, industry demand). These operations are mainly conducted by the AFF Forest District Management supported by the AFF Forest Management Units. In this stage, contingency plans are developed in response to disturbances.

Table 4.a. Austria - General framework of supply chain coordination between functions from long- toshort term.

Austria	Functions								
	Production	Transport	Market						
Long term (1-2	LO years)								
	Define budget and strategic	Plan and adjust terminal,	Negotiate supply contracts						
	targets, plan wood harvest,	storage and transport	(exit clause in case of price						
	define harvesting areas.	infrastructure, select carrier.	drop).						
Medium term	Medium term (year-month)								

	Develop top-down values for harvesting plan, compile harvest packages/projects, assign harvesting operation to internal or external harvesting units, re-plan in reaction to harvesting	Plan transport capacity, control terminal operations, monitor and adjust storage, re-plan in reaction to transport disturbances.	Coordinate and adjust volumes (Contract management), re-plan in reaction to market disturbances.
	disturbances.		
Short term (w	eeks)		
	Administer harvesting and forwarding, develop/use contingency plans in case of short term harvesting disturbances.	Compile transport packages from forest to industry or terminal, manage terminal operations, develop/use contingency plans in case of short term transport disturbances.	Develop/use contingency plans in case of short term market disturbances.

Risks (Table 5a) - The most critical risk factors for the AFF are strong wind storms which appear on average every ten years. The effects can be both direct (windthrow volumes in own forests), or indirectly (price slump from a sudden market surplus of wood). In both cases it may take years until the regular harvest plan can be fulfilled again. The recovery generally takes place in several steps and is also slowed by the ensuing development of bark beetle infestations.

On a seasonal level, heavy snowfall during the winter months (January, February, March) are the main risk factors. The hunting and holiday seasons are already considered in advance when assigning harvesting teams and areas. Heavy rains can also reduce the bearing capacity of forest soil and roads, stopping harvesting or truck transport activities, but in most cases the teams can catch up to planned volumes after some days delay. Operational risks such as a sudden delivery stops to mills or technical failure of harvesting respective transport machines occur several times a year, but do not endanger the overall supply process. The main risks in the multimodal (rail) system arise from two events; that the ordered rail wagons are not provided on time by the service provider or full loaded wagons are not picked up due to violation of security issues (e.g. incorrect load-securing by truck drivers or overloading).

In consideration to the relevant risk factors, only 60% of the annual allowable cut volume is assigned to scheduled harvesting projects. The remaining 40% are reserved to react to the actual events within the set of risk factors. The planned harvest projects generally take place during the first quarter of the year. Planned harvest volumes are generally reduced in the second quarter to make space at the timber stockyards for the more frequent risk events anticipated for the third quarter. For the fourth quarter, the impacts of risks such as smaller wind throws have been estimated and the remaining available harvesting capacities are assigned to planned harvesting capacities are concentrated in the involved area to curb the following bark beetle infestation and eventual financial losses. In these events, emergency plans are laid including renting of large stockyards, scheduling additional truck and train transport capacities and adjusting major supply agreements. In comparison, smaller wind throws are compensated by internal re-allocations and increased roundwood stock levels.

Austria	Event description				Event impact					
	Supply events			Demand eve	nts	frequency	Volume (%)	event duration	time to recovery	
Risk	harvesting	Transport	t		mill market	market	_			
frequency		Truck	rail	Ship						
Low	ice breaks treetops						20-30 years	10%	days-(weeks)	2-5 years
	windthrow						10 years	30%	1-2 days	5 years
	bark beetle calamity						10 years	15%	3-5 years	5 years
					capacity change		10 years		Months	months
					break downs		5 years		half a year	half a year
						rapid shifting market price	5 years		Days	one year
Medium	snow						Yearly	5 %	Months	weeks
	rain	Rain					twice a year		Days	week
	hunting season						Yearly			
	holidays						Yearly			
High					delivery stop		Monthly		Days	days
		Break downs					Several times a year		Days	days
			Not available				twice a year		Weeks	weeks
	Break downs						Several times a year		Days	days
			unsafe loading				Monthly		Hours	day

Table 5a. Austria - Overview of supply and demand risks according to typical event frequency and impacts.

3.1.2 Sweden

The market department has the main responsibility to balance supply and demand volumes and consequently request the organization to re-plan due to changes, e.g. decrease or increase harvesting /contracting and adjust transport rates (Table 4b). The market department is also responsible for delivery and updating of price lists and bucking instructions to the regions in order to ensure the correct distribution of log lengths and diameters to each mill customer. Subsequently, supply chain coordination is managed by the production and logistics functions. The core of the coordination process is a rolling three-month master plan where the upcoming month is planned in detail (sharp). The monthly plan includes the selected sites and their destinations, corresponding delivery quotas for deliveries to mill yards and train terminals as well supporting delivery plans for the individual truck companies. Using the three months rolling horizon, the organization always has a view of the coming three month goals and flows within which the plan can be rapidly adjusted for sudden events. All functions have access to the same master plan so adjustments are immediately disseminated to the rest of the organization. Sudden changes impact the planning for the upcoming month and effects all supply operations from harvesting teams, truck and rail transport, and final deliveries to mill yards and terminals.

The production function is responsible for all physical activities ensuring roundwood deliveries to mills, based on the annual plan, the rolling three months plans and sharp plan for the upcoming month. The production organization has three levels, chief production manager, regional production manager (VO) and forestry district managers (SBO). The production management controls and coordinates the total production per region. Initially they have an annual production plan which is scheduled per month according to expected seasonal conditions for that geography. The annual delivery quotas per mill customer (internal and external) and train terminals are then settled as corresponding monthly delivery quotas. When the quotas are settled, the logistics manager negotiates the transport capacity and prices. The negotiations are handled via one truck association for all the transport enterprises working in all the regions. The regions also contract the harvesting teams on an annual basis. The responsibility for fulfilling purchase volume targets from the association members is delegated to the regions and districts.

Table 4b. Sweden - General framework of supply chain coordination between functions from long- to short term.

Sweden	Functions							
	Production	Transport	Market					
Annual plan								
	Plan annual production to meet	Plan supply rate to	Forecast and calculate					
	demand, forecast harvesting	mills/terminals, contract	supply-demand quotas.					
	resources and stand priority, plan	truck resources, plan supply						
	for contracting additional	rate to train terminals.						
	volumes per assortments.							
Intermediate	term (rolling 3 month plan)							
	Plan production from updated	Plan deliveries per district	Balance supply and					
	plan, compare requested	(VO), follow up delivery	demand -stop/increase					
	transport and road side inventory	quotas at train terminals,	production, alter price					
	to prioritize landings. Forecast	terminals and internal and	lists. Update the					
	production, sent plan to logistics	external mills. Plan quotas for	organization with					
	and production districts. Route	truck companies and inform	supply/demand status.					
	harvesting teams according to	VO about updated quotas.						
	volumes and assortments.							
	Update prognosis upcoming							
	month. Contract round wood.							
	Report road side inventory to							
	truck companies.							
Short term								
	Follow up deliveries and	Re-plan at sudden delivery	Follow up monthly plans					
	production on monthly plan,	disturbances, update trucks	from delivery information.					
	report disturbances to logistics,	delivery plans.						
	re-allocate logging teams.							

Risks (Table 5b) – The organization handles risks and events of both low and high frequency. Certain events occur predictably within the annual cycle but at varying times while other events occur more rarely but can have greater consequences. The eight regions (wood areas, VO) covering an extensive supply from the mountainous areas in the northwest to the coastal areas in the east. Accordingly, the regions have varying conditions with respect to planning and risk events. Eventual wind storms strike conifer stands unevenly between these regions. If, for example, the storms affect the mountainous areas of the northwest, the round wood must be transported long distances to train and land terminals, requiring more production and transport resources than for the areas closer to coastal mill customers.

A typical seasonal event is the loss of bearing capacity during the spring thaw. Most of the time, the bearing capacity in the road network can be forecasted and results in closed public roads in specific areas as declared from the road authorities. The time for closure for heavy transport emerges at approximately the same time each year. During other times of the year heavy rainfall can also cause closure of public roads but this more often concerns the private forest road network. In the private road network, roads can be closed with short notice (from one day to another) such that harvested roundwood can be trapped until the roads dry and sufficient bearing capacity returns. One typical way of dealing with these events is overproduction during the winter months to build up stocks and to have numerous landings to transport from during difficult periods. The same applies to the autumn rainfall, where overproduction is planned during late summer on roads with higher bearing capacity and seasonal availability. Unusually cold temperatures (e.g below 25 °C) can also lower the production pace.

These conditions are typically handled by a temporary halt of harvesting operations until temperatures rise again, or moving the machines to warmer areas.

Demand risks include increased or decreased mill demand or even complete stops for all deliveries for mill customers in different time periods. On the short-term, these adjustments in mill demand can also entail changes in price lists or bucking instructions to divert wood flows to other customers with varying demands for log dimensions. These changes can also effect the routing, scheduling and costs for harvesting and transport resources, depending on stand characteristics. Events such as customer investment in higher mill production are more predictable and can be integrated in the annual and consequent monthly forecasts for required roundwood purchase and resource capacity. Events such as permanent loss of industrial capacity or reduction of order volumes over longer periods, on the other hand, may that the market manager reduces these risks by distributing deliveries of the relevant assortments between alternative customers.

The duration and response for the above-mentioned events may be seen in relation to the planning horizon for roundwood purchasing and capacity contracting. In this context wood purchasing is contracted on horizon up to two-years (e.g. the association has two years to harvest and deliver the purchase stands) while harvesting and transport resources are contracted for one year at a time. Loss of individual entrepreneur capacity for harvesting or transport often occurs on an annual- or intermediate basis. In most cases this concerns contractors who terminate their business, go bankrupt or change their service buyers.

Table 5b. Sweden - Overview of supply and demand risks according to typical event frequency and impacts.

Sweden	Event de	scriptio	on		Event impact					
	Supply events				Demand events	frequency	Volume	event	time to	
Risk frequency	Harvesting	Transport			Mill	Market	7	(%)	duration	recovery
		truck	rail	Ship						
Low	Windthrow						10-20 years			6 months
						Changed wood flows (decreased mill demand)	Every 10th years	5%		1 month
						Changed wood flows (increased mill demand)	Every 5 years	25%		6 months
	Lose contracto	or capacity					1-2 years	1,5-2,5 %	2-4 weeks	2 weeks
Medium					Holidays (complete stop for sawmills, reduced production for pulp mills)		1 /year		3 weeks	
	Very low temperature s						1 / year		1 week	1 week
	Bearing capac	ity					2 / year	n.a	2 weeks	1 week
High					Delivery stop (maintenance)		2-3 / year		1 day – 1month	
					Delivery stop (mill or terminal stock full)		4-5 / year		1-2 days	1-2 days

3.1.3 Norway

Truck transport costs on the coast of Norway are relatively high due to topography and infrastructure. The ready access to public ports and log docks motivates the use of vessel transport to both replace the longer distances to domestic customers. Ports and log docks also enable cost-efficient transport of excess volumes to export markets. A core aspect of coordination between functions includes the constant geographic balancing of available harvesting volumes with customer demand per planning period. The coordination of functions along the Allskog supply chain has been grouped within three time horizons: annual, intermediate and operational (Table 4c). On the annual and intermediate levels, coordination between functions includes market/sales, chief transport- and regional production managers (including purchase). At the operational level (monthly, weekly, daily) coordination of supply activities is more focused on the district-levels.

The annual coordination starts with the forecasting of total domestic mill customer demand (within the truck transport function). After a review of possible purchase volumes from the association members (production function) the market function sets sales goals for domestic vs. export markets and begins to negotiate mill customer volumes and prices. Subsequently, the functions coordinate to develop an annual delivery plan with supporting annual harvesting budgets, truck transport- and vessel plans, with necessary adjustments of capacities before confirming the annual delivery plan.

On the intermediate term, the forecast of member purchasing volumes per district/region is updated with subsequent adjustment of harvesting capacity and re-distribution of expected volumes per area to the respective mill customers' delivery plans. Later, the contracted harvesting capacity is allocated to the respective areas with respect to the actual purchase volumes and the functions monitor progress to adjust plans accordingly and balance transport capacity needs between truck and vessel transport on the subsequent operational level. Historically, coordination was based on an annual plan with detailed monthly distributions of deliveries. Coordination is now based on a rolling planning horizon which is updated eight times per annum. The rolling re-planning is focused on updating the sharp plan for the coming period and improving the forecast for the following periods.

On the operational level the purchased volumes per area are scheduled with the allocated harvesting capacity. The transport function manages monthly and weekly truck deliveries of the harvested volumes accordingly and synchronizes truck deliveries to terminals with a rolling two-week planning of vessel arrivals. The respective functions monitor harvesting and transport conditions and deliveries continually and re-plan according to progress, conditions and events.

Norway	Functions								
	Production	Truck transport	Market						
Long-term									
Annual plan		Identify total annual customer demand.							
	Forecast possible purchase volumes, develop annual harvesting budget, adjust harvesting capacity.	Develop annual truck transport plan, adjust truck transport capacity	Set market goals and negotiate customer volumes, develop annual vessel plan, adjust vessel capacity, develop & confirm annual delivery plan						
Medium term									
Rolling plan	Forecast purchase volumes per area, adjust harvesting capacity per area.		Re-distribute volumes to customers, update delivery plan.						
	Continue purchasing wood Allocate capacity to areas		Monitor progress per period						
Short term	Short term								
Monthly/ weekly/ daily deliveries	Schedule and manage harvesting.	Manage monthly deliveries, synchronize daily deliveries with vessel arrivals.	Coordinate deliveries between truck and vessels, monitor progress per month/week.						
	Monitor conditions and re- plan.	Monitor deliveries and re-plan.	Update vessel plan, update delivery plan.						

Table 4c. Norway - General framework of supply chain coordination between functions from long- to short term.

Risks (Table 5c) – Wood supply on the coast of Norway is characterized by a number of seasonal trends. Historically, wood harvesting in member was predominantly a winter activity. Seasonal variations remain, driven primarily by the varying bearing capacity in the forest and forest roads. A typical disturbance has been the thawing of roads after winter, with typical arrival around Easter and duration of a few weeks. In later years the absence of a stable mid-winter cold period has resulted in reduced frost- and snow depths with subsequent increased planning efforts to locate harvesting sites with sufficient bearing capacity. Variations in bearing capacity are therefore now more often driven by variation in rain intensity, instead of frost- or snowpack depth. The time for recovery from such events is then dependent on the temperature and time necessary for drying or drainage, where high rain intensity during the cooler autumns can be particularly challenging. The areas most sensitive for these events are the low-lying coastal sites with fine-textured soils (silt and clay). The standard mitigation alternative for these seasonal events consists of relocation of harvesting resources to areas of higher bearing capacity, where such sites are normally "saved" by the district managers for the most difficult periods. Generally, winter and spring harvesting capacity generally follows the snowpack up from the coastal fjords to the higher altitudes in the interior, returning to lower areas when frost or drying provides sufficient bearing capacity. Harvesting capacity can also be relocated to the interspersed areas with thinner soils over bedrock. Harvesting capacity is also moved between regions for specific seasons, for example, from the fine-particle soils around the central county to coarser soils in the southern county. Each of these responses to harvesting conditions are reflected in the geographic re-balancing of supply and demand in the market and transport functions.

Otherwise, typical events with low frequency and large consequences include major windstorms and regional losses of mill capacity. The historical frequency of major storms has been every 10-20 years

where in the case of a 100-year storm may include a whole year's harvesting volume for the county. For such an event the recovery time was 1,5 years with work progressing from prioritized large areas to later salvaging scattered patches. In contrast, regional losses of mill capacity have typically occurred as a consequence of sector structural development every 5th year, with two such events during the last four years, where consequences have been limited to approximately 10 % of the annual sales volume and recovery times to adjust roundwood flows to alternative mills customers have been limited to one month.

Medium frequency demand events associated with annual cycles include mill holidays and maintenance. Planned mill holidays result in complete shutdowns for sawmills and reduced consumption for pulp mills during a 3 week period. Mill maintenance events can be expected 2-3 times per year. Occasionally, full delivery stops may be enforced for a period ranging from one day to one month when terminal or mill stocks reach their limits.

With respect to multimodal vessel transport, weather-related events include delays during periods of high wind speeds. These periods are most frequent during December to February and typically have a duration of one to two days. Otherwise, mechanical vessel failures occur with a frequency of approximately once per quarter, with a return to service after 1 week. Minor delays in vessel arrival (12-24 hours) occur often.

Mitigation responses for events which are typical for the annual cycle are included in the annual and intermediate planning. The varying number of working days per month also influence the sum monthly flows for all activities. The pace of harvesting operations is also often slightly reduced during the fall hunting season. Overall the available volume of purchased roundwood generally exceeds demand during January to June, with a deficit in August (after summer holidays in July) and November (due to expected reduced bearing capacity). The available volumes purchased and ready for harvesting varies between two months (in the best case) to one day (worst case during critical periods). Harvesting production must often be accelerated during the first two weeks of January to compensate for reduced roadside and mill stocks during Christmas holidays. Harvesting production at the end of the winter must often be reduced to prevent large road-side stocks and resulting long lead times. During periods of low harvesting production trucks can be assigned to routes with longer transport distances, retarding delivery pace while short-haul routes are prioritized during periods requiring a higher delivery pace.

Norway	Event de	escript	ion			Event impact				
_	Supply even	ts			Demand events		frequency	Volume	event	time to
Risk	harvesting	Transport			Mill	Market		(% annual	duration	recovery
froquoncy		truck	rail	Ship				volume)		
nequency										
Low	Major						Once every	Varying		Varying
	windthrow						10-20 years			
					Regional loss of		Once every	10 %		1 month
					mill capacity		5 years			
	Loss of						1 time per			
Medium	contractor						year			
	capacity									
					Holidays		1 time per		3 weeks	
							year			
	Temporary						1-2 times		3 weeks	
	loss of						per year			
	bearing									
	capacity									
				High			2 times per		1-2 days	
				winds			year .			
					Planned mill		2-3 times		6-9 weeks	
					capacity		per year			
					reductions					
					Delivery stop				1 day_1 month	
				Manal	Delivery stop		1/			
				vessel			1/ quarter		т меек	
High				out of						
				service			-			
				Minor			«often»		12-24 hours	
				delay						

Table 5c. Norway - Overview of supply and demand risks according to typical event frequency and durations.

3.2 Supply chain coordination processes

3.2.1 Austria

Annual cycle (Figure 2a) - The annual planning activities at AFF start with the harvesting function, where, based on a ten-year plan, annual values (e.g. harvesting volumes, assortments) for the different enterprise levels of the AFF are developed applying a top-down approach. Afterwards in a bottom-up approach values are consolidated and finalized in an aggregated AFF harvest plan, which will be adjusted monthly in coordination with the sales department. A complete re-planning can be caused by short-term selling contracts, which would be performed on a monthly basis. The transport and market functions are initiated by the defined budget targets of the AFF's management board. On the annual level market plans are rather general and concentrate on customer acquisition and first negotiation of supply contracts. At the centre of the transport planning are adjustments of terminal, storage and transport infrastructure, based on the defined budget targets, and long term partnerships with carriers. The communication between the different functions is more or less limited to risk management.

Intermediate cycle (Figure 3a) - On the intermediate planning level for the harvesting function the forest management units (regions) plan the monthly harvest volumes, by assigning harvesting systems and forest districts to 60% of the target value. The remaining 40 % of harvest volume acts as a buffer capacity, where solely the harvesting system is predefined. This happens in consolidation with the forest districts management, which specifies stand and schedule for the harvesting projects which is optimal for operation of expensive machinery (eg. harvester or cable crane). Afterwards the defined harvesting projects are compiled by forest management units (regions) and are assigned to the internal harvesting division or, after a tendering process, to external enterprises. Communication between the harvesting and market function slowly increases, in form of provided information of actual supply volumes, which results of concluded supply contracts. Furthermore, the transport function benefits from this information, and receives accurate values to plan transport capacity, storage volume and strategy. Risk information is also shared between functions so occurring disruptions can cause adjustments or a complete re-planning at the intermediate level.

Short-term cycle (Figure 4a) - Short-term planning activities show a more intensive information flow between the different functions. AFF forest district management is in the very centre of the processes and coordinates harvesting as well as transport activities. The transport planning is based on daily production data of the harvesting and forwarding teams. Roadside stocks are split into individual transport orders to maintain control over wood flow. In case of multimodal transport, rail wagons as well as trucks have to be coordinated, in contrast to the simpler management process for truck transport direct to customer mills. Harvesting, transport and risk data allow to monitor the wood flow and to react with contingency plans in case of short term disturbances.

Multimodal management - Multimodal management starts at the roadside stocks. The forest district manager constantly checks the volumes and location of piles according to the logging information in the database system and informs local carriers once a week (Friday) about the upcoming transport orders for the following week. After coordination with the carrier, the forest district manager compiles transport packages in the system and sends electronic freight orders to the carrier, who schedules these and instructs the truck drivers. At the same time the forest district manager requests wagons using Railcargo Austria's online system for the planned delivery date. Railcargo Austria shuttles the requested wagons at the terminal and informs the carrier that wagons are ready

for loading. Individual truck drivers are informed via the carrier and coordinate unloading and queuing with other drivers upon arrival at the terminal. Wood is either directly to the provided wagons or to the stockyard. After loading wagons the driver is responsible for securing the wagon cargo, cleaning the loading area and completing the delivery message for the truck and the consignment note for the rail transport (and sending this information to the AFF database system). The loaded wagons are picked up by the next shuttle train, if correctly loaded and secured. Safety discrepancies are reported to AFF by Rail Cargo Austria. AFF is also responsible for informing the carrier of the need to fix the problem. Scaling is done upon delivery of the wagons to mill customers and this data is transferred to the AFF for payment of transport services.

The local carriers play an important role in the coordination of multimodal operations. The contracted carriers have good knowledge of the local forests and road network. They are also flexible in scheduling their transports since AFF is their main customer. They also have the opportunity to correct the weekly data on harvesting production and roadside stocks by checking the wood piles (often on weekends). Each carrier has an individual storage section at the terminal and AFF's role is limited to monitoring the process. Business relations between the AFF forest district manager and the carrier's dispatcher are therefore tight.



Figure 2a. Austria - Annual supply chain coordination processes.



Figure 3a. Austria - Intermediate supply chain coordination processes.



Figure 4a. Austria - Short-term supply chain coordination activities.

3.2.2 Sweden

Annual cycle (Figure 2b) - The market department is responsible for balancing supply and demand in the procurement plan. Much of this work consists of negotiation to fulfill multiple goals of ensuring sales of all member wood, good prices, while at the same time maintaining good business relationships. The balancing is based on monitoring of contracts and forecasted production and is supported by predicted volumes per assortment based on historical data in the different areas. At this level the logistic function is responsible for negotiating with all transport resources and development of plans/ quotas (annually and monthly) to all mill customers and train terminals. In the same way the production function is responsible for negotiating with harvesting resources and allocating geographies for the respective harvesting teams and ensuring contracting and preparation of a sufficient stock of suitable round wood.

Intermediate cycle (Figure 3b, three-month rolling plan with sharp monthly plan (Figure 3b) – At the annual level, the monthly plan is only a forecast. At the intermediate level planning is based on a three-month rolling forecast horizon where the upcoming month is confirmed ("sharp"). The forecasted three month plan can be changed until the sharp month has started, unless events require adjustment during the present month. In monthly and weekly terms, the market function monitors activities in order to follow the balance of supply and demand. The production and logistic functions have the responsibility to ensure that the promised round wood show up at mill gates and train terminals. To do this, both the logistic manager and the production manager monitor supply operations weekly and evenly daily to make sure they are on the schedule. Only if an event occurs (most often reported via the truck association) do they update the sharp monthly plan. The chief production manager compiles the volumes produced in the eight regions through monitoring the reported harvested and forwarded volumes and road side inventory per assortment. Each month the chief production manager is in continual contact with the regional managers to be able to regulate the flow of round wood to the right assortments and volumes to the right customers. The regional managers are responsible for keeping control of logging operations and re-planning sites and truck deliveries to ensure the monthly quotas. The managers have monthly meetings with both the logistic manager and the local truck association/enterprises to ensure deliveries according to delivery plan. Contact is particularly close during periods of road closure due to reduced bearing capacity.

Weekly cycle (Figure 4b) – At this level logistics and production managers adjust transportation and production in order to maintain the pace of the monthly delivery plans. The logistic manager is in contact with the truck associations to update the weekly quotas as well as capture information from the regions about upcoming events requiring action. The quotas at each demand point are followed up and the logistic plan can by adjusted according to occurring events. The production manager has the responsibility for monitoring road side inventories in the eight regions and checking that production fulfills the monthly plan. In case of disturbances or events, the production manager replans and coordinates the revised plan with the relevant regions. This can mean reallocation of harvesting teams, especially during events regarding bearing capacity or change in customer demand. The regional production manager monitors the daily production plan, stand priorities and deliveries for the truck association/enterprises. At this level the harvesting teams are expected to follows the plan delivered by the production managers and report disturbances as well as daily harvested and forwarded volumes.



Figure 2b. Sweden – Annual supply chain coordination processes.





Figure 3b. Sweden – Supply chain coordination processes at the intermediate level (three months rolling plan with sharp monthly plan).



Figure 4b. Sweden – Supply chain coordination at the weekly level.

	0
	followed up
Continue delivering roundwood	- -
	Round wood delivered
3.2.3 Norway

Annual planning cycle (Figure 2c) - Preparation for annual planning of the next year is initiated during the summer with the identification of next year's customer demand. Since the daughter transport company is a main supplier of transport services for all suppliers and mill customers this part of the planning process is initiated early in order to ensure sufficient transport capacity for all parties. After subsequent forecasting of purchase volumes, market goals are set for sales to domestic vs. export mill customers. This is the basis for the development of harvesting budgets, truck transport and vessels plans and capacity contracting, consolidated in the annual delivery plan confirmed by all functions.

Intermediate planning cycle (Figure 3c) – For each intermediate planning cycle the main functions (harvesting, transport and market) re-plan according to updated forecasts and events which have occurred. The impacts of larger supply or demand events such as major storms, loss of contractor capacity or mill capacity are generally met at this level. The intermediate planning is four times per half-year focused on a confirmed plan ("sharp") for the coming period and an updating of forecasts for the following periods. Given the resulting balance between supply and demand volumes the subsequent deliveries by truck and vessel are planned and coordinated at the following monthly and weekly level.

Operational coordination of supply chain activities (Figure 4c) – After monitoring of purchase, harvesting and deliveries progress during the previous period, the allocation of harvesting capacity between areas may be adjusted and operational management for the coming month is initiated. For the harvesting function this includes routing/scheduling of harvesting teams to the contracted harvesting sites. At this level, continuous monitoring of weather conditions and production levels can initiate re-planning and relocation of harvesting teams. Events such as minor storms and windfall can also initiate re-allocation of harvesting capacity between districts by the regional manager. Given the expected road-side stocks, weekly transport quotas per transport company and mill or terminal are generated for the coming months of truck transport. At the same time the shipping function checks available lay-times at PoDs and resulting production balance per PoL before confirming the vessel plan for the coming 2 weeks for coordination with truck transports. At this level typical disturbances met by the truck and vessel transport functions include planned mill capacity reductions, delivery stops and vessel failures. The impacts of the disturbances are noted in the delivery monitoring are taken into account in the transport quotas for the following week.

Multimodal management (Figure 4c/5) - The tightest operational synchronization is between truck deliveries and vessel arrivals (Figure 4c, far right). At the weekly level, the necessary transport pace to the PoL has already been calculated by the area transport manager as a basis for the weekly delivery quota per PoL. At the daily level, after checking vessel status the shipping function sends a message confirming pending vessel arrivals to the area transport manager. This initiates a final check of the distribution of terminal volumes (dock-front vs rear stocks) at the PoL and any adjustments to transport pace and loading capacity. At this level vessel delays or vessel plan revisions (e.g. revisions of nominated sequence of PoL) are handled immediately.

Expected vessel cargo volumes may vary between a partial or full and complete cargo. For cargoes volumes which are too large for the dock-front, supplemental volumes are transferred from the rear stocks or occasionally direct from arriving trucks (Figure 5). Loading continues until declared complete by the vessel crew (based either on agreed volume or vessel stability).



Figure 2c. Norway – Overview of the annual supply chain coordination process.



Figure 3c. Norway - Overview of the intermediate supply chain coordination process (8 times per year).



Figure 4c. Norway – Overview of supply chain coordination activities at the monthly- and weekly level.



Figure 5. Norway – Coordination of activities during vessel loading.

4. Discussion

The results presented consist primarily of a descriptive cataloguing of operating conditions, risks and supply coordination processes. The discussion starts by positioning the three cases in their industrial context before comparing conditions, risks and processes. The discussion concludes with an interpretation of results with respect to principles for system control before presenting a more general framework of roundwood supply processes which were common to all three cases.

Context - Industrial context frames the development of organizational goals, strategies and management processes. Using the wood sourcing and market classification of Erlandsson (2013), the three respective organizations can be positioned in three different contexts (Figure 6). The empty quadrant closest to the origin (enterprises both having their own forest and mills) represents the position most dependent on securing sufficient harvesting and transport capacity.





The Austrian case represents the only organization with own forest areas to manage. The Swedish case is the only organization with supply responsibility for own sawmills. The Norwegian case has neither internal supply responsibility nor own forest areas requiring constant management attention. These positions appear consistent with the way respective organizations balance supply and demand; AFF has a long-term planning horizon (ten-year) with harvesting projects selected up to one year ahead of time. In this case harvesting operations are initiated when matched with sales orders and after the harvesting operation has been tendered on the open contractor market. The Swedish case secures harvesting contracts with their members with a maximal two year horizon to ensure a stable supply to their own mills. Thereafter schedules for harvesting operations may be adjusted according to the priorities of delivery plans for internal and external mill customers. The Norwegian case has a shorter purchase horizon with their members (months) and re-directs surplus wood flows to export markets when supply per assortment exceeds domestic delivery agreements.

Operating conditions – The variation in operating conditions between cases (Table 2) can be linked to their seasonal trends. Northern Sweden has the driest and most stable operating conditions; terrain difficulties being primarily limited to areas of low bearing capacity. In this case frost and moderate amounts of snow in flat terrain represent supply enablers, not hinders. Climate-driven risks are linked to the transitional period between high availability winter harvesting and the more

demanding summer season. In this case, a large operating area enables relocation of operations when required. AFF has the most varying climatic conditions as well as the highest proportion of steep terrain. This presents additional operational risks during winter periods where deep snow can hinder operations. The Norwegian case, in contrast to the Swedish case has more mountainous terrain and a coastal climate entailing warm and wet autumn and winter conditions.

Risks – A comparison of supply risks between the three cases show many similar elements, but with varying frequency and impact (Tables 5a, 5b, 5c). All three cases refer to windstorms and windthrow. The reported frequencies for storms vary as do their volumes. At the one extreme is the 100-year storm in 2005 which felled large areas over whole regions (up to 100 % of annual growth in Sweden). More typical, however, are the 10-20 year storms which are still cause considerable disturbances, but require time and less movement of resources to salvage (equivalent 20 % of the regions' annual growth such as in Austria). In exposed coastal areas such as Norway, minor storms may also result in fragmented areas of windfelling, which may be salvaged continuously by the local harvesting teams. Recovery times in these cases vary between the time for the actual salvage work (from 1,5 years for a widespread 100-year storm to a few weeks for harvested smaller fragmented and harvesting volumes have rebounded to previous levels.

Regarding demand events, mill capacity increases or decreases vary in frequency from five to ten years with impact varying from 5 to 25 % of annual harvest volumes, depending on the degree of structural change in the region. The reported temporary demand reductions vary in frequency from once in five years (for a half year break down) to multiple times per year for holidays or maintenance (two-three weeks) or quarterly/monthly for shorter delivery stops due to full mill- or terminal stocks (typically with a duration of days, but up to one month).

Regarding seasonal risks outside of seasonal trends, the Austrian case reports snowfall commonly hindering operations during the winter months but resulting in only a few weeks to recover per snowfall event. In contrast, intense rainfalls only occur a few days per year after which operations recover within a week. Unique risks in the Swedish case include periods of low temperatures hindering harvesting (typically for one week per year). Common seasonal events for both Sweden and Norway are the seasonal losses of bearing capacity. Earlier these typically occurred twice a year (spring and fall) with a weekly duration. For these events the interior areas of the Norwegian case are similar to the Swedish case, while the coastal areas are more dependent on windows of opportunity provided by dry or cold periods. For both countries an increased lack of stable snow and frost conditions during winter has been mentioned by respondents.

Functions – The different cases have both similarities and contrasts with respect to functions and their responsibilities (Tables 3a, 3b, 3c). While the Austrian supply chain is preceded by a long-term forest planning cycle the Swedish and Norwegians supply starts with the purchase of members' wood (integrated in the district harvesting function). The Austrian and Swedish forest district functions are similar in the respect that the organization's own managers have the decentralized responsibility for coordinating harvesting and transport, while the Norwegian case has a separate transport organization coordinating with central harvesting and market functions. Hypothetically, the two different solutions could result in alternative scales of response when handling disturbances through re-allocation of resources.

Regarding the responsibility for coordinating multimodal transport, this is appears to be handled in different ways. AFF delegates this to the district level with direct coordination between the district manager ordering wagons and the carrier's dispatcher/drivers coordinating work at the terminal. In contrast, the Norwegian arrangement of vessel arrivals and departures is handled as a part of the central shipping function which coordinates with area transport managers. For these cases, the contrast may be linked to two conditions; first, the greater proportion of deliveries in the Norwegian case handled via the multimodal system and second, the fact that PoD laytimes for unloading at customer mills are often more restrictive than PoL availability for loading.

Supply coordination processes – Supply chain coordination activities at all three organizations (Tables 4a, 4b, 4c) are segmented in some variant of the conventional hierarchy from long-term (strategic) to short term (operational) planning. At the annual level, planning cycles generally set goals, contract resources and consolidate functional plans in the master delivery plan based on an anticipated distribution of delivery volumes per month. At the tactical levels, however, there appear to be a number of contrasts. At AFF the lower proportion of harvesting and deliveries initiated in response to the inflow of customer orders from the market function corresponds well to the large proportion of risk- and event-driven harvesting. In contrast, the Swedish case has a greater obligation to maintain stable supply because of their responsibility for own mills. This can perhaps be linked to their apparently leaner supply chain with a rolling updates based on frequent communication of flows and stocks between functions. In the Norwegian case, the development of a rolling 2-period plan updated 8 intervals per year, focusing on a sharp plan for the upcoming period and a forecast for the following period is a development in the same direction. As noted under the discussion of industrial context, the different ways of coordinating supply operations are also partially reflected in the contracting horizon for harvesting resources where AFF tenders harvesting packages on an open contractor market, while Sweden and Norway assign their purchased volumes to their entrepreneurs whose services are contracted for a horizon of 1-2 years. These differences are consistent with the respective positions in Figure 6. Hypothetically, the varying frequencies and horizons of response provide varying potentials for system response and control. Capacity restrictions, however, limit the opportunity for response to variations in supply or demand and therefore, system resilience. In these three cases, the most consistent use of rolling development of tactical plans is seen in the Swedish case where supply operations have a lower proportion of harvesting in response to eventdriven disturbances.

Multimodal management – The three multimodal systems, as used by the respective organizations, vary in terms of their need for coordination between forest supply operations and the multimodal transport to mill customer. In the Austrian case, smaller volumes of individually ordered rail deliveries (1-5 wagons at a time) favors the practice of synchronizing truck arrivals with rail wagon loading. At the same time, the limited length of the loading track and adjacent stock areas may limit the development of increased rail volumes. In the Norwegian case, collecting full vessel cargoes from multiple ports also necessitates strict truck fleet management to ensure delivery of the respective volumes to the nominated ports within the expected times-of-arrivals. In this case, the length of the dock-front limits the volumes directly available for loading by geared vessels (most common) requiring coordination of extra capacity for transfer of supplemental volumes to the dock-front. In the Swedish case, however, stable schedules of system train solutions being loaded from terminals with larger inventory capacities provides a basis for a greater degree of freedom for fleet management, particularly where they have a role as supplemental supplier.

Multimodal coordination in reference to principles system control – The supply mapping in WP1 is based on a few fundamental principles. The first of these is that most logistics systems are managed with a basic PEC cycle of planning, execution and control (NEVEM 1989). Subsequently, such systems are typically decomposed into self-managing sub-systems and elements which each have their own PEC cycles in order to ensure a requisite variety of responses to disturbances (Hulten and Bohlin 2002) where the planning in each cycle may be based on both feed-forward and feed-back (Fowler 1999). These cycles are placed within a strategic-tactical-operational hierarchy for coordination between sub-systems or functions along the supply chain. This hierarchy is based on similar frameworks presented by Boston (2003), Carlsson and Rønnqvist (2005) and D'Amours 2008. With respect to the ultimate goal of the project; multimodal strategies for efficiency and resilience, numerous interpretations of the term *strategy* are available. To simplify this it may be advantageous to first refer to the perspectives provided by Evered (1983) and Andrews (1987) who differentiate between the expression of strategy as 1) a specific goal or plan for a given time frame versus 2) the process enabling development of the goal or plan. For the purpose of WP1, the explicit definition of a supply strategy by Nollet et al (2005) as consisting of a series of plans with consolidation in a master plan to ensure contribution to business objectives, represents a straightforward interpretation. Nollet's differentiation between the business strategy, the *functional strategies* (such as supply strategy) to be coordinated and finally the specific supply management strategies (i.e. the particular way of doing things) imbedded in the functional strategy (eg. supply plan) helps position *multimodal strategies* within a consistent structure for further discussion.

In terms of the relationships between flows and physical system elements, the three cases are not particularly complicated. However, given the respective risks and disturbances typical for the wood supply operations, the differences between the cases provides opportunity for developing further insight and solutions. A fundamental question is then "to which degree of control is possible to maintain in the different risk situations". Also in this context some introductory terminology may also be useful to provide a consistent structure for further work. According to Ashby (1958), the two ways of maintaining system control (termed requisite variety) include decreasing the variety of the controlled system or increasing the variety of the controlling system. The first and most common way to reduce the potential variety of the controlled system is through buffering. Læstadius (1990) noted that different wood supply systems may have different approaches to buffering, where some buffer capacity while other buffer roundwood, depending on their respective costs. With respect to maintaining requisite variety and system control in the current study, roundwood stock strategies will vary and the frequency and duration of events such delivery stops (noted in the risk/event tables for all three cases) can be interpreted as symptoms of varying system control. With respect to the multimodal deliveries, the Swedish supply organization has the role of a supplemental supplier delivering wood to a customer terminal with stable rail schedules and spacious inventory areas. This reduces the need for control of inflows to the terminal. In the other two cases (Austria and Norway) chosen solutions increase the need for synchronization necessitating greater control through more strict fleet management.

4.1 A general framework of management processes

Based on the mapping of management processes presented in the results a general framework of common activities is presented in Table 6. The framework follows the basic sequence of activities necessary to attain balance between deliveries per period and sales agreements. For each process, imbedded activities with typical variants are noted. The sequence includes feed-back loops for re-

planning of harvesting and transport after monitoring of deviations ("return to" in Table 6). Categories for specification of period length and flow resolution are shown in Table 7.

Process	Activities	Variants		
FORECAST SUPPLY	Forecast potential supply	based on AAC or expected purchase		
		volumes		
	Forecast flows	from supply area to demand point		
	Forecast operating conditions	based on typical conditions		
DEVELOP SALES	Evaluate sales options and set sales goals	internal mills		
PORTFOLIO		external domestic mills, export markets		
	Coordinate sales goals with other functions			
	Negotiate sales and delivery plans	annual intention agreement		
		negotiation of volumes/prices per		
		period		
		confirm orders for delivery per period		
DEVELOP CAPACITY	Evaluate capacity requirements for	harvesting function		
	forecasted production and transport flows	transport function		
		multimodal system		
	Develop and contract capacity	contract/tender harvesting capacity		
		contract transport capacity		
		plan terminal development		
PLAN HARVESTING	Set production goals per supply area	per harvesting technology		
PRODUCTION	Coordinate production goals with other functions			
	Allocate harvesting capacity	route /schedule harvesting capacity		
		assign site/package to harvesting		
		teams		
		send site instructions/bucking		
	Dependent have cating (for use rating (alcideling	Instructions		
MONITOR HARVESTING	production	weekh		
PRODUCTION		at end of operation		
	Report production events /disturbances			
	Compare reported production to goals and	return to PLAN HARVESTING		
	evaluate responses	PRODUCTION		
MANAGE DELIVERY	Compile status of road-side stocks	Current		
		Expected		
	Set delivery goals per demand point	direct to mills		
		to multimodal terminals		
	Coordinate delivery goals with other functions			
	Distribute delivery goals as delivery quotas to	assign delivery quota/task to transport		
	transport association/carrier	enterprise/truck		
		coordinate truck deliveries with rail		
		loading plan or vessel plan		
		direct truck deliveries to terminal front-		
		stock/rear stock		
		airect truck deliveries for direct transfer		
	Devent travels della solare to the total	to rail wagon/vessel		
WONITOR DELIVERIES	Report truck deliveries to demand points	scaled volumes from delivery		
	Papart delivery events disturbances	sculed volutiles from delivery		
	Report delivery events/disturbances			
	Compare reported deliveries to quotas and	return to WANAGE DELIVERY		
	evaluate responses			

Table 6. Draft framework of general wood supply management activities and variants from supply forecasting to delivery monitoring.

Regarding specification of period length and flow resolution, management activities of low temporal and spatial resolution are handled at the strategic levels of the decision-making hierarchy (Table 7, middle) with progressively higher resolution as one approaches the operational level. Assuming that

that management is successful in terms of providing requisite variety for system control, varying process configurations could reflect the variability of the supply chain environment (Table 7, upper). Under the same assumptions, varying levels of resolution in wood flows could reflect corresponding levels of mill customer service (Table 7, lower) which management processes enable.

Category		Description		
Supply chain	Low variability	Limited seasonality or subject to minor events/disturbances		
environment	High variability	Considerable seasonality or subject to major events/disturbances		
	-			
Decision- making	Strategic	Focus on setting supply goals and developing resources to support business strategy		
horizon	Tactical	Focus on developing plans balancing sales and supply with specified flows and stocks		
	Operational	Focus on routing/scheduling of res	sources to fulfill supply plan	
Flow	Volume	total roundwood		
resolution		per assortment		
		with distribution of dimensions		
		(diameter/length classes)		
	Flow	assortment volume per period (from supply area to demand point)	Period-duration (annum/period/month/week/day/hour)	
	Pace	assortment delivery rate to demand point		
	Dispatch	assortment delivery load volume dispatched from landing to demand point		

Table 7. General categories of supply chain environment, decision-making horizon and flow resolution for further specification of management processes/activities/variants.

4.2 Conclusions

The introductory mapping links varying context, operating conditions and risks with wood supply management processes. The management processes mapped in the Austrian case reflect a tactical configuration evolved to handle a higher proportion of non-predictable events such as windthrow storms (more typical for continental conditions). The tactical and operational processes in the Swedish case show configurations evolved to ensure supply in the face of seasonal variation in bearing capacity (more typical for sub-arctic conditions). The tactical and operational processes in the Norwegian case have evolved to handle both seasonal trends for varying bearing capacity as well as windfall events typical for areas with coastal exposure. Quantitative comparisons of predictable seasonal trends versus non-predictable events continue in WP2. The cataloguing of demand risks for the respective cases shows similar trends and events where structural development of customer mills is a driving force. All three cases show occurrences of delivery stops to single customers, varying from periodic one-day stops to more isolated stops of up to one month's duration. Development of corresponding test scenarios continue in WP3.

In all three cases the savings of transport costs between direct truck transport and multimodal transport depends on efficient transfer between incoming trucks and the multimodal system. The three cases represent a gradient of direct transfer from truck to wagon/vessel. During regular

operations the limited rail shipment volume (1-5 wagons) of the Austrian case allows direct transfer from truck to rail wagon. In the Norwegian case, the vessel size (1500-5000 m3) requires stock accumulation at both dock-front and shore stocks before vessel arrival with an occasional supplement of direct transfer from incoming trucks to dock-front. In the Swedish case, spacious rail terminals enable delivery of roundwood to rail-side stocks sufficient for a full train load (24 wagons) with the opportunity for direct transfer when convenient. The potential for the multimodal system to provide lower costs, enable stable wood flows or increase buffer capacity depends on the proportion of wood supply handled by the system. In the current cases this proportion varies from under 10 % to over 30 %.

Based on the case-specific process maps, the general process framework drafted captures the basic sequence of management activities necessary to forecast, plan, execute and control wood supply. The framework contains 7 basic processes, 22 activities and numerous variants with categories for specification of decision-making time horizon and flow resolution. This framework will be further developed as the project progress.

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MultiStrat interim work report for WP2 (Supply chain operations analysis)

Common framework for analysis of variations in harvesting production, truck-, rail- and ship transport of roundwood



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Introduction

The forecasting of wood flows from forest to mill is challenging. Company prognoses are therefore based on historical trends, local experience and frequent updating. There are few methods which are proven to provide precise prediction of weather and operating conditions over longer time horizons, but in later years new alternatives are being developed and tested. Variations in temperature and precipitation can quickly change operating conditions, foiling well-laid wood supply plans. Conditions can be particularly hard to predict during seasonal transitions and the frequency of re-planning for logistics response increases accordingly.

Supply chain flows start with harvesting and forwarding to roadside. Truck hauling direct to the mill yard or to multimodal terminals completes the delivery to the next stage of processing. The supply network consists of numerous entrepreneurs from harvesting and forwarding, truck transport, train transport to shipping. These strive to fulfill the agreed delivery quotas to landings, mill yards, or multimodal departures make process- and material planning quite intensive.

The scope of this study is to catalogue parameters for quantifying the effects of weather and seasonal events on wood procurement. The effect of weather parameters and events on production and transport varies between regions. The project case studies in Austria, Sweden and Norway represent different wood supply chains in continental, sub-arctic and oceanic conditions having different challenges. The aim of the analysis in WP2 is to therefore to identify the patterns of weather and procurement between the respective regions and to quantify their impacts on production versus transport with resulting variation in lead times. This requires a common framework to capture similarities and differences between the case studies (cf. Fjeld et al. 2017). Within this common framework, the analysis compares production and transport data sets together with corresponding weather data sets to quantify the effect of region-specific driving factors for variations in wood procurement.

The project hypothesis is that by examining these relationships between the contrasting conditions of the continental, sub-arctic and oceanic climate zones, differences in key driving factors will be more apparent.

Materials and method

Data collection

To capture differences between production and transport in the three study cases, possibilities for collecting similar data were identified and refined throughout the early stages of the work. The selection aimed to enable consistent comparative analysis between the cases, with similar data format and period. The common denominator for time window was found to be 2015-2016, for which most data is available for all three host companies.

The framework provides a common structure for description of the round wood flows from forest to customer, including seasonal variations and resulting lead-times. In this context the lead-time refers to the transport lead time which describes the time from harvest to delivery, primarily by truck to the mill yard or terminal, but even from terminal to destination. The data is the base for the later experiments with simulation and optimization in work package 3 (WP3).

Each national sector or host company has its own context and specific data, collected from different actors and information systems in the supply chain. However, in this study all three host organizations reported and stored data for contract-specific harvesting production and truck transport. The work to connect wood flows (loads, volumes, logs) from a specific harvesting site, on a specific day, to the receiving mill with all intermediate nodes and stocks is challenging. The different data sources had varying temporal resolutions (e.g. hours vs. days or weeks) and often contained errors such as incomplete or incorrect data. Even though production and transport reporting has been common practice for many years, development work remains to maintain consistent, accurate and available flow data through the whole supply chain. As project experience showed, some data providers rarely used this data and were unused to providing such data sets for multi-year time-series in a standardized format.

The data collection for all three case studies was limited to the identified regions and districts and involved a selection of the following variables:

- production data from harvester, forwarder or harvesting teams
 - unique contract or site identification number
 - round wood volumes (m³sob, m3sub or tons)
 - classification of volumes according to assortments and species (spruce, pine saw logs and pulpwood or even and mixed conifer pulpwood)
 - site location (GPS coordinates)
 - time interval for production
- transport data
 - o truck transport
 - unique contract number if available
 - load volumes or weight (m³sob, m3sub, tons)
 - geographical start and end node of transport (GPS coordinates)
 - transport date

- transport distance or transport time
- o train transport
 - train set identification
 - arrival and departure time/schedule
 - cargo volume per set and wagon (m³sob, m3sub, tons)
 - start and end node
- o vessel transport
 - vessel identification and port-of-discharge
 - ports-of lading and loading dates
 - cargo loaded per port-of-lading (m³sob, m3sub)
- weather data from local weather stations
 - temperature, daily or weekly averages and weekly maximum and minimum values (mm/week)
 - precipitation, daily or weekly averages and weekly maximum and minimum values (mm/week)
 - \circ snow depth (cm/dm), daily or weekly averages

Framework for common analysis

The common framework for collecting country specific input data for comparable analysis was developed over the time span of the project during WP discussions after supplemented knowledge about available data. The framework includes: (1) seasonal supply curves for production and transport, (2) corresponding transport lead times, (3) multimodal operations and (4) weather effects on the above.

Seasonal supply curves are based on production data from harvester, forwarder or harvesting team data, depending on availability. These are presented primarily on a weekly basis as a relative pace (%) in relation to the annual average (100 %). Transport lead times are presented in two ways: first as LT_{start} , which considers lead time from the first harvesting day to the day the last load is transported to the mill, and second as LT_{finish} , which represents the days between the last harvesting day to the day the last load reaches the mill. The difference between LT_{start} and LT_{finish} also represents the duration of the harvesting activities at the site or contract.

Weather effects on weekly production and transport were analyzed by several statistical methods. These include analysis of variance (ANOVA), regression and multivariate analysis in a variety of software packages. Each respective regions' weekly production and transport pace is presented in an identical format with the corresponding weather data to enable direct comparison.

Austrian case (continental)

The Austrian data sets were collected for the case study region Großreifling for two forest regions Styria and Lower Austria) in two districts of the Austrian Federal Forests (AFF) for 4 forest regions (district numbers 1, 2 and 8, 9). The available data sets include weather (1981-2010), production (2014-2016), train transport (2007-2016), truck transport (2015-2016) and risks (detailed 2015-2016 with estimates for last 10 years).

Nine interviews were conducted with regional and district management, logistic management, rail management, terminal management, foresters and transport companies and documented in a five to ten pages long protocol together with additional files. These protocols provide insides to the management of the Austrian wood supply chain and offer estimates for important parameters, which were missing in other datasets (e.g. service times and terminal processes, terminal layout and maximal capacities, former bottlenecks and irregularities, improvement potential).

The analyses show the main trends for production and transport, distributions, irregularities and lead times. These were checked during follow-up interviews with the management to discuss driving forces and draw conclusions.

Production data

The harvesting and forwarding data are based on daily messages and mails of the forwarding teams or harvesting teams (e.g. if cable crane logging was used), which are integrated in a database of the AFF. Harvesting and forwarding data (e.g. date, project number, purchase contract number, project name and information, region, district, activity, customer, amount harvest, amount forwarding, plan and actual volumes) was made available by the AAF.

Transport data

The transport data is based on delivery records for truck and train transport. Risk, terminal and cost data were collected in interviews and additional information were delivered in excel sheets and other documents. Train data (e.g. date, wagon number, destination, transport quantity, wagon type, time, costs, customer) for the terminal in Großreifling was provided by Rail Cargo Austria. Risk data (risk type, frequency, volume, duration, time to recovery, supply events, demand events) was collected by expert interviews and supplemented by a data set of the AFF. Truck transport (e.g. date, project number, truck number, time, costs, supply and demand points, transport volumes, use of snow chains, customer, transport company) was made available by the AAF.

Weather data

Weather data based on daily measurements of temperature, precipitation and snow depth of the weather station in Hall/Admont (closest weather station to Großreifling) was requested by the central agency of metrology and geodynamics (ZAMG).

Statistical analysis methods

The statistical analyses for descriptive statistics (boxplots, diagrams, bar charts, scatter plots) as well as correlation, regression and ANOVA analyses were conducted in SPSS24. Regression analyses were performed to quantify the correlations of weather with production and transport data. Temperatures, precipitation and snowpack were considered both separately and together. Monthly, weekly and daily resolutions were tested. Varying delay periods were

also considered (e.g. the influence of the weather one, two, three, four weeks before the production or transport or even moving averages).

Swedish case (sub-arctic)

Production data and transport data for the Swedish case were collected from SDC (Skogsbrukets Data Central: the national forest sector information hub) with permission from the host company. Data collection was limited to the region Södra Lappland region for 2015-2016. The data standards employed by SDC ensure uniform data sets following independent of companies and organisations. SDCs main task is to collect, store and process information on production, stock levels, transport and final scaling for roundwood and biomass transactions. All information sent, stored or processed by SDC is confidential.

Production and transport data

The harvester data collected included information about each bucked stem, the log dimensions and assortments. Harvester data is collected at least once a day during harvesting, assuming mobile net coverage in remote areas and the reporting routines agreed to, between the harvesting entrepreneur and the forest company. After being received by SDC, the data is processed and presented for Norra according to agreed formats. Corresponding truck transport data were also collected from SDC for 2015-2016. All truck transports are registered for transport payment and measured for payment to forest owner. Transport data collection is, compared to production data, of a better and more coherent quality since it makes a foundation for settlement of payment for the transport.

Weather data

Weather data are collected on daily basis. Temperature and precipitation are collected daily and presented as weekly median and mean in the regression analysis. Snow depth are based on weekly average of depth from daily observations. The weather station is chosen to be suitable for the key parts of the landings in the region VO Södra Lappland. Weather data is collected from SMHI, (Swedish Meteorological and Hydrological Institute) and from the weather stations in the central parts of the forest area of Södra Lappland.

Statistical analysis methods

Using SAS software for statistical analysis and ANOVA as the method, temperature, snow depth and precipitation data represent the independent variables with the relative weekly volume (% of annual average) as the independent variable. Additional classifications of parameters were done to better suit the real conditions regarding snow and season.

Norwegian case (oceanic)

The Norwegian data sets were collected during 2014-2016 via SkogData, the national forest sector data hub, with the permission of the host organization. All production and truck transport data were identified with unique contract numbers.

Production data

Production data consists of volumes (m3sub) per assortment reported forwarded to roadside by contractors and forest owners. Reports of contractor production were done daily or weekly while production from forest owners had a more sporadic frequency. Truck transport data was based on daily reports of volume per assortment per load. Both production and transport data were aggregated to a weekly level and the sum weekly volumes converted to relative pace per week in relation to the annual average (100 %).

Weather data

Weather data was collected from 60 weather stations distributed over the 3 counties, distributed between sea level and 450 meters. The main variables included daily temperature, precipitation and snowpack.

Statistical analysis methods

Calculations and presentations were done in Minitab and regression analysis was used to quantify the effect of driving factors on weekly production and transport pace.

Results

Monthly wood supply trends in production and transport

The average monthly supply curves for 2015-2016 are compared in the figures below for all three regional cases. For the Austrian continental case, both production and transport are lowest during January, gradually increasing to its maximum during September and October. In the Swedish sub-arctic case, production was at its maximum during February, decreasing to July before increasing again throughout the autumn to a second peak in November. In the Norwegian oceanic case, the annual production pattern was like the Swedish sub-arctic, but with a later winter peak (March) and limited production rebound during the late fall. The transport curves for Sweden and Norway were both flatter than the production curves, but otherwise quite similar, again except for the lack of a transport re-bound during the late autumn for the Norwegian case. All three cases exhibit the typical supply reductions during Christmas and summer holidays (August in Austria, July in Sweden/Norway).



Figure 1. Relative monthly production volumes, Austrian, Swedish and Norwegian cases (2015 and 2016).



Figure 2. Relative monthly transport volumes, Austrian, Swedish and Norwegian cases (2015 and 2016).

Weekly trends in production and transport

Austria

Production and transport curves

Analyses are based on three years of production data and two years of transport data. The responsible managers along the supply chain confirmed these periods to be representative for the intended analyses. Figure 1 shows the average production during 2014-2016. The seasonal trend shows a very low production in the first quarter of the year. At the middle of the year (week 26) the production rises significantly and stays on a high level, except outliers in the weeks 32-34, which identify the reduced production during Austrian summer holidays (in August, this effect is also driven by the Italian holidays, when Italian lumber customers close their plants in August). The last week of the year is not included in these analyses because mainly adjustments and corrections due to bookkeeping issues take place and result in unrealistic production peaks, while real production amounts stay low. For instance, managers balance the datasets to include production reports.



Figure 3. Austrian case; relative weekly production volumes during 2014-2016.

The average amount of transport (truck and train) of the years 2015 and 2016 can be found in Figure 2. During the first quarter of the year transport is on a low level. Starting from week 13 transport rises steadily. At the very end of the year fluctuations are higher, but overall transport stays on a high level. Conspicuous decreases can be found during February and March, where it is hard to pick up wood because of high amounts of snow in this region, and during the summer holidays (week 31-33).



Figure 4. Austrian case; relative weekly truck transport volumes during 2015 and 2016.

Differences between production and transport

The AFF timber production volume for the observed time horizon of two years is 15 % higher than the transport volume. This can be explained by overestimation of the harvested volumes by forwarding teams and long lead times. Timber production data shows more variability then transport data. The transport pace is rather stable, since roadside stocks buffer abrupt timber productions stops and facilitate a more continuous transport.

Figure 5 relates timber production to transport volumes of 2015 and 2016 by calculating the weekly inventory level. At the beginning of the year transport is slightly higher than production which is slightly indicated by the first year, but much stronger noticeable in the second year. During the year production rises and peaks in the middle and end of the year. Here the difference between production and transport is higher in the first than in the second year. Compared to the more stable production and transport volumes during 2015 a rising trend can be observed for 2016.



Figure 5. Austrian case; calculated inventory level per week during 2015 (weeks 1-52) and 2016 (53-104).

Sweden

Production and transport curves

Wood procurement volumes, produced and transported to industry, are shown in the figure 6 and 7. The patterns are roughly similar between years, with higher production volumes during winter using frozen ground for better bearing capacity. During the summer period with holidays and mill maintenance industry demand decreases. This type of variation is well known even if the specific variation between years is hard to predict in detail and forecast for an optimal planning. For example, in week 13 the average production (related to annual average) differ 136% (210%, 74%) between the two years.

Difficult periods, described in interviews with production managers, include heavy rainfall in combination with high temperatures in autumn and wintertime, i.e. when the temperatures lie above zero. The production to the landing, i.e. forecast of which logging sites and what volumes will appear, are more difficult to predict than for other periods.



Figure 6. Swedish case; relative weekly production volumes during 2015-2016. Periods for holidays can be seen in week 27 - 30 and 51-1.



Figure 7. Swedish case; relative weekly transport volumes during 2015-2016. Periods for holidays can be seen in week 27 - 30 and 51-1.

For transportation, transport capacity represents a bottleneck. The truck fleet and their transport capacity are sufficient enough as long production follows the planned levels and geographies. However, when production capacity is forced to move to areas off the plan, subsequent truck and transport plans are afflicted. This leads to over-capacity in some areas and under-capacity in others, requiring capacity re-allocation to areas outside the entrepreneur's normal work area in order to ensures fulfillment of agreed delivery quotas. The cost for these variations arises throughout the wood supply chain, distributed between harvesting and transport links both before landing, at terminal or mill yard.

Norway

Production and transport curves

The relative variation in weekly production and truck delivery for the Norwegian case is shown in the figures below. The weekly production pace varies more than the weekly transport pace. Production is noticeable higher during the first half-year until the spring thaw (weeks 14-16).



Figure 8. Norwegian case; relative weekly production volumes for 2014-2016 (m3/week where 100 % = annual average).

Transport maintains a high pace throughout the first half-year until summer holidays. For both, considerable reductions are seen during the Christmas and summer holiday (weeks 51-1 and 29-31, respectively). Both production and transport show reductions in pace during the spring thaw (weeks 14-17).



Figure 9. Norwegian case; relative weekly truck transport volumes during 2014-2016 (m3/week where 100 % = annual average).

Transport lead times

This chapter presents the lead time in days for the three cases. The Austrian case includes 101 harvesting projects or contracts, the Swedish case 453 and the Norwegian approximately 3000. The two definitions of transport lead times used here are defined earlier in the report. Both definitions refer to when the last load is delivered which means that the lead time for a single truck loads can be faster.

Austria

The largest proportion of the overall lead time is assumed to be the storage time for wood along the supply chain. This is highly relevant, because storage periods can significantly reduce the wood quality, depending on assortment and weather conditions. The first lead time is defined as the time between the first production report and the last transport report (LT_{start} , blue boxplot in Figure 10). The sample includes 101 harvesting projects, where both production and transport reports were available and the transport was already concluded, with an average volume of 785 m³ per harvesting project. 0 shows the average lead time of a harvesting project of 104 days, including wide spread data from 21 to 263 days. Most of the very long lead times result from salvage wood harvesting, partly with wet storage times included.

The second lead time is defined as the time between the last production report and the last transport report (LT_{finish}). The red boxplot in Figure 10 shows LT_{finish} from the same sample of 101 harvesting projects with an average lead time of 63 days, including a spread between 3 and 210 days. LT_{finish} results in shorter lead times, because the production is neglected, but seems to be more appropriate for the forest sector. The reason for the better fit lies in the focus on wood transport, the importance of freshness and thereby wood value and the relative short production times compared to transport and storage time.



Figure 10. Austrian case; box plot of LTstart (blue) and LTfinish (red) for 2015-2016.

Figure 11 complements the lead time analyses by showing the variation of the lead time for the harvesting projects throughout the year. Both LT_{start} and LT_{finish} were assigned to the week of the last truck delivery, to show the variation and document seasonal trends.



Figure 11. Austrian case, weekly lead times LTstart (left) and LTfinish (right). Average, max and min days for 2015-2016.

Sweden

 LT_{start} for the Swedish case is shown in Figure 12. The maximum number of days is 297 days and minimum 10 days. The values are calculated as mean, min and max values measured in a week. The peaks were greater in 2015 than 2016, probable because of differences in temperature and rainfall.

The difference between LT_{start} and LT_{finish} consist of the days for harvesting. The size of the harvesting site is therefore responsible for this difference. The physical conditions at harvesting sites therefore also contributes to these differences.

Lead times in the Swedish case were quite even in the beginning of the year, between 30 to 60 days. The 453 harvesting contracts vary considerably in volume, which naturally effect the length of the delivery period. Figure 13 shows the variation in lead time. At first glance, the time for harvesting increases in summertime. Though, the many days in week 23 and 26 reflect also large volumes in specific weeks, a peak before holidays and a large wood contract. In 2015, 13% of the volume were produced week 23 and in 2016, 27% of the volume in week 22.

In week 23 2015, the lead times grew relative to the beginning of the year. The reason most likely being the upcoming summer holidays, forest hygiene legislation and the demands for collection of remaining "last loads". During this period inventories typically build up before holidays and the ensuing stop in harvesting production. The last loads remaining at harvested sites are collected to ensure that all round wood of spruce and pine are out of forest before the end of June. The resultant increase in transport volumes is seen in the presentation of transport pace (Figures 2 and 7), where the production and transport volumes are both higher than other summer weeks. Shortly before holidays the pressure on the transport operations increases to its peak for both years. As also can be seen in Figure 1 and 6Figure 2, the transport fleet stands still only one week during holidays while production is reduced for about four weeks, 27-30 (31). In the late autumn and early winter, the lead time varies, as can be seen from about week 40 to some weeks in January. This is most likely an effect of weather conditions, as earlier described having higher temperatures and precipitation during periods where harvesting was otherwise planned for frozen ground.



Figure 12. Swedish case; box plot of lead times LTstart (blue) and LTfinish (red). Average, max and min days for 2015-2016.



Figure 13. Swedish case; weekly variation in lead times LTstart (left) and LTfinish (right). Average, max and min days for 2015-2016.

Norway

The seasonal differences between production and transport paces gave rise to corresponding variations in lead times (LT) throughout the year. Typical lead times varied between 10 and 45 days, depending on assortment and definition. The median lead times per assortment class for both lead time definitions (LT_{start} vs LT_{fnish}) are shown in the Figure 14 below (left). Both lead times were longer for pulpwood than sawlogs. The seasonal variation in LT_{fnish} is shown in the same figure (right) according to the week the wood was delivered by truck. For sawlogs lead times peaked just after the end of the winter high season. For pulpwood, lead times started high after Christmas holidays, decreasing until the spring thaw, thereafter increasing until an early autumn peak. Throughout the rest of the autumn lead times declined towards Christmas holidays.



Figure 14. Norwegian case, left: box plot of lead times per assortment group. Right, weekly variation in lead times (LTfinish) per assortment group according to the week of delivery (2014-2016).

Multimodal operations

The weekly transport volumes and distances for the unimodal and multimodal transports for each regional case are shown below (Figures 15, 16, 17). The corresponding geographies are shown in Figures 18, 19 and 20.



Figure 15. Austrian case; relative weekly volumes (left) and transport duration (right) for wood delivered direct to industry (blue, unimodal) versus rail terminal (red, multimodal) for 2015-2016.



Figure 16. Swedish case; relative weekly volumes delivered to terminal (left) and average transport distance (right) for wood delivered direct to industry (blue, unimodal) versus rail terminal (red, multimodal) for 2015-2016



Figure 17. Norwegian case; relative weekly volumes delivered to terminal (left) and average transport distance (right) for wood delivered direct to industry (blue, unimodal) versus ship terminal (red, multimodal) for 2015-2016.



Figure 18. Austrian case; Geographical location of Großreifling terminal (blue) and mills (red).



Figure 19. Swedish case; Geographical location of railway terminals (green) and receiving industries (red).



Figure 20. Norwegian case; Geographical location of ship terminals (red) and mills (green).

The Austrian multimodal volumes increase through the year with a peak around week 42, decreasing thereafter until the end of the year. More variation can be found in the Austrian case where around 50% of the volumes are transported multimodal. For Scandinavian cases the level of multimodal transport is has a maximum of 20% in the Swedish case and 50% in the Norwegian case. While for the Swedish case the truck transport distances are roughly twice as far as for the Norwegian case, the distances to multimodal terminals were roughly half the distance of transports directly to mills. The Austrian case, however, used transport duration (hrs) instead of distance.

Austria

The observed region is appropriate to examine differences of multimodal (train) transport and unimodal truck transport, because the transport volumes are nearly on the same level. In 2016 exactly 50% of the volumes were transported multimodal and unimodal, while in 2015 multimodal transport was slightly higher (56%) as unimodal transport, which result in an overall relation of 47% unimodal transport to 53% multimodal transport. Figure 21 shows the number of wagons per weeks which vary between 1 and 16 with an average of about 7 wagons. During 2015 the fluctuation in the number of wagons was higher than in 2016 where there could be observed a rising trend.



Figure 21. Austrian case; number of rail wagons delivered per week during 2015 (weeks 1-52) and 2016 (53-104).

The average duration of a truck transport was 6.93 hours, but on average only 4.37 hours were driving time. The truck spent on average 1.53 hours at the industry and 2.7 hours in the forest district. Due to different transport modes, a distinction between truck transport to industry and truck transport to terminal was made. The average duration to industry was 9.34 hours, compared to 5.13 hours to the terminal. This was mainly due to the reduced driving time of only 3.13 hours to terminal compared to 6 hours to industry. Furthermore, the specific processes times of truck transport were collected in expert interviews. The averages of these expert estimations result in 5.3 hours of truck transport time to the terminal, which is very close to the 5.13 hours calculated with historical data.

The average process time for train transport was 2.26 days, with a maximum value of 22 days. The number of wagons in Großreifling decreased over the

last years. More than 80% of the wagons were delivered to industry within 3 days of truck transport, 90% within four days, and 95% within 5 days (Figure 22).



Figure 22. Austrian case; distributions of rail transport duration (days).

Sweden

In Figure 16 the percental wood deliveries to railway terminals per week was highest in the beginning of the year, here around week 10-15 for both years. The deliveries to railway terminal are prioritized, since Norra Skogsägarna has delivery contracts, quotas, to the terminal and terminals are their "selling point" in the supply chain. Deliveries are quite even over the year as can be seen and at a maximum 20% of the volumes. The total supply responsibility to fill specific departures from the train terminal, is owned by the buying company and the train schedules are therefore not displayed. The typical departure frequency is up to two train sets per week where a typical train set consists of about 20 wagons with a cargo capacity of approx. 1800 m³ (maximum 730 m length). The geographical distribution can be seen in Figure 19 with production streching up to the northwest and the mills located mainly along the eastern coastline. The railway terminals are placed to provide effective truck transport with respect to break-even costs between unimodal and multimodal deliveries to the coastal mills.

Norway

For 2015 and 2016, the relative weekly transport volumes transported directly to mills (0) versus to port for vessel transport (1) are shown in Figure 17 (left). Multimodal transport was used for delivery of 28% of the volume for the selected area and time frame. This proportion is well under the 40 % cited by the host organization, primarill as a result of missing GPS-coordinates for terminal destinations in the southern terminals. The weekly average transport distance for truck transport is shown in the the same Figure 17 (right). The annual average distance was 79 km for direct transport (0) and 42 km for transport to port (1).

Main terminals Orkanger and Surnadal

In total, 10 shipping terminals (PoL) were used for multimodal transport in the selected study area. Data for in- and outflows for the two main terminals (Orkanger and Surnadal) during 2016 are presented below. The Orkanger port was primarilly used to transport of pulpwood (1100-1200 m³ inflow per week), while the Surnadal port was used primarilly for transport of sawlogs (600-650 m³ inflow per week). The flows to both follow the winter high season pattern which was typical for the rest of the study. The same figure shows the calculated inventory balance per assortment group, which averaged 1890 m³ and 1380 m³ for Orkanger/pulp and Surnadal/sawlogs, respectively. The vessels loading at Orkanger had an average cargo size of 2750 m³, comprised of the more numerous cargoes of approx. 2500 m³, and a few cargoes in excess of 4000 m³. The vessels loading at Surnadal collected their cargoes from multiple ports, where the average cargo from Surnadal was 1475 m³, comprised of numerous partial cargoes often under 1250 m³, and a few full and complete cargoes of 2500 m3. For the average case, the lead time for building up a typical cargo in inventories (average cargo divided by average inflow rate) was 2,4 weeks.



Figure 23. Norwegian case; weekly in- and out-flows for two shipping terminals (Orkan=Orkanger, Surna=Surnadal) with corrresponding inventory balance per week (blue line: truck deliveries in m3/week, red square: vessel cargoes in m3/vessel, green line: PoL inventory balance in m3).

The effects of weather on production and transport pace

To better visualize the effects of regional weather patterns on production and transport, a common diagram format was selected to enable direct comparison between the regional cases. Each diagram shows the weekly production and transport pace on the lower panel with the corresponding weather parameters (temperature, precipitation, snowdepth) on the upper panel (Figures 24-26). The observed time horizons were two years for Austria and Sweden and three years for Norway. The figures allow a visual inspection of different presumptions such as response lags for transport and production volumes after weather events (snowfall) or seasonal transitions (freeze/thaw cycles). More detailed analyses are presented in the following case-specific chapters.

Austria

In the Austrian case study region, production and transport started on a low level at the beginning of the year and increased steadily to the late autumn – except a slight drop during summer holidays in August (Figure 24). In this case, the low production and transport season was primarily associated with

winter snowpack. The snowpack has an immediate impact on timber production and effects transport after a delay of a few weeks.



Figure 24. Austrian case; weekly production and transport pace (lower panel, right y-axis) with corresponding weather data (upper panel, left v-axis) for 2015-2016 (week 1-105).

Sweden

In contrast to the Austrian case, the highest production is associated with the winter season. The extremely low temperatures found only in the sub-arctic



Figure 25. Swedish case; weekly production and transport pace (lower panel) with corresponding weather data (upper panel) for 2015-2016 (weeks 1-53). The spring than period is noted with red circles.

zone as seen during January. The figure also shows longer periods of melting snowpack during the transition to the thawing period, with higher temperatures and precipitation (rain and slush) reducing supply drastically (red circles in Figure 25). These intersections between weather effects and production are of interest for further analysis.

Norway

Similar to the Swedish case, the highest supply in the Norwegian case is during



Figure 26. Norwegian case; weekly production and transport pace (lower panel) with corresponding weather data (upper panel) during 2014-2016 (weeks 1-156).

the winter. Production peaks are seen during periods when lower temperatures enable the accumulation of a stable snowpack. A decline in production is seen during the final melting of the snowpack during the spring thaw, but this decline was not as obvious for transport. The data also shows one uncharacteristic event of interest; the pronounced decline in both production and transport during the final weeks of the time series (late 2016) when daily precipitation exceeded 10 mm/day while temperatures are low but still above zero. In the oceanic zone these interactions are of interest for further analysis.

Quantitative analysis of weather effects

The quantitative analysis of weather effects is presented country-wise. The diverse data sources, materials and wood procurement strategies entail different contexts to interpret the results.

Austria

The first impressions of weekly averages for snow, precipitation and temperature (Figures 27-29) demonstrates the role of deep snowpack during

the beginning of the year as a driving factor for low production and transport volumes during these periods.



Figure 27. Austrian case; seasonal variation in air temperature (2015-2016).



Figure 28. Austrian case; weasonal variation in precipitation(2015-2016).

Regression analysis showed that weather data explained 16-62 % of variation (R^2) in production or transport volumes during 2015 and 2016. The R^2 increased with the duration of the planning period (delay of weather data), with the highest R^2 given by a delay of about four weeks (here interpreted as the



Figure 29. Snowpack for the Austrian case study region.

period for re-planning response). The ANOVA analyses concluded that these effects were statistically for both production and transport during 2015 and 2016 (Table below). The best results were found when all three independent variables (temperature, snow, precipitation) were included in the regression analysis on a weekly basis. Analyses of daily as well as monthly production and
transport data resulted in very low values for R^2 , even when holidays and other production free periods were excluded.

Table 1. Austrian case; a comparison of the coefficient of determination (R^2) for regression analysis with varying delays between weather data and their effects on production and transport pace.

Delay in weather effect (weeks)	Stage	R ²			
		2014	2015	2016	
0	production	0,044	0,159	0,221	
	transport		0,234	0,183	
1	production	0,056	0,201	0,262	
	transport		0,162	0,268	
2	production	0,083	0,133	0,321	
	transport		0,107	0,340	
3	production	0,127	0,116	0,372	
	transport		0,094	0,448	
4	production	0,125	0,171	0,449	
	transport		0,156	0,522	

Sweden

Using data for both 2015 and 2016 an ANOVA was performed using the SAS statistical analysis software to quantify the effect of temperature, snow depth and precipitation patterns on variations in procurement.

Initial observations of seasonal patterns

For the Swedish data, the beginning of the year generally has a higher pace of transported volumes. Comparing the weeks in the beginning of the year during the period with normally frozen ground (Figures 30, 31), 2015 temperatures fluctuated around zero together with precipitation (rain or snow). The fluctuation of the snow depth (Figure 32, 33) may also be noted, indicating a potentially negative effect of wet or grainy snow on forwarder mobility. Comparing 2015 and 2016, the transported volumes between week two and week 18 during 2015 had about the same pattern during spring time as the weeks 14-18 in 2016. On average, however, the volumes for the same weeks during 2015 were lower than for 2016.



Figure 30. Weekly median and extremes of temperature and precipitation for VO (wood region) Södra Lapland 2015.



Figure 31. Weekly median and extremes of temperature and precipitation for VO (wood region) Södra Lapland, 2016.





Figure 32. Weekly median and extremes of temperature and snow depth for VO (wood region) Södra Lapland, 2015.

Figure 33. Weekly median and extremes of temperature and snow depth for VO (wood region) Södra Lapland, 2016.

Figures 30 and 31 show the temperature versus precipitation in the two years. Figures 32 and 33 show the temperature versus snow depth. In the beginning of 2015, the combination with, for the season, high temperatures together with precipitation in the form of rain or snow influenced production. This period is typically part of the most effective harvestings period of the year. The effect the warmer winter period had on production consequently also had an impact on transport with lower transport volumes in relation to the year and to 2016 in the whole area of Södra Lappand. The impact of holidays can be seen during the summer weeks when production declined to almost zero, while inventories ensured continued wood flow to the industries. Since holidays have an impact in procurement, the weeks 27 to 30 are excluded from the analysis since they are potentially confounded with weather effects. The weeks are also weighted according to the number of working days according to the Swedish holidays calendar.

Analysis of weather impacts on production and transport

To analyze the correlation between the produced volumes in a district and the weather factors (temperature, precipitation and snow depth) an ANOVA was used. The total model explained a low proportion of the variation in production (R^2 of 30%). Temperature and precipitation had no impact on the model and were therefore excluded. The single parameter indicating significance was snow cover (p < 0,0007).

To further examine the effects of snow, classes were introduced; "no snow", "some snow" (< 0,5 meters) and "snow" (> 0,5 meters). The classification of snow cover provided a slightly higher significance, though still provided a low explanation of the variation (\mathbb{R}^2 of 28 %). Adding these classes to the model, and separating different weeks in seasons, made the model more sensitive to wet periods. For seasons with snow cover (week 49 to 18 for mid-Sweden), production rose above the annual mean. However, during winter, when beginning with already frozen ground, snow depth did not have an impact on harvesting.

Table 2. Swedish case; Ave	erage weekly production	pace per snow cover classes.
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Class of	Relative weekly production pace (1=100 %)						
snow cover	Mean	Std Dev					
No Snow	0.92025652	0.42009643					
Some Snow	1.11273755	0.51430479					
Snow	1.28067181	0.34747497					

In the early stages of winter, the snowpack varied, strongly correlated with temperatures fluctuating around zero. It is generally known that a thin snow pack has a bigger impact on harvesting. The most difficult situation is when there is no snow during late fall– beginning of winter, i.e. wetter harvesting sites. Fall periods in this case means wetter ground and increased difficulty to find harvesting sites with sufficient bearing capacity. This also leads to increased risk that some parts of sites will be inaccessible. To capture the situation with the impact of season, excluding summertime, with no snow and probable wetter ground, a season class was introduced; "summer" (week 19 to 31), "fall" (week 32 to 48) and "winter" (week 49 to 18). This is done to isolate periods which typically have a snow cover and correctly model how they interact with temperature. Using the ANOVA together with these two classifications provided a higher level of statistical significance (p<0,0004) and increased the coefficient of determination to 36% for the model.

For transport, the same type of ANOVA was made. Precipitation and snow depth were included at the start, showing no impact on the model, i.e. rejected due to too low significance. Keeping temperature, which in comparison had a higher level of significance and adding the two-way classification of snow and season showed slightly better correlations but still too low to consider temperature as a significant variable to explain variation in transport pace. The conclusions from the ANOVA for production versus transport differ. In the case of how snow depth affects the variation in production, it can be shown that a combination of a minor snow cover can indicate poor production conditions and consequently the negative impact on procurement. To be able to properly model the effect of snowpack at a weekly level more data covering several years are required. Figure 34 below shows inconsistencies between 2015 and 2016. If such a two-way classification is the key to showing a clearer pattern between years than snow depth, the bars should exhibit a more parallel pattern than seen here. For transport, no weather impacts can be shown from the 2015-2016 data sets. An explanation for this can be found in the management responses inherent in the data, where re-allocation of capacity and re-planning is done continually during challenging weather conditions to ensure fulfilment of mill demands. What is not shown, is the extra cost for reallocating production and transport capacity to secure these volumes. The prevailing supply chain strategy of increasing mill or terminal inventories prior



Figure 34. Box plot of weekly production pace using a two-way classification of season (autumn, summer, winter) and snow cover class during 2015 and 2016.

to expected seasonal events is well developed over the years to meet regional patterns of seasonality. This makes it difficult to demonstrate direct effects of weather conditions on transport since the expected patterns are included in wood supply planning.

Norway

Seasonal trends for production and truck transport

As noted earlier, significant individual events driving weekly variation in production and transport for the Norwegian case were seasonal holiday times. At first glance, much of the remaining variation could be linked to seasonal variations in temperature. Initially, a simple quadratic regression formula explained 40 % of variation in weekly production using the average temperature 8 weeks previous to the date of production reporting. The highest production was initiated during periods of low temperatures (under 0 degrees C). Between 0 and 5 degrees there was considerable variation in production during the following period, dropping to a minimum between 5 and 10 degrees. Production increased slightly thereafter when temperatures rose to above 10 degrees.

After production to roadside, the level of roadside stocks set a maximum limit for the truck transport pace to mills or ports. During high production periods such as midwinter, considerable stocks accumulated at roadside when transport capacity does not maintain the same pace as harvesting. During this period, transport capacity was typically prioritized to high value assortments (sawlogs) which were closest to customer mills or ports. As the high season passed and both production and roadside stocks sank, the remaining contracts at longer transport distances were subsequently delivered as transport capacity allowed. Figure 35 below illustrates the relationship for the current data.



Figure 35. Norwegian case; Regression curve between the calculated level of roadside stocks (cover time in weeks, x-axis) and the relative transport distance (1 = 100 % of annual average, y-axis).

Beyond the balancing of production and transport capacity as described above, other factors also play a role, such as the imposed reduction of axle weights and truck payloads during critical periods such as spring thaw. Figure 36 below visualizes the typical variation in weekly transport pace throughout the year as well as the coinciding variation in average truck payload (2014-1016).

Seasonal trends for temperature, precipitation and snowpack in the region are shown in the figures below. The greatest variation in daily temperatures exist during the winter and fall (Figure 37, left). Median temperatures between 0 and 5 degrees celcius were common before week 20 and after week 40. Median



Figure 36. Norwegian case; Seasonal variation in weekly transport pace (left) and average truck load size (right). The reduction of weekly transport pace (around week 15) coincides with reduced payloads during the spring thaw.

temperatures exceeding 10 degrees could be expected during the interim period of weeks 20 to 40. Daily precipitation often exceeded 5 mm/day, with extremes over 15 mm/day. Precipitation during the study period was was highest during the last 6 weeks of the year.



Figure 37. Norwegian case; box plots of daily temperatures (left) and precipitation (right) per week (2014-2016).



Figure 38. Norwegian case; Box plots of snowpack depths per week for three different altitude zones (1: < 100 m, 2: 100-300 m, 3: >300 m, 2014-2016).

Snowpack depths varied between altitude zones. At lower altitudes (< 100 m), midwinter snowpack rarely exceeded a few cm, while at higher altitudes (> 300 m) a stable snowpack could be expected. The main spring thaw generally ocurred around week 15, where the weekly reduction of snowpack provided an indication of this event. For 2014 and 2016, an accumulated snowpack melt more than 5 cm/week coincides with the typical time for imposed load reductions (week 13-18). For 2015, two periods of snowpack melt occurred, but earlier in the season (weeks 2 and 9).

Outside of the spring thaw, periods of high rainfall before the cold winter months also reduced trafficability for logging trucks. For this study period, periods of high precipitation (> 5 mm/day) in combination with cold, but not sub-zero temperatures ocurred during the final weeks of 2014, 2015 and 2016, coinciding with christmas holidays. The final weeks of 2016 represented a particularly unusual event with over 10 mm of precipitation per day in combination with temperatures of 2-4 degrees above zero.

Modelling of weather-driven effects on production and transport pace

Compared to an ealier plot of production against temperature alone, the curve set below (Figure 39) provides gives simple but useful illustration of the interacting effects of weather variables on production pace. The positive effect of winter snowpack (> 5 cm, green dotted line) increased production up to approx. 40 % as temperatures decline below 5 degrees celcius. In the same way, the negative effect of high precipitation (> 4 mm/day, blue line) reduced production by up to 40 % as temperatures dropped from 15 degrees to 0 degrees, after which precipitation comes as snow and begins to contribute to snowpack development. In the absence of either snowpack or high precipitation (indicated by the red dashed line) temperature alone had no apparent effect on the pace of production.



Figure 39. Norwegian case; Regression curves tracking the interacting effects of temperature (8 weeks previous to production report, x-axis) with snow cover (green line: > 5 cm snow) and precipitation (blue line: > 4 mm/day) on weekly production pace (y-axis). The red line represents weekly observations with no snow and low precipitation.

Using the same data resolution to examine transport pace shows the effect of precipitation on the next link of the supply chain (Figure 40). Even though the transport pace varies between the first and second half of the year, the effect of precipitation drives a reduction of average transport pace up to 20 %.

Overall, the effect of precipitation on transport pace is quite similar between the first and second half-year. The precipitation represented on the x-axis is the average daily precipitation over the week.



Figure 40. The effects of the daily precipitation (X-axis, mm/day) on weekly transport pace (Y-axis, 1=100 %) during the first half of the year (blue) and second half of the year (red).

Given the asumption that the arrival of the spring thaw was preceeded by an sustained level of snowpack reduction, this signal can be used to identify the relevant weekly periods and observations during the first half-year. The reduction of transport pace associated with these such periods increased with increased precipitation. These conditions, such as rain-on-snow events, are generally recognized by transporters as worst case winter driving conditions, and transport is temporarilly restricted to the least challenging roads.

Discussion

The study has compared and quantified seasonality in wood supply for cases in continental, sub-arctic and martime climate zones. Wood supply management in all these regions faces significant challenges. Although the host organizations have varying supply structures and management strategies, the common analytical framework enables direct comparisons and is applicable to many other cases.

In terms of broad contrasts shown in the results, the effect of winter snowpacks on wood supply varied between regions. In the Austrian case snow act as a hindrances, while in the Swedish and Norwegian cases it acts as an enabler. This has both to do with the varying magnitudes of snowpack in the regions as well as the respective bearing capacities of forest terrain and roads.

Regarding the statistical analysis used to quantifying the effects of weather on supply, this type of analysis is challenging. Most of the weather parameters have interacting effects and their effects can be delayed before becoming apparent on production reports. Further downstream effects of reduced production on transport can be delayed in accordance with the mapped lead times and smoothed by road-side stocks. Regardless of the main factors driving variation in supply flows such as market demand and tactical supply planning from alternative sources, these analyses have succeeded in explaining up to 50 % of the residual seasonal variation. Further discussion of the country-wise analyses are provide below.

Austria

Missing datasets and low data quality were detected and company partners were given the opportunity to solve these challenges. The university partners were provided with an overview of available datasets in different countries and different methods for information tracking, which will improve further applications.

Production and transport in the Austrian case study region started on a low level at the beginning of the year and steadily increased during the year. The effects of weather on actual production and transport volumes were confirmed by ANOVA analyses. The main outliners were due to summer holidays in the middle of the year and unreported volumes that were balanced at the end of the year. The multimodal rail solution reduced transport time and enabled a more efficient deployment of the available truck fleet.

The annual planning routines are initiated with the plan volumes of the logistics managers and the corresponding request of the regional managers. The planning process ends up in a plan volume (green, Figure 41) that can be compared with the actual transport volume (orange, Figure 41). It can be observed, that the actual transport volumes differ noticeably from agreed/fixed plan volumes especially at the end of 2015 and mid-2016. Moreover, the year 2014 indicates, that the logistic management tried to motivate the regional management to supply higher volumes earlier in the year and lower volumes at the end of 2015 again reflects corrections in the datasets due to missing volumes earlier in the year.



Figure 41. Austrian case. A comparison of planned and actual production volumes (2014-2016).

Sweden

The most difficult period in the Swedish case study area was the fall, having both high temperatures (above 0 degrees C) and snowfall. The effects of snow were in one sense shown by the ANOVA analyses. However, in the supply chain, expected periods of low production are usually considered in the inventory volumes prescribed during tactical planning. This aspect also explains why seasonality impacts differ between production and truck transport.

In the studied years, 2015 and 2016, problems in procurement occurred during periods planned for harvesting during winter time with frozen ground. In the collected datasets the correlation between high temperature and snow cover in wintertime were analysed in more detail. The result pinpoints an interesting area for further analyse, since the significance of warmer winter temperatures in the sub-arctic zone poses a production risk for large supply areas.

In contrast, transport operations were not shown to be influenced of weather conditions in the study area. This fact is also supported from experiences from the interviews. The variation in transported volumes are from experience an effect of a movement of the truck fleet to alternative supply areas and consequently effect the transport capacity in the area. The movement of truck capacity follows because of re-allocation of harvesting capacity, as noted earlier. Given the role of roadside inventories in wood procurement planning, the harvesting operation is a key area of interest for developing better procurement strategies with more precise descriptions of variations and deviations from planned procurement. This motivates further studies of weather effects on variation during specific seasonal periods.

To fully analyse the extent of weather impacts, a data set covering several years together with higher quality and wider geographical coverage would be interesting. Provided a better data set, a more precise analysis per assortment and supply district could also improve the analysis of local seasonal variations on procurement and could improve the planning processes.

Norway

The study examined three links in the multimodal supply chain; harvesting, truck- and vessel transport with the main inventory points at roadside and terminal. The seasonal patterns for production follow the trends which have been typical for much of Norway with the corresponding management responses. Winter frost and snow enables temporary access to soil types of low bearing capacity such as the lower coast marine deposits and upper peatlands. Areas lacking a deep winter frost can also often be by-passed by pre-packed snow-roads. In the coastal areas many of the most productive stands are located on fine-textured marine deposits (silt, clay) at low altitudes. In this case occasional dry summer periods also enable temporary access. In general as the winter season concludes, harvesting capacity is relocated to take advantage of the remaining snowpack at higher altitudes (Figure 42 below).

Allocation of harvesting and transport capacity is coordinated at the yearly level, and the more even pattern for transport pace balances with production volumes per half-year, but lead to increasing lead times as the summer approached. This trend was more apparent for pulpwood than sawlogs, as sawlogs were the prioritized assortment for use of truck transport capacity. The higher production pace during the first half-year was also matched by multimodal transport. In practice, however, terminal inventories were often empty after vessel loading with eventual seasonal excesses coinciding with the spring thaw, when truck transport capacity is otherwise reduced.



Figure 42. Norwegian case; Distribution of production to roadside (y-axis) per month (x-axis) from varying altitudes above sea level (<150 m, 150-300 m, >300 m).

Regarding the modelling of supply pace, both weekly production and transport pace could be linked to weather variables. For production, temperatures played a key role, but primarilly through their interaction with precipitation forms. The effect of time-lag for temperature, however, is not completely clear. Alternative time lags of 0, 2, 4, 6 and 8 weeks were tested for best prediction of subsequent harvesting levels with the highest proportion of variation being explained by an 8-week lag. One plausible explanation for an 8-week lag could be the effect of forest owners' evaluation of trafficability on their ownerships as a determinant for their willingness to initiate harvesting contracts. From this perspective, the 8-week lag could be interpreted as the time lag from observation of suitable conditions to the actual initiation of production by the association's contractors. The initial curve showing the lowest production pace at 5-10 degrees, with increasing production for colder and even a slight increase with warmer temperatures is verified by local production planning practices. The subsequent interaction curves illustrating the effect of snowpack and precipitation also contributed to describe production variations from a bearing capacity perspective. However, inherent in these variations are the underlying differences in stand conditions associated with the alternative areas selected by production planners to maintain production during varying weather.

The effects of coastal weather on the first link of the supply chain is dramatic, and the resulting range of production variation (40 %) is considerable . The remaining 20 % variation in transport pace is relatively mild, but not necessarilly less dramatic. As the key link responsible for maintaining mill supply, there is more immediate pressure to maintain deliveries, regardless of operating conditions. While typical rainfall during summer and fall was limited to 4 mm/day, the extremes of 15-25 mm/day present a considerable risk for reduced bearing capacity, low traction and forest road rutting. The duration of these effects is assumed to be shorter during warmer weather due to increased evaporation. This modification was not appparent in the present study data.

The separation of the first half-year into periods of stable vs. sinking snowpack enabled a clearer insight into how rain-on-snow reduced transport pace, presumably due to the combined effects of both reduced bearing capacity and traction.

While far from a complete analysis, the present study succeeded in mapping some main effects of weather on coastal wood supply operations. Seasonal variation in terrain and road bearing capacity are key issues and result in increased lead times when harvested roundwood is trapped at roadside during poor weather. In the present study, lead times differ considerably between sawlogs and pulpwood, presumably as a consequence of the differing potential value reductions for the respective assortment classes.

The multimodal transport link is subject to the consequences of the noted variations in production and transport pace. The reductions in production and transport typical during the spring thaw period, however, were not as apparent for the multimodal link. The tracking of PoL inventories at Orkanger and Surnadal showed peak inventories during this period, with a corresponding possibility to compensate for reduced truck transport direct to mills. The shorter transport distances from forest to PoL also enable high volume flows to multimodal terminals with limited transport capacity. Compared to rail transport, short-sea shipping with mini-bulk vessels provides potential advantages such as increased transport capacity and reduced restrictions for infrastructure use and arrival/departure times at PoLs/PoDs. However, the larger cargoes also requires improved coordination with truck transport to build up terminal stocks and harvesting to ensure wood availability in roadside stocks for the approriate areas.

Future work

The collection, preparation and analysis of data from WP2 form the basis for further simulation and optimization analyses in WP3. The data provides a base for study designs, scenario designs and validation. Study designs can exploit more realistic parameters. Scenario design can incorporate representative risks and extreme values as well as fit distributions for production and transport rates, arrival and service times. Validation can utilize historical input data for simulation/optimization and compare the modelled system output with real output data.

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MultiStrat interim work report for WP3 (Supply chain modeling)



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1. Introduction

Wood supply chain simulation models for testing multimodal strategies will point the way to a greener and more resilient wood supply in Central and Northern Europe. Therefore, the need for an integrated framework focusing on risks will be satisfied by discrete event simulation models and an optimization model to support managers in their decisions and contribute to a better understanding of the multimodal wood supply chain. Increasing occurrences of natural disturbances such as windstorms lead to supply chain risks and seasonal irregularities in wood harvest and transport. Moreover, the forest based sector is lacking a comprehensive multimodal concept to improve the sustainability, resilience, efficiency and cost-effectiveness along the wood supply chain. These significant challenges for wood supply management require an integrated framework for modelling and analysis of efficiency and resilience to supply chain risks. The simulated supply chain reaches from the forest to the industry and covers wood harvest and pre-carriage to wood terminals, storage in terminals, transhipment to rail wagons or vessels and final transport to and unloading at woodworking plants. Innovative multimodal systems via rail and sea terminals offer the potential to increase buffer capacity and to reduce greenhouse gas emissions. Therefore, terminals are included in a new virtual environment to enable manager involvement in testing, analysis and evaluation of a complex multimodal system. The simulation and optimization models facilitate carrying out experiments, case studies and scenario designs for international strategy comparisons in workshops with supply chain managers. Furthermore, adapting collaborative supply chain control strategies in participatory simulations will enhance the development of advanced risk management and therefore improve supply chain resilience.

To cover the differences between the three regions three case studies were surveyed to investigate wood supply chains in Austria, Sweden and Norway. These case studies were suitable to develop models for deeper analyses, because data availability, quality and process insides as well as willingness to cooperate of the industry partners were given. Therefore, discrete event simulation models were created with the software AnyLogic for the Austrian case and with ExtendSim for the Swedish case and an Excel-based optimization was developed to study the Norwegian case. These models are independent and highly customised for the individual cases proving deep insides in the chosen supply chains and regions.

This report builds up on the earlier reports of WP1 and WP2. On the one hand the report of WP1 contains key number of the participating organizations, typical operating conditions per enterprise, functions per organization, general framework for coordination between functions from long to short term, overview of supply and demand risks, supply chain coordination processes, process charts and general wood supply management activities. On the other hand, the WP2 report includes information about data and data collection, framework for common analysis, wood supply trends in production and transport, lead times, multimodal aspects, weather effects and statistical analysis.

The remaining part of this report consists of (2) literature review, (3) case study Austria including the description of the discrete event simulation model, (4) case study Sweden including the description of the discrete event simulation model, (5) case study Norway including the Excelbased optimization model and (6) conclusions.

2. Literature review for simulation studies

In the last twenty years the relevant literature (see Table 1 and Table 2) for discrete event simulation of multimodal wood supply chains was mainly published by Scandinavian, Canadian and Austrian research groups. The majority of these research projects include a case study, consider risks and concentrate either on train, vessel or both transport modes. Every research group seems to have a preferred simulation environment (AnyLogic, ExtendSim or Witness) to simulate time periods from weeks to one year incorporating a wide spread of abstraction level and planning horizon.

Reference (Year)	Region	Journal	Abstraction level	Planning horizon	Assort- ment	Transport mode	Software
De Mol et al. (1997)	NLD	Netherlands Journal of Agricultural Science	abstract	tactical	forest biomass	multimodal	ProSim
Asikainen (2001)	FIN	International Journal of Forest Engineering	detailed	tactical	timber	multimodal (vessel)	Witness
Saranen and Hilmola (2007)	FIN	World Review of Intermodal Transportation Research	abstract	operationa I	timber	multimodal (train)	Quest
Karttunen et al. (2012)	FIN	Silva Fennica	abstract	tactical	forest chips	multimodal (vessel)	Witness
Karttunen et al. (2013)	FIN	Silva Fennica	intermediate	tactical	forest chips	multimodal (train)	AnyLogic
Mobini et al. (2013)	CAN	Applied Energy	detailed	strategical	forest pellets	multimodal (train, ocean vessels)	ExtendSi m
Etlinger et al. (2014)	AUT	HMS Conference Paper	detailed	tactical	saw logs, pulp wood	multimodal (train)	AnyLogic
Mobini et al. (2014)	CAN	Journal of Cleaner Production	detailed	strategical	forest pellets	multimodal (train, ocean vessels)	ExtendSi m
Wolfsmayr et al. (2016)	AUT	Annals of Forest Research	intermediate	operationa I	timber, forest chips	multimodal (train)	AnyLogic
Rauch and Gronalt (2018)	AUT	unpublished	detailed	operationa I	timber, forest biomass	multimodal (train)	AnyLogic

Table 1: Classification of the research articles

De Mol et al. (1997) design an early simulation model for biomass and respond to network structure and biomass mixture decisions with a mixed-integer linear programming model. Asikainen (2001) investigates inland-waterway transport with barge systems from islands to a mill, including logging, loading and unloading modules. Saranen and Hilmola (2007) show the competitiveness of a unit train railway transportation concept (i.e. permanent locomotive equipped with a timber loader) for long distance with competitive prospect even for short distances. Kattunen et al. (2012) compare waterway transport of forest chips with truck transport and find benefits in case of loading capacity and bulk density, resulting in a cost advantage of waterway transport to road transport if transportation distance is more than 100 to 150 km. Karttunen et al. (2013) combine a GIS with a simulation model to find cost-efficient alternatives for long-distance transportation of forest chips. The entire wood pellets supply chain starting at the source over procurement, truck transportation, storage, pellet production and distribution to customer by truck or for export by train and vessel is modeled by Mobini et al. (2013).

Etlinger et al. (2014) show in their DES model for multimodal truck-train transport a way to nearly double the amount of round wood transport. In a subsequent work, Mobini et al. (2014) include a torrefaction process, this pellets supply chain demonstrates the trade-offs between reduced transport costs, higher capital and operating cost and is, therefore, particularly attractive for long transportation distances with ocean vessels. Wolfsmayr et al. (2016) investigate multimodal biomass transport and focus on one module for terminal operations and aggregate the upstream and downstream components of the supply chain by in- and outgoing flows. Gronalt and Rauch (2018) add to the work of Etlinger et al. (2014) and analyze through complementary simulation experiments supply chain bottlenecks and train schedules.

Reference (year)	RC	cs	Simulation period (resolution time)	Supply network	Objective
De Mol et al. (1997)		(X)	1 year	source, collection, pre-treatment, transhipment, energy plant	gain insight into the costs and energy consumption of logistics
Asikainen (2001)		Х	1 month	harvesting, forwarding, 15 vessel terminals, powered barge / push barge, mill	cost comparison of push barge systems to a powered barge system for waterway transport
Saranen and Hilmola (2007)		Х	2 weeks	28 rail terminals, railway network, 2 mills	evaluate the competitiveness of a unit train concept by cost considerations
Karttunen et al. (2012)	х	х	9 months	3 fuel terminals at harbors, waterway network, 3 bio-power plants	determine the efficiency of waterway transport and compare the costs to truck transport of forest chips for Lake Saimaa
Karttunen et al. (2013)		х	1 year	roadside storage, chipping, container truck transport, terminal, railway transportation, combined heat and power plant	compare the cost-efficiency of a multimodal supply chain with an intermodal container supply chain for long-distance transportation of wood chips by road and rail with a combined simulation and GIS model
Mobini et al. (2013)	x	х	1 year	5 suppliers, transportation (10 trucks, railcar, ocean vessel), raw material handling and storage, 1 pellet mill (drying, size reduction, pelletization, cooling, storage, packing, distribution), end customer	estimate delivery cost to customer and CO ₂ emissions along the wood pellet supply system in scenarios with different fuel types and different raw material mixtures for pellets
Etlinger et al. (2014)	x	х	1 year (minutes)	forest and prehaulage, 4 rail terminals, railway network, 2 saw mills, 2 paper mills	improve efficiency of supply chain and determine transhipment time / cycle time, stock levels at terminals over time, utilization of terminal infrastructure, network capacity and terminal size
Mobini et al. (2014)	Х	Х	1 year	5 suppliers, truck transport, export port for incoming rail and outgoing vessels, raw material handling and storage, 1 pellet mill (drying, torrefaction, pelletization, cooling, storage, packing, distribution), end customer in north western Europe, Japan, Korea or China	extend a wood pellets simulation model by developing a torrefaction process module to compare the delivered cost to markets, distribution costs, energy consumption and carbon dioxide emission with those of regular pellets
Wolfsmayr et al. (2016)		х	1 year (minutes)	3 rail terminals	investigate potentials of existing transhipment infrastructure (rail sidings, storage areas, access roads) for biomass
Gronalt and Rauch (2018)	Х	х	1 year (minutes)	forest and prehaulage, 4 rail terminals, railway network, 2 saw mills, 2 paper mills	compare scenarios for different railway operation schedules (shuttle train vs. single wagon traffic)

Table 2: Multimodal DES models. RC = Risk Considered, CS = Case Study included

Within multimodal wood supply chain studies, a focus on terminal operations was found as a common feature in literature. Research gaps exist concerning detailed simulation modules for upstream processes of terminals, which allow a more realistic consideration of relevant supply risks. These risks, as well as demand risks, should be observed in comprehensive case studies applying stochastic simulation and optimization. Currently, risk is often considered rudimentary, mainly as internal transport risks such as machine breakdowns or transport delays and observing short simulation horizons (i.e. up to one year). Nevertheless, important external risks exist such as natural disasters (e.g. windstorm, bark beetle infestation), weather (e.g. rain, ice) and delivery stops of mills. These risks play a major role in supply chain performance and should be proactively managed by robust risk management. Simulation of different risk scenarios in a long-term setting (i.e. up to 10 years) can provide valuable decision support in such scenarios. The simulation study on hand is a first step in this direction and should be extended and further complemented.

3. Case Study Austria

3.1 Case description

The Austrian case study is motivated by the challenging management of the Austrian wood supply chain, especially when it comes to natural disturbances. To provide insights in the management views of different supply chain actors, some of the recorded challenges are listed in Figure 1 and contrasted by a short answer.



Figure 1: Motivation for the Austrian case study

To overcome these challenges, multimodal strategies based on simulation results were developed. Multimodal strategies offer the potential for greener supply chains including reduced emissions and the involved terminals provide buffer opportunities to overcome risks and enhance the resilience of the whole supply chain. Especially when natural disturbances occur, inefficient contingency plans dominate. Supply chain managers find it often hard to make right decisions, because an improvement in one part can result in downgrades elsewhere. Furthermore, network capacity, queuing times and lead times are difficult to estimate. Therefore, an integrated framework for simulation and testing multimodal strategies provides valuable decision support to managers, allows to track every log and shows maximal capacities as well as bottlenecks to contribute to further development of the Austrian wood supply.

To investigate these challenges a comprehensive case study supported by interviews and data collection of the Austrian Federal Forests' multimodal supply chain concentrating on a train terminal in Großreifling (Styria) was conducted during the last years and sets the stage for the development of a simulation model based on a real life case. The map (Figure 2) shows twelve forest management units of the Austrian Federal Forests in different colours and a pin for the location of the investigated wood terminal.



Figure 2. Case study region and terminal

The Austrian Federal Forests are property of the Austrian state and administered in a stock company. Their 1100 employees are responsible for 15% of Austrian forests and deliver a supply volume of more than 1,5 million cubic meters, of which about a quarter is handled multimodal. Four of 121 forest districts directly supply the observed train terminal in the small Styrian village Großreifling (Figure 3). Regularly, three regional carriers transport about 2000 cubic meter wood per month to the terminal. Once (twice after storms) a day a locomotive picks up two to four (up to nine after storms) wagons and leaves empty wagons until the next day at one of the not electrified loading tracks. After natural disturbances like wind storms up to 30.000 cubic meters per month pass through the terminal. In this case up to 10.000 cubic meters can be stored directly at the terminal.

The relevant processes of the supply chain ware captured for deeper analyses in numerous process maps with the software Adonis in different abstraction levels. Figure 4 shows a very abstracted process map to give an overview of the supply chain. The actors in the described supply chain are the Austrian Federal Forests, logging companies, carriers, Railcargo Austria and mills. After the planning is concluded (1) and logging is assigned (2), either to internal and external units, and executed (3), there start the relevant processes for the later simulation. Transport has to be instructed and the decision of multimodal or unimodal transport has to be made. In case of multimodal transport there is a higher managing effort necessary, caused by a complicated ordering system of Railcargo Austria and poor communication, which can be detected by a longer process chain. This is the main reason, why truck transport is favoured by the regional management, even when costs for truck and train are similar. To give an unbiased comparison of multimodal and unimodal transport a simulation including a set of key performance indicators is needed to give decision support to managers. Moreover, the managers are groping in the dark, when it comes to estimating values for lead times of the supply chain and queuing times at the terminal. Therefore, discrete event simulation is an

appropriate method to gain insides in this KPIs especially in scenario settings reflecting natural disturbances.



Figure 3: Impressions of the train terminal in Großreifling



Figure 4: Process map of the Austrian wood supply chain

Figure 5 shows an aerial photograph of four 200 m long rail tracks, only the two in the middle are electrified. The upper one is private owned and the lowest one is the loading siding of the Austrian Federal Forests. The 175 meters long and 30 meters wide stockyard is separated in areas for round timber and biomass. After a truck drove to the forest landing, loaded wood and transported it to the terminal, it accesses the terminal at the point 1. In point 2 the driver removes safety belts that enclosed the wood and he loads the wagon at point 3 before securing the wagon load on 4. In 5 he cleans the truck loading platform and in 6 he completes the delivery note.



Figure 5: Aerial photograph of the terminal in Großreifling

These processes can be also found in Figure 6 (the process map for managing terminal operations) which includes relevant details for the terminal operations. The truck enters the terminal, coordinates with other drivers if necessary, loads directly on the wagon or unloads to the stockyard or waits, secures belts, cleans the loading area, sends GPS coordinates for completed delivery and completes the delivery note for the truck transport and the consignment note for the train transport. Interesting queuing and scheduling problems occur after windstorms when many trucks want to load wagons at the same time. Such issues will be also addressed by discrete event simulation.



Figure 6: Process map of the terminal in Großreiflling

According to the case study the goal was to design an easily adoptable and executable discrete event simulation with scenario and parameter selection, different views for code, logic, statistics and animation to gain inside in the Austrian wood supply chain. Moreover, a standard system configuration (BAU = business as usual) had to be compared with a scenario with reduced production due to a high snow cover (-75% production in the first quarter of the year) and one with an increased production after a windstorm (+300% production in the third quarter of the year). To allow a high involvement of the industry the simulation model should be intuitively operable by a graphical user interface including a detailed animation view and the possibility to parameterize the model via Excel.

The rest of the Austrian report summarises this process: (3.2) Input data and model parametrization: describes the used datasets and necessary assumptions; (3.3) Model description: explains the model logic, modules and views; (3.4) Results: gives insides in scenario design, outcomes and conclusions; and (3.5) Further research: lists further development steps.

3.2 Input data and model parametrization

The input data for the model configuration is based on historical production and truck transport data of the Austrian Federal Forests (datasets for 2015 and 2016), train transport data of the Railcago Austria (dataset 2007–2016) as well as expert estimations (9 interviews with managers, foresters, carriers during 2016 and 2017). Datasets were used to follow process flows during model development, initial parametrization and final validation of the model. The process flows, working times, process times as well as other logic sequences were either observed or documented in interviews and displayed in business process diagrams or assumption documents to set the stage for the implementation of the agent flow through the supply chain. Statistical analyses indicated, that triangular distributions are a reliable approach to integrate expert estimates and keep an intuitive usability as well as robust results.

The first screen of the simulation model shows the parameterization window (see Figure 9, Figure 10 and Figure 12). This screen is split in a general parameterization part including transport module, terminal module and cost (Figure 7), the scenario bar with the run button (Figure 8), the different control method options (Figure 9–Figure 12) and the AnyLogic control bar.

Figure 7 shows the general parameterization parts, which are available in all scenario settings. Since the transport costs are negotiated as a lump sum between the Austrian Federal Forests and the carriers, they are also implemented in that way. The cost frame includes average costs in euros per cubic meter of wood. Costs can be adjusted for every district (D1, D2, D8 and D9) for truck transport to terminal or industry as well as the multimodal transport costs from terminal to industry. The transport module includes triangular distributions for process times and truckload capacity. In the terminal module triangular time distributions for process time at the terminal as well as the maximum truckload capacity at the landings in the four districts can be chosen.

Costs	Transport Module	Terminal Module
Truck transport per solid cubic meter	Triangular time distributions in minutes	Triangular time distributions in minutes
D1 D2 D8 D9 Average costs to Terminal 8.2 9.1 9.8 9.8	MIN AVG MAX Drive to landing 10 46 83	MIN AVG MAX Remove Belts 7 10 12
Average costs to Industry 14.22 12.75 17.72 13.15	Load truck 30 35 40	Load Wagon 35 55 55
Average costs from Terminal to Industry 8.9	Transport to terminal 15 45 105	Secure Wagon Load 5 8 10
	Truck transport to industry 60 105 150	Clean Loading Platform 3 5 10
	Train Transport 1440 3258 31680	Complete Delivery Note 10 13 15
	Triangular capacity distribution in solid cubic meters	Unload at Terminal Stockyard 35 45 55
	MIN AVG MAX 20 22 30	Unloading Truck at the Industry 35 60 180
		Maximum capacity in truck loads
		D1 D2 D8 D9 Stockyard 10000 10000 10000

Figure 7: Parameterization window for costs, transport module and terminal module

The scenario bar with radio buttons for control methods, train pickups, transport modes, transport priorities, runtime and a run button can be found in Figure 8. The control method radio button activates the settings for manual, plan or Excel control. The number of maximal train pickups per day can be defined in the next frame. A train only visits the terminal if loaded

wagons are at the terminal or new empty wagons have to be provided. The first train pickup happens at 09:00, the second at 15:00 according to the real time plan of Railcargo Austria.

To simulate the transport process four scenarios were implemented, which again can be easily changed by switching the according radio button.

In case of selecting *Multimodal* every transport includes a transhipment at the terminal to a wagon and a train transport to industry, while the *Unimodal* case simulates direct truck transport only. The selection *Both (50/50)* results in unimodal and multimodal transport randomly chosen on the same probability level, while *Real* uses different probability levels (based on historical transport data for the particular district). Transport priority defines the stock policy at the forest road landings. *Largest Stock* sends the next available truck to the district with the largest stock. Whereas, *Shortest Lead Time* sends the next available truck to the district with the oldest wood in order to keep lead time short. The last frame enables a cyclic pause of the simulation model (the model can also be stopped manually by the control bar), to observe actual statistics after a year, month, week, day or train pickup or to change parameters periodically. Finally, the *Run Simulation* button starts the simulation and reads the configured parameter settings.





To simulate the production and transport plans per week three different control methods (see Figure 9, Figure 10 and Figure 12) can be selected, which can be easily changed by switching the according radio button in the scenario bar.



Figure 9: Manual week by week input for wagons, trucks and production by sliders

Firstly, the manual control method (see Figure 9) enables the adjustment of number of wagons (between 0 and 9), number of trucks (between 0 and 50) and weekly production for the districts (D1, D2, D8, D9).

This option is designed to stop the simulation once a week and adjust the parameter iteratively according to the actual situation and limitations. If no changes were performed until Friday afternoon (19:00), the parameter setting stays the same as in the week before.

The manual control option is helpful for the practical usage by wood supply chain managers to gain insides about interdependencies of the chain and to see effects of decisions before real costly changes are made. Therefore, this option is highly suitable for workshops to give a step by step (minute, hour, day, week) explanation of the simulation model.

Secondly, the selection of the plan control method activates radio buttons to choose between four built-in standard scenarios (see Figure 10) enabling fast demonstration of different simulation runs. One of these scenarios, the *Standard (distribution)* takes into consideration random numbers (see Figure 11), the other ones define fixed production and transport values. The first option the *Standard (distribution)* takes into account monthly production patterns (little production during the first months, high production during the last months of the year) by reading input parameters (arrays based on historical production data). In a twostep process firstly a random number is generated to choose if wood is produced on this day in the respected district. If a production day was chosen, a production value is randomly drawn from a triangular distribution based on historical production and transport plan for the whole year in advance. The *Extrem* scenario sets fixed values for production and transport for the whole year based on historical maximal system capacities. Finally, the *Standard (fix)* scenario sets fixed values for production.



Figure 10: Input of an individual plan for wagons, trucks and production

Productio	n prob	ability	per di	stict	Production amounts in solid cubic meters												
Ĩ	D1	D2	D8	D9		D1			D2			D8			D9		
		Ave	rage		MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX	
January	41%	5%	10%	15%	3	57	175	107	304	500	2	349	1186	11	30	77	
February	56%	12%	15%	2%	15	110	380	5	55	134	32	100	256	14	14	14	
March	51%	44%	33%	0%	5	79	304	15	79	336	4	45	85	0	0	0	
April	46%	63%	41%	32%	8	66	234	1	97	229	6	48	191	9	64	251	
May	68%	49%	49%	43%	9	83	630	2	97	684	13	76	203	7	72	160	
June	67%	53%	42%	51%	0	86	317	12	103	344	13	101	665	10	115	274	
July	64%	48%	66%	100%	12	93	301	7	112	450	1	66	324	5	117	501	
August	63%	56%	58%	53%	10	130	968	20	94	423	5	53	120	2	106	515	
September	98%	68%	59%	73%	10	140	601	18	141	845	3	99	406	7	104	433	
October	80%	56%	59%	56%	5	196	985	17	129	1221	8	94	540	12	116	771	
November	63%	41%	37%	20%	3	171	802	27	177	417	21	125	325	20	188	585	
December	62%	23%	38%	21%	30	477	3203	30	418	1058	0	90	283	1	156	563	

Figure 11: Plan control method, Standard (distribution) scenario

Thirdly, the *Excel* control method activates three additional scenarios, which read the parameters directly from standardized Excel documents. Therefore, this control method allows the storage of scenario settings for direct comparisons and analyses. Together with the industry partners three practically highly relevant scenario settings were designed: BAU (business as usual), SNOW (high snow coverage in the first quarter of the year and therefore low (-75%) production) and STORM (high (+300%) production in the third quarter of the year due to windthrow). These scenario settings are used for the analyses in the results section.



Figure 12: Input of a STORM scenario by reading a standardized Excel file

3.3 Model description

The model consists of five modules (A) Forest, (B) Truck Transport, (C) Terminal, (D) Train and (E) Industry, which can be observed in six different views (1) Animation, (2) Scenarios, (3) Statistics, (4) Logic Supply Chain, (5) Logic Terminal and (6) Code.

- (1) The Animation view shows graphically the flow of agents (tree: 1 m³ wood, truckload: 20–30 m³ wood = brown rectangle, trainload: 2 truckloads = grey rectangle, trucks: red and grey if loaded: with brown truckload during transhipment: with brown crane, trains: purple number of wagons in white letters) (Figure 13). Wood is produced at the forests and forwarded to the landing of the respective district. Trucks start at the truck garage and carry truckloads from the landings either to the terminal or directly to industry. At the terminal trainloads are placed in the waiting wagons or at the stockyard and a train carries them after transhipment to industry. Moreover, at the top of the screen the number of trucks at the terminal (maximum 9, otherwise queuing), the loaded wagons (maximum 9 otherwise transhipment to stockyard) and the stockyard level (maximum 450 truckloads, otherwise unimodal transport) is displayed.
- (2) Selecting the Scenario link, it is possible to change the initial parameter settings of train arrivals, runtime, transport mode and transport priority, number of wagons and trucks directly during runtime (immediately effective) as well as to overwrite the production plan (production amount for every district) of the upcoming week to observe effects of changing decisions (Figure 14).
- (3) The *Statistics* link provides the management cockpit consisting of automatically updated key performance indicators (Figure 15). The presentation of tables, numbers and

diagrams for production, stockyards, transport and duration changes during runtime and gives an interactive feedback of the actual and past performance of the whole wood supply chain.

- (4) After selecting the Logic Supply Chain link the flow of agents through the system elements of the wood supply chain can be observed (Figure 16). Four modules show a clear arrangement of AnyLogic's process modelling library elements. The small numbers next to the elements for source, moveTo, queuing, batch, unBatch, delay, enter, hold, selectOutput, pickUp, dropOff, sink, restrictedArea represent the number of agents entering, passing through and leaving every single element (Figure 16). In the forest module wood is batched to truckloads and stored until a truck is generated in the truck transport module and picks up the truckload. The truck transports the truckload either directly to the industry module or to the terminal module (see point 5), where a train, which is generated in the train module, picks up the truckloads and transports them to industry.
- (5) The flow of agents through the terminal is visible in the *Logic Terminal* view, which is directly connected to the logic of the supply chain, but too complex to visualize both in one window (Figure 17). In addition to the already mentioned elements a rack system, rackStore and a match element are in use. The seven lines on top represent the queuing at one rail track (maximum 7 trucks simultaneous) whereas the four lines on bottom are for the second rail track (maximum 4 trucks simultaneous).
- (6) The *Code* link provides all implemented functions, variables, data sets, parameter, schedules and events appear in a structured overview (Figure 18). The single elements show actual information (except functions) and can be selected to see more details.



Figure 13: Animation view with truck garage, forests, landings, terminal, industry, trees, wagon loads, train loads, trucks and trains

Animation	n Scenarios Statistics Logic Supply Chain Logic Terminal Code									
Wagons	Trucks	Train arrivals	Runtime (pause simulation)	Transport mode	Transport priority					
0 9 9 9 Number of ordered vagons, which will be delivered when the next train picks up based wagons at the terminal	0 20 Number of trucks, which will be provided do operating hours (increase every minute, de after join is completed during operating to	One pickup at 09:00 Second pickup at 15:00 Second pickup at 15:00	Year North Veek Day Train Pickup The simulation model stops in the defined interval and can be continued manually	Multimodal Unimodal O Both (50/50) ® Real Distribution of fuck vs. tran bransport, which is 190% tare for the multimodel. (30% block to the unemode) will drawship for one he kernmel also for every different (10% eVs. unemode) will areaship for one he kernmel also will drawship for the set will be also will drawship for the kernmel also will drawship for t						
District 1			Plan							
0 888 1,000 Amount of available wood in solid cubic meters in district 1 (compare 2/89) delivered every finday 19.00	D1 D2 D8 D9 1 1000 503 6 0 2 .1 97 .6 15	Trucks Wagons D1 D2 D8 D9 0 14 55 73 65 14 15 15 2 193 106 106	Trucks Wagons D1 D2 1 1 27 500 500 2 1 28 1104 900	D8 D9 Trucks Wagons D' 555 605 25 6 40 1 512 124 25 6 41 1	1 D2 D8 D9 Trucks Wagons 545 346 254 121 23 4 410 345 257 238 28 29					
District 2	3 146 188 288 16 4 362 188 9 14	16 4 16 100 128 65 2 14 3 17 205 193 111 1	29 23 1952	455 1503 25 42 5 604 1532 25 43 5	509 705 160 272 20 0 601 594 258 165 20 0					
0 860 1,000	5 185 20 0 0 6 129 239 0 0		31 703 1943	804 1432 23 44 3 544 1363 26 45 3	394 371 179 178 20 9 360 212 118 216 20 9					
District 8	7 46 0 32 0				585 512 116 253 29 2					
0 556 1.000	9 324 100 25 0									
District 9	10 3.63 1.62 99 0 11 368 45 47 0	0 23 400 150 150 150 0 3 24 331 300 74 10	36 100 100	Dot THE 2 49 738 1372 2 50 1	337 339 109 237 24 392 182 332 379 25 27					
0 608 1,000	12 312 40 50 0 13 53 72 34 0	25 460 464 66 15 0 1 26 233 569 111 14	38 100 200 100	1146 1228 128 51 1146 1424 28 52 52	2019 220 309 303 20 20 40 40 40 50 50 50 50 50 50 50 50 50 50 50 50 50					

Figure 14: Scenario view



Figure 15: Statistic view (management cockpit)



Figure 16: Logic view of the forest, truck transport, train and industry module

A	nima	ation	S	icena	arios	Sta	atistic	s Logi	c Sup	ply Cl	hain	Logi	c Ter	mina	Cod	е					
										Terminal	Module										
wedfallum seesff	select1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	movetoP1 movetoP1 movetoP2 movetoP3 movetoP3 movetoP3	prepare1 prepare2 prepare3 prepare4 prepare4	QueveP1 queveP1 queveP2 queveP3 queveP4 queveP4	titain holdP1 ditain holdP1 holdP2 holdP2 holdP2 holdP2 holdP2	EVerfavora i SV07avora i SV07avora i SV07avora i SV07avora i SV07avora i	isLoadedP1 isLoadedP2 isLoadedP3 isLoadedP3 isLoadedP4	GidapAStodyardF1	J tret/VagorP2 J tret/VagorP2 J tret/VagorP3	Perminal unlag/StockP1 2 0 2 unlag/StockP2 2 0 2 unlag/StockP2 2 0 2 unlag/StockP2 2 0 2 unlag/StockP2 2 0 2 unlag/StockP2 2 0 2 unlag/StockP1 2 0 2 unlag/StockP2 2 0 2 2 0 2 0 2 2 0	Module				o 10 o eueriti notificagan 10 o 10 o	moveToC1	cleanC1 cleanC2 cleanC3 cleanC3 cleanC4	completeC1		ckiComplete1	OutOfficeminal
	select5 select5 select7 select7	moveToPS	prepare5	queuePS queuePS queuePS queueP7	holdP5	i moveToWS	isLoadedP5 isLoadedP6 isLoadedP7	pickupAtStocky ardP5	heelWagonP5	uniaadStockP5 2 0 2 3 unioadStockP6 3 0 3 3 unioadStockP7 2 0 5	s dropottStopP5		s loadWS s	ecureW5 ques	will's hold/lagons	moveToC6	cleanC5	completeCS	queueCS	holdComplete5	oHome 1
raci System	 ♦3 select3 ♦3 select9 ♦3 select10 ♦3 	moveToPS	prepares prepar	0 3 4 4 4 4 4 4 4 4 4 4 4 4 4	holdTrainP2	toldP8	moveToW19				queueStocky	ard moveTruck	adToRack	secure/V/9 secure		moveToC8	3 G 3 cleanC3 cleanC3 cleanC3 cleanC10 2 G 3	completeC8 completeC8 completeC9 completeC9 completeC10 completeC10	0 0 0 0 0 0 0 0 0 0 0 0 0 0	Ou Ou NoidComplet NoidComplete NoidComplete NoidComplete NoidComplete	60/Terminal2 12 12 12 12 12 12 12

Figure 17: Logic view of the terminal module

Ani	imation Sce	narios Statisti	cs Logic Supply C	hain Log	ic Terminal	Code			
	Functions		Scenarios	Stati	stical Counters		Data Sets		
output calculateTruckUtilization calculateServiceLevel	(2) pickUpNumberOfNiegons (2) provideWagons	() removeLoadingsFramRack () arrangeTrainWagons	gritteredWagons gonkolifethod ourtibleOfWilgons gannoterNumberOfWilgons	Counter/Week	SoundRumberOfTrucksBefore9	dataProduction 13 asreptas (200, 500) Maar00 datasetProduction 13 asreptas (201, 40, 200) datasetProduction 13 asreptas (201, 40, 200) datasetProduction2 13 asreptas (201, 40, 200) datasetProduction2 13 asreptas (201, 40, 200)	datasetQueueLanding1 89 samplas(123.540.788.7) datasetQueueLanding2 t18 aampias(123.645.850.0) datasetQueueLanding5 118 aampias(123.645.872.0) datasetQueueLanding5 t18 aampias(123.645.877.0)		
woodProductionStandard woodProductionCase	holdPPlatform1 holdPlatform1 holdWagonPlatform1 holdCompletePlatform1	holdPPlatform2 hold/WagonPlatform2 hold/CompletePlatform2	o numberOfTrucka o parameterfilumberOfTrucka o trainScenario	OtrainsDelivered OtrainsLoaded	numberOfTransportJobsD8 numberOfTransportJobsD9 118 numberOfTransportJobsD9 regitemodalTransportedWood	datasetProduction8 datasetProduction8 datasetProduction8 datasetProduction8 dataSetUpoduction8 dataGueuing dataGueuing dataSueuing dataSueuing	statistics/ServiceLevelD1 (ServiceLevelD2 (ServiceLevelD2 (ServiceLevelD2 (ServiceLevelD3 (Ser	datasetFullLoadedWagonTA 50 samples(120.000.0) datasetHalfLoadedWagonTA 20 samples(120.000.0) datasetEmptyWagonTA 20 samples(120.000.1)	
changeTransportScenario controlTrucks controlJobs	chooseQueueP1 formeroPresePreparationPlaceP1	chooseQueueP2 moveToFreeProperationPlaceP2	garameterTranScenario tyangortPlanScenario garameterTransportPlanScenario garameterTransportPlanScenario transportScenario	o stockyardTerminal arrayProductionSum [4] transportedTLMutt	A.00 MultimodalTransportedWoodD1 1.363 multimodalTransportedWoodD2 1.758 multimodalTransportedWoodD8 320	datasetOuotaD1 U2 samplas _[22,479,1] datasetOuotaD2 datasetOuotaD2 datasetOuotaD3 t2 samplas _[122,470,1] datasetOuotaD6 t2 samplas _[122,470,1]	etatistics Service Level D9 12 samples (1.1), Maanen gataset Queue Terminal Jaangies dataset Utilization 12 samples _ (122,479, 0.264)	statisticsFullLoadedWagonTA statisticsFullLoadedWagonTA statisticsFallLoadedWagonTA so samples (0. 2) Maximil 3 statisticsEmptWagonTA so samples (1. 2) Maximil 4 statisticsCharupt Company	
driveHome driveHome driveHome driveHome waiToEnterTerminal	moveToFreeLoadingPlaceP1 moveToFreeCompletionPlaceP1 placeToLoadP1	moveToFreeLoadingPlaceP2 moveToFreeCompletionPlaceP2 placeToLoadP2	garameterTransportScenario gobControlScenario garameterJobScenario garameterJobScenario pauseScenario	o actualD1 o actualD2 o actualD8	multimodalTransportedWoodD9 multimodalTransportedWood unimodalTransportedWood unimodalTransportedWoodD1 unimodalTransportedWoodD2	Schedules	E27 samples (3,721 to7 _ 32,5077	vents \$ eventOnceADay	
@ uniosdOnWagon	@dxxxxRxxP1 @dxxxxRxAP2 Parameter est Module Truck Transport Module		Costs	o 1argetD1 0 targetD2 0 targetD3	330 unimodalTransportedWoodD8 2.024 unimodalTransportedWoodD9 1.650 gounterDeliveredTransportJobsD1	Din, naci in 1.00 Schedule Wesky Statistics 1750 Din, naci in 2.340 Schedule Wesky Statistics 1905 Din, naci in 2.340 Schedule Wesky Statistics 1905 Din, naci in 5.111	Pause Reset ario		
parameterProductionProb. [12] parameterProductionDistri parameterProductionDistri parameterForestCapacity parameterArrayCaseProd. parameterForwardingCapa parameterForwardingCapa	ability button constraints	meterDrive TimeToLanding meterLoadTuckTime meterTranspurtToTerminal meterTruckTransportToHodustry meterDuckTucksArray	© gyameterCostTeminaD1 © gyameterCostTeminaD2 © gyameterCostTeminaD3 © gyameterCostTeminaD9 © gyameterCostIndustyD1 © gyameterCostIndustyD1 © gyameterCostIndustyD2	targetD9 targetD1LastWeek targetD2LastWeek targetD2LastWeek targetD3LastWeek targetD3LastWeek	counterDeliveredTransportJobsD2 counterDeliveredTransportJobsD3 counterDeliveredTransportJobsD9 counterDeliveredTransportJobsD9 counterPlatform1 counterPlatform2	ArrayProduction ActualTrucksinSystem CounterClueusP1 ActualTrucksinSystem	Variables	voordD8 voordD9 voordD9 tee TransportJobs 1 free TransportJobs2	
All Capacity	Module	Terminal Module meterRemoveBettiTime meterLoadWisponTime meterSecserWisponLoadTime meterSecserWisponLoadTime	C 12/2 C paysgranter Costinutary DB C paysgranter Costinutary DB C paysameter Costivuspon Train Module	deliveryQuotaD1 deliveryQuotaD2 deliveryQuotaD2 deliveryQuotaD3 deliveryQuotaD3 deliveryQuotaD9	truckaviotUBlicedMinutes vorsingTimeInMinutes proceedingTimeInMinutes proceedingTimeInMinutes vorsetlyTruckUBlication	ArtayPrepareP1 artayPrepareP1 artayCargoAreaWagonsP1 (14) artayCongleteP1 artayCongleteP1 ff1 colectionEditExD1	arayCargoAreeP2 (4) arrayCargoAreaWagonsP2 (5) arrayLoadingPlacesP2 (7) arrayCompleteP2 (7) (7) (7) (7) (7)	the TransportJobs2 the TransportJobs8 the TransportJobs8 the TransportJobs9 the TransportJobsTermin the CasebonTest the TransportJobsTermin	
O parameterUnicadingTruck	AttedustryTime	meterCompleteDeliveryNoteTime meterUnloadAfTerminalStockyardTime	parameterTrainTransportTime D parameterNumberOfWagonsArray 152	O working Time LastWeek	O trucksNotUBlizedLastWeek	CollectionEditBoxD2	& collectionWagonsP1	& collectionEditBoxTrucks	

Figure 18: Code view of functions, variables, data sets, parameter, schedules and events

The logic modules of the simulation model consist of 305 elements of the AnyLogic process modeling library, which are enriched by a detailed control logic coded with java to boost the functionality of these basic elements. They are divided in 20 elements for the forest module, 39 for the truck-, 232 for the terminal-, 6 for the train- and 8 for the industry module, which demonstrate the focus areas of the study. In addition to these elements 35 functions, 80 global variables and statistical counters, 9 variable collections, 5 schedules and 6 events control the simulation model based of 39 input parameters to store information in 33 datasets. Table 3 gives an overview of the transition of inputs to outputs based on the main interrelated simulation processes, stochastic effects and other model components.

	INPUTS	PROCESSES	OUTPUTS
FOREST	production volume per day weekly production plan forwarding capacity forwarding time forest stockyard capacity landing stockyard capacity truckload size	generate wood queue wood batch wood forward truckload queue truckloads	distribution of production amount stockyard at forest street landing provided wood for transport per district
TRUCK	number of trucks transport cost to terminal transport cost to industry drive time to landing loading truck time transport time to terminal transport time to industry transport priority transport mode type (unimodal, multimodal, both, real)	generate trucks enter trucks delete trucks queue at truck garage queue at terminal pickup truckloads transport to industry transport to terminal drive to terminal drive to landing drive to home	loaded trucks not delivered transport tasks delivered transport tasks fulfillment level truck utilization delivery quota
TERMINAL	remove belts time load wagon time secure wagon load time clean loading platform time complete delivery note time unload at terminal stockyard time unload at industry time capacity terminal stockyard	drive to platform remove belts pickup truckload from stockyard unload at wagon unload at stockyard secure wagon load clean loading platform complete delivery note queue at the platform drive home drive to landing	stockyard terminal queuing time distribution of queuing times trucks at the terminal
TRAIN	number of train pickups transport cost to industry transport time to industry number of wagons	generate trains pickup wagons transport to industry delete trains	loaded wagons delivered wagons full loaded wagons half loaded wagons empty wagons loaded trains delivered trains
INDUSTRY	unload at industry stockyard time	drop off wagons at industry drop off truckloads at industry delete wood	received wood CO ₂ emissions transport costs lead times

Table 3. Overview of main inputs, processes and outputs of the simulation model
As Figure 19 shows, the agents are generated in the *Forest* module, flow to the *Truck Transport* module, where they either go directly to the *Industry* module (unimodal) or first to the *Terminal* and then to the *Train* module (multimodal), before they end at the *Industry* module.



Figure 19: Multimodal vs. unimodal transport

(A) Forest Module:

The *Forest* module generates the *Wood* agents (= $1m^3$ of wood) in four different sources representing disctrict 1 and 2 of the forest region in Styria and district 8 and 9 in the forest region Lower Austria, which supply the terminal Großreifling. Depending on the selected scenario settings wood is produced either on every working day at 17:00 (scenario: Plan - Standard (distribution), function: woodProductionStandard) or on every Friday at 19:00 (all other scenarios, function: woodProductionCase). This corresponds to the reporting times of the harvesting teams, which declare their daily or weekly volumes. After an agent is generated, its parameter source is set according to its production district (1.2, 8 or 9) and its parameter timeEnteredSystem is set to the actual time. The moveTo elements in the chain are necessary for the animation, only. Since there exists no reliable information on forwarding capacity and forwarding time the forwarding capacity parameter was assumed to be 100.000 and the forwarding time parameter to be zero so that both values do not influence the simulation results but offer the possibility to be changed, when appropriate input datasets are available. Also the capacities for forest (felled wood in the forest) and landing (wood at the forest street) were assumed to be 100.000 for the same reason. The four queuing elements queueForest represent cut wood in the forests, which will be forwarded and batched to a truckload (according to the parameterization settings, for Austria 20-30 m³) and stored at the four *queueLanding*. When a truckload (batch of wood agents) reaches the landings, the free Transport Job variable increases and statistical data (queue size, arriving time) gets updated.

(B) Truck Transport Module:

In the *Truck Transport* module trucks are generated by a source element and stored in a queuing element representing the truck garage. The *controlTrucks* function controls the numbers of trucks in the system, working times and the number of tours per day. The *controlJobs* function sends unloaded trucks to the correct landing (according to the scenario settings) or to do a transhipment job at the terminal and the preloaded trucks from the day before directly to the terminal. The trucks moving to the landing pick up one truckload. After loading is completed statistical variables are updated (number of loaded trucks, origin of the wood, priority) and the truckload appears in form of a brown rectangle on the loading area of the truck. In a next step the selectModality element defines the transport mode (unimodal or multimodal) according to the scenario settings (function changeTransportScenario). To complete a multimodal (unimodal) transport trucks have to pass the next elements before 13:00 (12:00) otherwise they are directly send back to the truck garage as preloaded trucks and finish their tour on the next day. After trucks passed these elements they transport the wood directly to the industry or to the terminal. Since there is a limited unloading space at the terminal, trucks have to queue on a parking space before they enter the terminal.

If they were not able to visit the terminal before 17:00 they are sent back to the truck garage. After a truck completed a tour it enters the *Truck Transport* Module via the *enterTerminal* or *enterIndustry* element and waits for the next round.

(C) Terminal Module:

A maximum number of nine trucks can enter the terminal simultaneously, other ones have to queue at the parking space in front of the terminal. The terminal is divided in two unloading platforms. Platform one can provide up to seven train wagons and has an own stockyard, whereas platform two can maximally provide two wagons. If more than 7 wagons are ordered they are provided at the second platform. After a truck enters the terminal he gets routed by the choosePlatform function to the correct platform. At the platform the truck queues through the processes prepare (where belts are removed and the crane is unlocked), pickup (if the truck drove empty to the terminal and executes a transhipping job from stockyard to wagon), unload (either on a wagon or at the stockyard), secure (where the wagon load is secured with belts), clean (where the loading area is cleaned) and complete (where the delivery note is completed). Only one truck can unload at one wagon at the same time and it is not possible for trucks to pass each other, because of too less space at the terminal. Therefore, queuing problems result at the terminal and scale up with the number of trucks. Numerous hold elements and functions control the movement and queuing of the trucks through the different processes at the platforms of the terminal. When a Truckload agent is unbatched from the Truck, it is virtually stored in the queue of a rackSystem and displayed at a wagon. When a train picks up the full loaded wagons, the half loaded and empty wagons are resorted according to their loading status and time. After a truck leaves the terminal it either returns to the truck garage, queues for the next transhipment job at the terminal or directly drives to the landing to load a Truckload again.

(D) Train Module:

Depending on the scenario a train visits the terminal at 09:00 and additionally at 15:00, if full loaded wagons are available or empty wagons for parking were ordered. The train picks up full loaded wagons, moves half loaded wagons in the front of the chain and leaves empty wagons for loading. A wide range of datasets for full loaded, half loaded and empty wagons as well as variables like statistical counters for trains loaded, transport amount multimodal and arrays for provided wagons, free cargo area on wagons and the order are updated. After the transport of the trainloads is completed the loads are dropped off at the industry and the released *Train* agents are destroyed at the *sinkTrain*.

(E) Industry Module:

In case of unimodal transport, the drop off process releases the agent *Truck* from the agent *Truckload*. This enables the truck to leave the *Industry* module via *exitIndustry* and return to the *Truck Transport* module with default parameter settings. Counters for the delivered transport jobs are updated and the *Truckload* is not visible any more at the loading area of the *Truck*. The *Truckload* is unbatched to agents *Wood* before statistics about the unimodal transport volume and lead time are updated and the agents are destroyed in the sink. In the multimodal case a unbatch element change from agent *Truckload* to *Wood* before the agents are destroyed. Again in the sink element lead times and transport amounts are calculated and stored in data sets. Moreover, also in other elements of the supply chain statistical counters are raised, removed or stored to enable the output in the *Statistic* view via the *Output* function.

3.4 Results

The described simulation model offers a wide range of applications. Therefore, as a first step three practically highly relevant scenario settings (Figure 20) representing weather influences on production and a focus on multimodal vs. unimodal transport strategies were defined in discussions respective workshops with the Austrian industry partners. The first scenario setting is called business as usual (BAU) and represents an average yearly production volume of 43.491 m³ based on historical data (Figure 21). The production usually starts low at the beginning of the year and increases steadily to peak around the third quarter. One frequent occurring weather effect is a high level of snow coverage in the first quarter of the year. Effects of low production amounts due to difficulties in accessing harvesting areas are investigated in the SNOW scenario, which reduces the production of the BAU scenario in the first quarter by 75% and results in an overall production amount of 40.424 m³. Nevertheless, the most influencing weather effect is a windstorm immediately triggering high production. Therefore, the STORM scenario increases the production of the BAU scenario in the third quarter of the year by 300% resulting in a production of 87.342 m³.









Furthermore, three strategy options for combined multimodal and unimodal transport (BOTH = 50% multimodal and 50% unimodal transport), only multimodal transport (MULTI) and only unimodal transport (UNI) were compared on the basis of the same transport plan. Firstly, the number of trucks per week was defined by dividing transport volume per week by 1.5 (i.e. truck drives per day) by 22 (average load volume per drive) and by 5 (working days per week). Secondly, the number of wagons per day was calculated by dividing the number of trucks per week by two as two truckloads equal one wagon load. This value was not relevant for the unimodal strategy, because no train wagons were used at all, whereas the multimodal strategy includes a second train pickup at 15:00. Lastly, to meet capacity restrictions of the supply chain, the initial solutions were adjusted to keep the maximum number of trucks per week equal/under 20 and the maximum number of wagons per day equal/under 9. The parameters for the triangular distribution of the unloading time for trucks at the industry were set to MIN = 35, AVG = 60 and MAX = 180 minutes in case of the BAU and SNOW scenarios and to MIN = 80, AVG = 160 and MAX = 200 minutes for the STORM scenario to take into account longer queuing times based on expert interviews.

To evaluate strategy performance under the different scenario settings the results of these nine simulation outcomes were compared according to the key performance indicators: transported volume (solid cubic meters), stockyard volume (truckloads), average delivery quota (%), costs (€), amount of full loaded wagons, amount of half loaded wagons, amount of empty wagons, fulfilment level (%), CO₂ equivalents (t), truck utilization (%), average lead time (days), average queuing time (minutes) and transport costs per transported m^3 (\in). Therefore, transported volume defines the amount of wood, which was transported from the forest to industry, both unimodal and multimodal. Stockyard volume is a sum of the amount of truckloads at the stockyards of the four districts and at the train terminal. Average delivery quota combines the weekly delivery quotas, which were calculated by dividing the planed transport amount in truckloads in the actual week by the delivered transport amount in truckloads in the actual week. If there was no production in a district in one week the delivery quota was set to 1 (= 100%), because the transport plan was fulfilled. Costs provide the sum of the unimodal and multimodal transport costs based on the input transport costs parameters. The amount of full loaded wagons reflects the number of train wagons which were successfully loaded before a train picks them up, whereas half loaded wagons and empty wagons could not be picked up and therefore produce additional standing costs (which were not prized in this model). The fulfillment level combines the fulfillment level of the four districts, which were calculated by dividing the number of unfinished truck transport jobs by the number of planned transport jobs every week and subtract the result from one. If transport jobs from earlier weeks were not finished, they increase the level of unfinished truck transport jobs for the next week. CO₂ equivalents are the sum emitted CO₂ equivalents, calculated based on average distances from forest to terminal or industry customers, average speeds for truck transport considering road type and emissions key performance indicators for freight transport of the federal environment agency of Austria for trucks (148,8 g/Tkm) and trains (5,8 g/Tkm). To calculate truck utilization, truck waiting time at the truck garage is counted by multiplying the number of unengaged trucks with waiting time. KPI truck utilization is calculated as one minus the quotient of total waiting time and working time. Average lead time defines the average transport time from forest to industry for both, unimodal and multimodal transport. Average queuing time is the average of all waiting times of trucks at the train terminal. A waiting time arises, if the terminal is fully utilized, so that no other truck can enter the terminal or if another truck in the front needs longer process times and blocks a truck in the back. Finally, transport costs per transported m³ were calculated by dividing the overall transport costs by the transported amount of wood.

In a restricted Monte Carlo simulation each parameter setting was executed 10 times to calculate averages of the results of random seed (unique) simulation iteration. So, all together 90 simulation iterations were needed to generate the results on hand. After every simulation iteration, the simulation model writes the results of thirteen key performance indicators in the excel file Output, where every row represents one simulation iteration. Table 4 shows the rounded averages of these simulation iterations.

Production in the BAU scenario was 43.491 solid cubic meters, it was 7,3 % lower for the SNOW and 101% higher for the STORM scenario. The strategy BOTH impresses through a high transported volume, a low stockyard and a high delivery quota. The strategy MULTI performs with a high fulfilment level and the lowest CO₂ equivalents. In the BAU respective SNOW scenario the CO₂ emissions of the MULTI strategy were 19,5% respective 18,6% lower as in the BOTH and 24% respective 25% lower as in the UNI scenario. Also in the storm scenario it saves 15,4% emissions compared with BOTH and 12,2% compared to UNI. Due to a higher transport amount of the strategy MULTI in the STORM scenario the overall CO₂ emissions are higher compared to the UNI strategy. Disadvantages of the MULTI were high costs and long queuing times. The lead time of the strategy MULTI is around twice as high as the lead time of the BOTH strategy and only in one scenario - the STORM scenario - smaller than UNI. Truck utilization was highest and costs (as well as transport costs per transported m³) were lowest in all scenarios for the UNI strategy. Transport costs are implemented as a lump sum and no additional waiting costs were priced in, which results in similar average costs within one strategy between the different scenario settings. Additional costs of waiting times would especially effect the strategy UNI in the STORM scenario and therefore, these low transport costs per transported m³ should be considered with caution. In a real life situation after windstorms the truck carriers would tend to re-negotiate the former lump sum for transport to get compensated for additional waiting times. The number of half loaded and empty wagons was higher for the MULTI strategy compared to the BOTH strategy, especially in the STORM scenario, which indicates an ill-timed transport plan. Aggregating the results of these thirteen KPIs, we found that the strategy BOTH outperforms the other strategies, especially in the STORM scenario the most important KPIs after windstorms as lead time and stockyards are significantly better which helps to maintain wood quality and to reduce bark beetle infestation. Also the queuing time is not even half as long as the queuing time for MULTI and the fulfillment level is high compared to the strategy UNI. According to the bad performance indicated by the KPIs, the standard transport plan, used for all scenario settings was not suitable for the MULTI scenario. In order to find better transport plans a heuristic approach can be used in future studies to generate a better starting solution, which can be iterative adjusted until the defined objective(s) is (are) reached. For the starting solution, the number of trucks per week and wagons per day could be calculated by dividing the transport volume per week by 2 drives per day and 22 average load volume per drive and 5 working days per week. In a second step the values have to be adjusted to meet the capacity restrictions. In a third step the weekly transport plan should include information about the objective attainment, which can be gained through week by week test runs and adopted parameter settings.

Scenario	BAU		SNOW			STORM			
Strategy / KPI	вотн	MULTI	UNI	вотн	MULTI	UNI	вотн	MULTI	UNI
Transported (m ³)	41.581	37.563	39.771	38.360	35.082	37.628	86.651	80.258	75.469
Stockyard (truckloads)	66	225	158	67	195	111	0	183	487
Delivery quota (%)	1,12	1,11	1,04	1,08	1,08	1,07	1,32	1,25	1,2
Costs (€)	665.788	672.663	561.058	613.241	629.238	530.711	1.388.357	1.410.128	1.061.056
Full loaded wagons	437	819	-	398	751	-	913	1534	-
Half loaded wagons	85	92	-	81	90	-	140	310	-
Empty wagons	77	119	-	77	106	-	107	338	-
Fulfillment level (%)	0,96	0,98	0,81	0,98	0,99	0,96	0,9	0,97	0,67
CO ₂ equivalents	719 Mio.	579 Mio.	762 Mio	665 Mio.	541 Mio.	721 Mio.	1.500 Mio.	1.270 Mio.	1.447 Mio.
Truck utilization (%)	0,80	0,80	0,97	0,79	0,79	0,97	0,79	0,78	0,99
Lead time (days)	10,37	23,09	14,57	10,12	21,74	9,14	16,98	30,33	37,3
Queuing time (minutes)	13,21	24,38	-	13,76	24,93	-	20,26	41,83	-
Transport costs per transported (€/m ³)	16,01	17,91	14,11	15,99	17,94	14,10	16,02	17,57	14,06

Table 4: Results according to the most important key performance indicators (KPIs)

Also other key performance indicators were collected and can be compared exemplary for the BAU scenario for all three strategies (see Figure 22, Figure 23 and Figure 24). Especially for iterative adjustments of parameters and transport plans to better meet objectives the time series of wood production, delivery quota, stored wood, truck utilization, number of wagons, lead and queuing time and fulfilment level provide a good starting point. Moreover, many KPIs are split into results for four districts (D1, D2, D8 and D9) to allow comparisons. Multimodal performance indicators like the number of loaded and delivered wagons, loaded and delivered trains as well as the number of loaded trucks can be observed. Additionally, the number of not delivered transport tasks and delivered transport tasks is shown for every district. Lastly, two very important KPIs the lead and queuing time are further complemented by minimal and maximal values as well as a distribution for the queuing time to show their full range.



Figure 22: Result of one out of ten simulation runs for scenario BAU and strategy BOTH



Figure 23: Result of one out of ten simulation runs for scenario BAU and strategy UNI



Figure 24: Result of one out of ten simulation runs for scenario BAU and strategy MULTI

3.5 Further research

Complementing the already mentioned extensions and improvements new scenario settings and refined strategies as well as layout and capacity adoptions and additional statistics provide wide opportunities for future research. Scenario settings can include new production pattern as well as influences of natural disturbances and seasonal irregularities. Also other supply chain risks like wood quality, delivery stops, wagon availability and machine breakdowns should be observed. New strategies can include better fitting transport plans, which should be developed by detailed bottleneck analyses. Moreover, the stock policy, the number of train pickups, varying truck driver shift starting times and time slots for trucks at the terminal can improve the supply chain. A promising approach for a terminal capacity improvement would be a second truck lane at the terminal to avoid queuing. A statistic about the distribution of the waiting times during one day could give additional information to find better strategies. The application of optimization techniques and statistical analyses should be considered in future works. Another source of information for future research are the industry workshops, which help to validate the model and find new interesting questions to be answered.

4. Case Study Sweden

The purpose of the study was to develop and implement a model to analyze the behavior of lead times and road side inventories under the influence of variations in production and transport capacities. Production and transport patterns were based on the data collected in WP2. These are influenced by weather events typical for the sub-arctic region such as periods with rain, snow and low temperatures as well as a combination of those.

4.1 Case description

The case study is based on the wood procurement area of Norra Skogsägarna (same geographical region as in WP2 (Westlund, et al. 2018). The wood procurement area Södra Lappland is divided into four districts, Lycksele, Storuman, Vilhelmina and Dorotea-Åsele. The study focuses at three assortments (pine wood, spruce wood and conifer), which have different recipients. Saw logs and pine logs are delivered to two different mills in Sävar and Kåge and the conifer wood is delivered to a train terminal in Storuman. The study investigates the variation of lead time, affected by production and transport capacity as well as periods with changed weather conditions. The analysis uses the WP2 data for historical procurement.



Figure 25. Left, area of Norra Skogsägarna association. Right, wood supply area, a part of Norra skogsägarna's proccurement area, and three recipients

4.2 Input data and assumptions

The wood procurement in the case study consists of about 100 000 m^3 , composed of approx. 34% spruce wood, 35% pine wood and 30% of conifer wood. The volumes are produced from 963 single contracts with forest owners spread in Södra Lappland. An average annual production for a final felling harvester is 30 000 m^3 and for a tinning harvester 20 000 m^3 , operating over the whole area of Södra Lappland. The truck fleet consists of about 10 standard logging trucks with payload of 40 tons and gross weight volume of 60 tons. The transport distances for the saw logs is on average 21 km and for conifer, landing at the train terminal, about 210 km. At the train terminal Storuman, the train set can load about 2000 m^3 , the length of the train set (number of wagons) is determined by the maximum rail length at the recipient.

The data set used in the simulation model is based on the data set from WP2. The volumes in the system consist of received volumes of three recipients during the years 2015 and 2016. The data sets used include mean values for two years on variations in volumes and lead times over time, emerging from the weather events. The analysis is based on weekly periods in order to see rapid changes in procurement flows.

The simulation model enables evaluation and comparison of observed lead times (from start day of harvesting to the delivery day at industry/train terminal) (WP2) with simulated lead times (WP3) to aggregate conclusions.

4.3 Model description

A simulation model, built in ExtendSim, was used to simulate wood flows and lead time. The descriptions of wood flows, given the harvesting capacity, production, transports and train capacity were set up. The simulation was run over a year using data described above, based on triangular distribution.

The road side inventory in the beginning of the period was estimated from interviews and data from 2015 and 2016. Starting with empty inventories would skew the simulation. Inventories must be built up before the inventories in the simulation stabilize. The terminal inventory is set to 1800 m³. The terminal has a safety inventory of one fully loaded train. The simulation year starts in August and ends in July, elimination border effects, having historically the lowest road side inventories after summer holidays.

Schematically, the model consists of the harvesting production (yellow box), the road side inventory (green box) and a truck transport to two mills, and train (blue boxes). The work scheme is set as a shift schedule, working from four o'clock to midnight. The production generates wood volumes landing at road side, making an inventory. Trucks pick up wood (saw logs, conifer) from landings and transport to mills or a train terminal. Trucks deliver pine logs to Kåge and spruce logs to Sävar. Conifer wood is transported from forest to Storuman terminal (for further deliveries to SCA mills).

4.4 Results



Figure 26. Swedish simulation model for lead times

The road side inventory level rises from low production volumes in August to more inventory at road side before Christmas holidays (around day 145), building up stocks before holidays for the truck fleet to keep deliveries. A dip in procurement can also be distinguished from day 99 till day 120 (October to November). This is typical because of heavy rainfalls, high temperatures (above 0 degrees) and low bearing capacity at roads and harvesting sites, making sites difficult to reach. At the end of February the production decreases, which can be seen from day 190. Grainy snow from higher temperatures at sites contributes to decreased makes harvesting and production. The road side inventory decreases from peak values during winter, having lower temperatures and frozen ground, to lower later volumes due to reduced bearing capacity.

The next figure, presents results from the total lead time in the system, and shows that the real times lie in average between 11 to 43 days over the annual cycle. The lead time starts at a low level in the beginning of the production year, i.e. when the production re-starts in summer with low inventories at road side and mill sites. The lead time then grows over the year as an effect of variations in production and transport reported in WP2. If sites are closed, other sites must be opened resulting in longer lead times. During the spring thaw period, the increase in lead times can be seen at about day 243 (April). The peak values for lead time occur at the end of summer before and during holidays. A reason for this can be two-fold; the loads which were left at landings during the year and which must be collected to empty the road side inventories as well as the summer holiday production stop (July).



Figure 27. The annual development in total lead time (days on y-axis) according to day number (x-axis starting from August) for saw logs and conifer pulpwood.

The next figures show lead times for truck transport to Kåge (pine) and Sävar (spruce) sawmills together with lead times for conifer pulpwood via the Storuman train terminal to the respective pulpmill. The lead times to the saw mills are similar, about 20-30 days, and for the conifer pulpwood (including train transport) about 50 days. For the pulpwood the truck transport lead time constitutes about half of the total lead time. The truck transport lead time varies in the end of the production year (i.e. beginning of summer). The train lead time remains stable according to the earlier discussed longer transport distances to collect half-empty road side inventories over a larger geography. The lead time for train transport rises in the middle of the fall (around day 146). This is a result of the planned increase in pulpwood stocks to secure sufficient wood to fulfill industry demand during the summer holidays.



Figure 28. The annual development of lead time (days on y-axis) according to day number (xaxis starting from August) for truck transport to Kåge saw mill (pine)



Figure 29. The annual development in total lead time (days on y-axis) according to day number (x-axis starting from August) for truck transport of sawlogs to Sävar sawmill (spruce)



Figure 30. The annual development in lead time (days on y-axis) according to day number (xaxis starting from August) for conifer pulpwood. Truck transport to Storuman train terminat at left. Total lead time from forest to pulpmill, via terminal at right.

4.5 Further research

In the Swedish case study, procurement lead times are influenced by weather events. Lead times drive roundwood deterioration and quality degradation, dependent on seasonal conditions. For pine saw logs, blue stain occurs during warmer weather climate together after long storage times after felling. For saw logs, freshness is also of importance for smooth sawing processes. For conifer pulpwood, freshness is crucial for the pulp process.

Seasonal variation has a greater influence on production pace than transport. This has consequences for lead times through downstream processes; roadside inventories, transport operations, truck transport distances and terminal inventories. The simulation experiment shows that the planning of production according to seasonality will have the most effect on production results, i.e. the wood procurement. Since the capacity utilization for the truck fleet together with the multimodal system (train) following the available wood volumes, the bottle neck for the further development of the supply chain is the operative planning of production entities.

While the variation in lead times shown by the simulation study are in parity with the results from WP2, the levels are slightly shorter. This indicates that simulation methods are a suitable base for modeling wood deterioration in varying future scenarios, given a concurrent modeling of the weather conditions driving deterioration.

5. Case Study Norway

The goal of this study was to test a range of multimodal solutions for securing efficient and resilient delivery through the seasonal variations typical for the Atlantic coast region. The range of multimodal solutions include: vessel cargo volume, the number of terminals visited to accumulate cargo volume, and the maximum capacity per terminal.

5.1 Case description

The case study concerns the same geography and terminals as for WP2 (Westlund, et al. 2018). Seasonal variations in harvesting production, trucks transport, road-side stocks and terminal departures per district for 2014–2016 are visualized in a map-based supply chain demonstrator. The demonstrator allows the user to move through three years of weekly flows using a scroll bar function in the map interface.



Figure 31: The case area shown in the map interface of the Norwegian supply chain demo. The interface visualizes the 3 years series of weekly production, truck transport, road-side stocks and multimodal departures per supply district

The whole case study covers wood flows for 6 assortment groups from 65 supply districts to 10 receiving mills via 10 multimodal (shipping) terminals. The supply districts are grouped into three regions along the coast: north, mid and south, where 1 terminal is in the northern region, 1 in the mid-region and the remainder in the southern region. The analysis presented here is limited to pulpwood deliveries to 2 main mills. These are located in the northern supply region with supply from all three regions.

5.2. Input data and assumptions

The model input for pulpwood flows consists of 2016 supply and demand volumes. The truck transport is done with standard 60 t logging trucks, however actual payloads are determined by the maximum GVW allowed by the truck route used. The shipping transport is done with minibulk vessels of 2000-5000 m³ capacity. Vessels must collect a full and complete cargo (FCC) for the flow to qualify as feasible.

Two series of data analysis were run. The first series concerns a complete annual cycle with 12 consecutive balance periods (4-5 weeks per period). The second series concerns two specific balance periods; one period for mid-winter conditions and one period for mid-autumn conditions. The multimodal solutions per series were varied as shown below. Terminal capacity was based on the maximum volume handled per 4 week period during the entire data series (2014–2016).

	Vessel capacity (FCC)	Max. no. PoLs to accumulate FCC	Maximum PoL capacity (m3/balance period)
Complete annual cycle (12 balance periods)	2500 m ³ only 2500 and 4500 m ³ 4500 m ³ only	2	100 %
Winter and autumn (2 balance periods)	2500 and 4500 m ³	1, 2, 3	75/100/125 %

Table 5: The multimodal alternatives tested in the two analysis series (complete annual cycle vs. sample periods from winter and fall)

For truck transport costs a single average tariff was used per supply district. This was calculated according to the annual distribution of loads delivered with the respective GVW classes from the transport statistics and their corresponding tariffs. For vessel transport a time-charter based freight-rate calculator was used to calculate the costs per vessel capacity for each origin and destination pair according to the maximum no. of number of PoLs visited to accumulate the complete cargo.

5.3. Model description

An optimization model was used to simulate flows and costs for the varying multimodal solutions tested. The model consists of an extension of the basic cost minimization transport problem to the multimodal system. It is built in MS Excel and uses an open-source experimental solver for linear (integer) programming with an unlimited number of decision variables.

The use interface allows the user to scroll through the year and choose balance periods from 1-5 weeks for the selected assortment group. The model feeds in the relevant supply and demand assumption for the chosen time interval. The optimal flows are presented in a map-format with the destination (mill or terminal) indicated by colour per supply area. The visualization simplifies verification of typical flows and helps identify changes in these.

Beyond the typical supply, demand and terminal transhipment restrictions, the model added restrictions to test intervals of truck transport output (m³km/period) and ensure delivery of full vessel cargoes for the selected limits for ports-of-lading. Solution times for the given problem size are under 60 seconds.



Figure 32: The map and KPI-panels for the Norwegian transport optimization interface (supply chain demo-II). On the upper panel the user scrolls to the desired weekly interval for analysis. The same panel used to select assortment and multimodal alternatives to be tested. The resulting distribution of supply areas to the respective terminals are displayed on the map interface and KPIs such as costs, transport distances and volumes are shown on the lower panel

5.4. Results

Both analysis series are based on 2016 volumes of spruce pulpwood. Compared to the historical transport statistics for the data, the optimizations of the complete annual cycle followed the same general seasonal patterns for use of multimodal transportation, but were 10 % lower. The optimal use of multimodal solutions varied more between balance periods than the actual operations when restrictions for transport output interval were not used.



Figure 33: A comparison of the weekly proportion of multimodal transport for the annual cycle between the actual transport plans (weekly interval at left) and optimized transport per balance period (4–5 week balance interval at right)

The average transport distance for vessels also varied with seasons. During the winter high season, pulpwood was sourced primarily in the core supply areas in the north, average vessel transport distances ranged from 120–200 km. During the summer and autumn when sourcing increases from the southern periphery, vessel transport distances increased to 200–270 km.

The geographical variation in harvesting production between the core and periphery of the supply areas was considerable. Since these variations determine the weekly supply per district in the subsequent transport problem, the variation in optimal solutions was limited accordingly. A set of typical solutions for truck and vessel transport distances for varying delivery volumes are shown in the figure below (left). For the winter season, with a weekly delivery pace above 7000 m³/week, typical solutions were based on truck distances over 60 km and vessel distances under 175 km. During the summer and autumn, with a weekly delivery pace under 7000 m³/week, typical solutions were based on truck distances under 55 km and vessel distances over 225 km.



Figure 34: Left: typical combinations of truck and vessel transport distances for varying weekly delivery volumes (m³/week on z-axis). Right: all feasible solutions with corresponding variation in average costs per m³km (NOK/m³km on z-axis)

The range of sum average costs per delivered m³ was surprisingly stable (89-91 NOK/m³) for the optimal solutions, given the geographical dispersal of sourcing and varying use of vessel capacity. Given the limited variation in transport cost per delivered m³ the solutions provide a good demonstration of the structural flexibility provided by the multimodal system. The

corresponding cost per m³km was high for the winter season and low for the summer/autumn as shown in the figure above (right).

The first analysis tested varying vessel cargo alternatives (1:2500 m³ only, 2:2500 and 4500 m³, 3:4500 m³ only) during each balance period of the annual cycle. Average truck transport costs increased with 1-3 NOK/m³ with the increase in vessel capacity from 2500 to 4500 m³, with the greatest increase in system costs during the periods with highest multimodal use. The average vessel cost decreased with 4–7 NOK/m³ for the same increase in vessel capacity. The vessel cost reduction from system 1 (2500 m³ only) to system 2 (2500 or 4500 m³) was 3–7 NOK/m³. The remaining vessel cost reduction between system 2 (2500 or 4500 m³) and system 3 (4500 m³ only), however, was less than 1 NOK/m³.

In principle, mixed fleet capacity (2500/4500 m³) provides reduced sensitivity to varying terminal capacities and load collection practices. Therefore, the second analysis tested the effect of cargo collection practices during two selected balance periods; one during the high season (period ending week 13) and one during the low season (period ending week 39). Using varying terminal transhipment capacities (75/100/125 % of max. 4-week trans-shipment volume) 1, 2 and 3 cargo collection terminals were tested for the mixed fleet of 2500/4500 m³ vessels. Although collecting cargoes between 2 terminals consistently provided the lowest system costs, these differences were marginal when seen at the system level (< 1 NOK/m³). Having single cargo collection point was the most expensive alternative during the high season while three cargo collection points was the most expensive alternative during the low season. At the system level, the costs for limited transhipment capacity were most relevant during the high season.

The effect of cargo accumulation and collection practices became more apparent when examining the costs for the multimodal system, alone. The figure below illustrates the trade-off between decreased truck transport costs and increased vessel transport costs as the number of collection points increase.



Figure 35: Variation in modeled multimodal transport costs (to terminal and from terminal) with increasing number of cargo collection points for 2500/4500 m³ vessel capacities (2016: weeks 8–13 and 34-39)

5.5 Discussion and continued research

The aim of the Norwegian work was to experiment with multimodal strategies towards the goal of efficient and resilient solutions for wood supply in the oceanic climate zone. WP1 mapped the current management processes for both market, transport and production management as well

as common supply and demand risks (Fjeld et al. 2017). WP2 mapped the seasonality in wood supply and the weather factors driving seasonality, as well as supply system capacities.

In the Norwegian case, the main challenge to maintaining even wood supply is the climatedriven seasonality in both production and transport. Seasonal variation is higher for production than transport, resulting in a corresponding variation in transport lead times as documented in WP2 (Westlund et al. 2018). The first part of WP3 provided a visualization tool to provide insight into the geographical distribution of seasonality. The second part of WP3 experimented with optimal multimodal solutions to provide cost-efficient and resilient solutions to this seasonality. The experimentation showed that the existing multimodal terminal network combined with a mixed fleet of vessel cargo capacity and flexible cargo collection practices provides the basis for economically efficient solutions ensuring access to a wide geography of supply districts over 3 regions, with marginal variation in transport system costs.

A major limitation to the resilience of the multimodal system, however, lays in the seasonal variation in transport capacity requirements for truck transport (m3km/week). These in turn are a direct result of the current wood supply strategy and seasonal distribution of sourcing from the 3 respective supply regions. The figure below (left) compares the sum weekly delivery volume over the 3 year time series from the three regions (17:north, 16:mid, 15:south). This figure shows that the main component of seasonality for the supply organization is driven by the northern supply region (17:north). The right-hand side of the figure shows that the corresponding sum volumes from the main 3 soil types, where region 17 is dominated by marine deposits (silt and clay).



Figure 36: Left: comparison of sum weekly delivery volumes between the respective supply regions. Right: comparison of sum delivery volume from sites with the 3 main soil types between the same supply regions (2014-2016, 17: north, 16: mid, 15: south)

An overview of the weekly volumes from region 17 (below) shows a relatively even distribution between moraine, marine and peat sites throughout the year. Typically, only moraine sites provide sufficient bearing capacity for harvesting year-round. Marine deposits normally only provide sufficient bearing capacity during periods of frost/snow or very dry conditions and peat sites are normally only available during periods of frost or deep snow.



Figure 37: Distribution of sum weekly supply volumes from main soil types for region 17 (2014-2016)

The distribution indicates a potential to even out both delivery volumes and capacity utilization by a more selective use of site types during the weather conditions typical for the respective seasons. This means reserving marine deposits sites for cold and dry conditions and reserving moraine sites during difficult weather conditions.

After a mid-term seminar with the supply chain partners of the host supply organization it became clear that seasonality, capacity limitations and the resulting variation in lead times were challenges for coastal wood supply. A subsequent production planning workshop with 8 production managers indicated that the bottleneck for improved production planning was short purchase and production planning horizons. A simple optimization experiment was therefore set up to quantify the potential feasibility of more specific site type selection for expected seasonal weather conditions in region 17. The model base consisted of a decision matrix for re-scheduling the weekly volumes (53 weeks) per distance zone (10 zones) within each site type (moraine, marine, peat). The goal function minimizes the sum costs for truck transport, terrain damage and deviation from prescribed weekly total flow levels (all assortments). Weekly transport costs varied as a function of average truck payloads per week as limited by bearing capacity of public roads (2014–2016, figure below left). Weekly terrain damage costs varied with prevailing weekly weather (2014–2016), calculated by an experimental rut-prediction model (Fjeld et al. 2018a, Fjeld et al. 2018b). The model links daily estimates of relative depth to groundwater to bearing capacity for moraine and marine sites (figure below, right).



Figure 38: Weekly values for 3-year average truck payload size (left) and expected terrain damage per site type (right). Supply region 17 (2014–2016)

The weekly average truck payload was used to provide a proportional adjustment of truck transport costs (NOK/m³). The weekly rutting frequency was used to estimate the terrain repair costs after harvesting (NOK/m³). A delivery penalty was also applied for deviations from the prescribed seasonal or annual flow level (NOK/m³). Some simple restrictions were applied to the goal function. These included: a) delivery of all volumes per distance zones and site types within the 53 weeks as well as upper and lower bounds for b) sum volume (m³) and c) transport output (m³km) per week during the prescribed periods.

Three cases were compared. The base case for comparison consisted of the historical sum weekly deliveries during the three year period within the respective distance zone and site type (current seasonal trend in figure below). The base case was then compared to two alternative delivery profiles: first a prescribed interval of weekly delivery volumes and transport output for weeks 1–30 and 31–53 (even over half-year) and second a prescribed interval of weekly delivery volumes and transport output for all weeks year-round (even year-round).



1) current seasonal trend 2) even over half-year 3) even year-round

Figure 39: The potential use of weather-based site type scheduling (m3/soil type/week in middle row where 1: moraine, 4: marine deposits, 9: peat) to drive reduced seasonal variation. Sum weekly flows (m3/week) are shown in the upper row. Transport capacity utilization (m3km/week)

are shown in the lower row (Region 17: 2014-2016)

The model formulation was designed primarily to drive a plausible re-scheduling of the flows from site types based on expected seasonal weather conditions. Although the experiment was limited to 3 of 9 site soil types (80–90 % of total volumes), the formulation provided a logical response displayed in the middle row of the figure above. For the prescribed "even flows over half year" (middle column) moraine sites were reserved for the typical moist period of the spring thaw and late autumn, while marine deposits were scheduled during cold mid-winter and dry mid-summer. For the prescribed "even flows year-round" (right column) the same scheduling

trends were present. The calculated transport costs increased marginally from the base case to the two even-flow scenarios. Terrain damage repair costs, however, decreased from the base case (8.3 NOK/m³) to the "even over half-year" flows (5,9 NOK/m³) but increased again to the "even year-round" flows (6,9 NOK/m³).

As indicated by the rather schematic distributions of site types, the experiment includes several obvious simplifications. The first is a lack of actual supply and demand nodes with specific O-D distances as used in typical transport problems. The second is the lack of consideration given to typical lead times between production to roadside and subsequent truck transport. The third is the lack of relocation costs which would be enabled by a more advanced routing solution. In practice, the most sensitive sites (marine deposits) are easily located and generally found under altitudes of 175 meters. This final study provides therefore a simple demonstration of the potential use of on-line weather data for improving the agility of supply organizations towards increased resilience in wood supply.

6. Conclusions and continued research

The three case studies show that supply chains are constantly changing. Disturbances and supply chain risks are not the exception, but part and parcel. In this context resilience signifies the amount of stresses, which a system can absorb without becoming radical transformed and unstable. In research, if you find different shades of resilience, diversity is often mentioned. As an example, a forest with a diversity of plants, is more resistant and more adaptable to negative environmental influences. As a result of that, a forest still remains a forest after a fire, if the ecosystem is resilient, otherwise it would turn into a meadow. Similarities for supply chains could be found according to the combination of diverse transport modes enhancing the resilience of a system. The application of multimodal as well as unimodal transport strategies - each with its own advantages and disadvantages - covers the potential for a greener and more resilient wood supply.

Austria - The Austrian discrete event simulation model shows the advantage of a combination of unimodal and multimodal transport in the continental setting. The related strategy (BOTH) is resilient and outperforms the others in different scenario settings, especially in ecological terms because of reduced CO₂ emissions for train transport. The strategy BOTH avoids bottlenecks and ill-timed plans and fits perfectly in the observed case. Therefore, it indicates that similar supply chain designs including a train terminal can also perform well in other regions. The Austrian simulation model allows improved business as usual by finding best fits, testing new strategies to adapt to changed conditions, estimating impacts of decisions before costly system investments and managing risks by preparing contingency plans. Especially the intuitive usability of the simulation model through the animation view as well as the management cockpit and the ability to read input parameter from different excel files and get outputs in another excel document, impressed industry representatives in both already held workshops.

Sweden - The aim of the Swedish case study was to see quantify the impacts of seasonal and weather driven events in the sub-arctic zone on procurement lead times. The results have shown that the present bottleneck for supply chain development is production, since the transport operations follow the planned delivery quotas and collect roundwood where currently available. This shows that the operational planning considered both expected and, to some extent, unexpected events (e.g. heavy rain, high temperatures in winter time) to improve the effectiveness of wood procurement. Effectiveness in this context includes lowering production and transport costs as well as emissions from truck transport through and better operative planning, primarily production. Production can therefore be improved by applying better modeling of weather events, both current and future. Better operative planning is an area for further analysis and methodology development.

Norway - The aim of the Norwegian work in MultiStrat was to experiment with multimodal strategies towards the goal of efficient and resilient solutions for wood supply in the oceanic climate zone. The strategies started with the current management processes for market, transport and production management as well as response possibilities to common supply and demand risks. They build on the context of seasonality in wood supply and the weather factors driving this seasonality. In the Norwegian case, the results from WP2 show that the main challenge to maintaining even wood supply is the climate-driven seasonality in both production and transport. Seasonal variation is higher for production than transport, resulting in the documented variation in transport lead times. The first part of WP3 provided a visualization tool to provide insight into the geographical distribution of seasonality. The second part of WP3 experimented with optimal multimodal solutions to provide cost-efficient and resilient solutions to

this seasonality. The experimentation showed that the existing multimodal terminal network combined with a mixed fleet of vessel cargo capacity and flexible cargo collection practices provides the basis for economically efficient solutions ensuring access to a wide geography of supply districts over 3 regions, with marginal variation in transport system costs. A major limitation to the resilience of the multimodal system, however, lays in the seasonal variation in transport capacity requirements for truck transport (m3km/week). This is linked to the overall wood supply strategy and seasonal distribution of sourcing from different supply regions, where the greatest component of seasonality for the supply organization was driven by a single region. After a mid-term seminar with the supply chain partners of the host supply organization it was clear that seasonality, capacity limitations and the resulting variation in lead times are common challenges in coastal wood supply. A subsequent production planning workshop with production managers indicated that the bottleneck for improved production planning was short wood purchase and planning horizons. A simple optimization experiment was therefore set up to quantify the potential feasibility of more specific site type selection for expected seasonal weather conditions in the northern region. The model formulation in the final experiment was designed primarily to drive a plausible re-scheduling of site types. The model provided a logical response where moraine sites were reserved for the typical moist period of the spring thaw and late autumn, while marine deposits were scheduled during cold mid-winter and dry mid-summer. While providing a rather schematic solution, this final experiment provided a simple demonstration of the potential use of on-line weather data for improving the resilience of wood supply. This development enables maximal exploitation of the structural flexibility inherent to multimodal solutions.

Continued research - The upcoming project GreenLane (full proposal submitted to the forest value call 2017) builds on Era-Net MultiStrat (Multimodal Strategies 2016-2018) which quantified regional seasonality for harvesting production and transport, with the corresponding variation in lead times which drive roundwood value development. Forest industries depend on a stable year-round supply of even log quality. GreenLane focuses on assortment-specific value-tracking in order to develop managerial responses giving improved mill customer value in the face of challenging climate scenarios. The overall goal of the project is to develop a virtual supply chain laboratory environment enabling value-tracking and interactive testing of harvesting and transport responses to challenging climate scenarios. The focus is on implementing weatherdriven models for wood quality and availability. The study compares the same three European case study areas in continental, sub-arctic and oceanic conditions. The development of multimodal strategies (combined use of road, rail and sea) provides the foundation for more efficient and resilient supply chains, which because of climate impacts on forest operations are of growing importance. Even for natural disturbances such as windthrow with subsequent risk for bark beetle outbreaks, multimodal solutions provide the structural flexibility for efficient supply chain responses to such events. These solutions demand tighter management of lead time thresholds during critical seasons. GreenLane continues the work of MultiStrat to further develop the competitiveness of European wood supply.

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