Proceedings of the 2017 Winter Simulation Conference
W. K. V. Chan, A. D'Ambrogio, G. Zacharewicz, N. Mustafee, G. Wainer, and E. Page, eds.

PERSPECTIVES OF A FUTURE-PROOF PRIMARY RESOURCE LOGISTICS CHAIN

Oliver Meier
Sebastian Trojahn

Department of Logistics Systems
Otto-von-Guericke University Magdeburg
Universitaetsplatz 2
Magdeburg, D-39106, GERMANY

Henning Strubelt

Department of Logistics
Otto-von-Guericke University Magdeburg
Universitaetsplatz 2
Magdeburg, D-39106, GERMANY

ABSTRACT

Energy policies and energy prices have increasingly been influencing the demand for wood. For long-lasting profitability and sustainable growth of companies involved in the wood market, logistics for raw material supply is of crucial importance. This article addresses possible measures for supply chains in the wood-processing industry based on a five-year forecast horizon derived from a simulation study. It describes the design and implementation of a simulation model to derive strategic action recommendations for raw material supply logistics for the raw material wood. Decisions concerning the size of storage locations, the number of operators in the system and the system costs can be supported by this analysis.

1 MOTIVATION

Scientists regard the raw material wood as more than just construction material, heating material or the basis for paper. They consider wood an alternative to fossil energy sources, such as crude oil or coal. Like mineral oil, wood can be divided into its elements and its basic or intermediate elements can be processed in the chemical industry. The percentage of renewable raw materials being processed in the chemical industry currently amounts to about 13 percent. It is, however, expected that this share will increase to about 20 percent in 2030 (Pufky-Heinrich, Leschinsky, and Unkelbach 2012).

This could lead to large potentials and challenges for the whole wood industry and its supply chain. By representing all influence parameters, such as weather, availability of harvest and logistics operators, accessibility of roads, harvesting seasons, etc., in a single simulation model, it is possible to map and compare multiple scenarios for the wood supply chain. Different (long-term) strategies for the supply of the study area, in this case the Harz region in Germany, can be included and compared in the model. The planning capabilities of the natural material provision supported by a flexible supply chain can already now be adapted to future demands. In addition, it is possible to develop recommendations and measures on how to react to certain events already in advance. Possible improvements of the study region's infrastructure conditions based on the model's output and developmental actions taken accordingly can increase the attractiveness of the region for the industry and attract additional new businesses.

This article addresses the challenges of planning a wood supply chain with the help of a simulation model. The complexity of the whole supply chain with its restriction that wood can only be harvested for a period of at most six months (reduced by weather-related shortfalls), but is required continuously over the year for production, is considered for the first time.

978-1-5386-3428-8/17/$31.00 ©2017 IEEE

2 SIMULATION PREARANGEMENT

2.1 Selecting a simulation approach

“Classic” modelling and simulation approaches all suffer from significant disadvantages when modelling and simulating larger logistics systems. The most-often used model in logistics, the discrete-event model, demands a heightened effort in modelling and requires high computing times during simulation. Other simulation studies in the wood processing industry provide operational decision support, cf. exemplary Asikainen (2010), Mobini, Sowlati, and Sokhansanj (2011), and Windisch et al. (2015). These studies, however, do not include the whole value chain, but are characterized by a high level of detailed model input data. This high level of detailed data is not available in the present case, therefore a discrete-event approach is not feasible. In addition, these detailed data are not required for the task at hand, giving strategic action recommendations. The selection of the applied software tool, ExtendSim, can be gathered from Table 1 with regard to the projects objectives and available data. Contrasted with this, the mesoscopic simulation is based “on the basic principles of material flow calculation” (Schenk, Tolujew, and Reggelin 2008). This shortens computing time of the simulation as it is independent of the modelled product amount. System dynamics models are unsuitable for the logistics tasks, as they show them on a level that is too aggregated. Only discrete-rate simulation allows for a sufficiently fast simulation as well as for a sufficiently detailed modelling of linear continuous processes. However, it describes the flow between knots of a network with only one variable. Therefore, it is unsuitable for most logistics tasks. Mesoscopic models, in contrast, use “input data that are close to real process data” (Schenk, Tolujew, and Reggelin 2008). Another advantage of mesoscopic models when modelling logistics systems is the simple and universal form of presentation that can be applied to most real logistics processes. In addition, only two main components (multi-channel funnels and transport elements) are needed to map the system structure onto the conceptual model (Tolujew and Reggelin 2008).

It can be concluded that mesoscopic simulation is suitable for processing logistics tasks. Therefore, our simulation study is conducted using this simulation method. Table 1 compares the most important characteristics of the mesoscopic approach to simulation with the discrete-event, discrete-rate, and continuous system dynamics models.

Table 1: Mesoscopic approach to modeling and simulation (Schenk, Tolujew, and Reggelin 2008).

	Discrete-event	**Mesoscopic**	**Discrete-rate**	**System Dynamics**
Application	Logistics processes at the object level	Logistics processes on an aggregated mesoscopic level	Linear, continuous processes	Aggregated logistics processes (One product model)
Software tools (Selection)	Plant Simulation, AutoMod	MesoSim	ExtendSim	Vensim, Powersim
Exactness	High	Medium	Low to medium	Low
Effort	High	Medium	Low to medium	Low
Status changes by	Events regarding location and status changes of the objects	Events regarding changes to flow rates and the occurrence of impulses	Events regarding changes to flow rates	Proceeding simulation time
Time steps	Variable	Variable	Variable	Constant

2.2 Analysis of the Simulation Environment

The system of wood processing to be examined is first separated into partial systems. Partial systems are interconnected with each other from a logistics point of view, but possess clearly differentiable structures and system borders. These processes determine the degree of detail of the system to be mapped and so form the basis of the later concept model for the simulation study.

2.2.1 Timber Harvest

The source for wood processing are defined forest areas in the examined Harz region. The timber harvest in the designated area is the first process step. This process is separated into the partial process of logging and timber extraction.

Logging is either conducted fully or partially mechanized. Partially mechanized logging consists of an interplay of motor-manual work with supporting use of machines. At this point it is sufficient to know that depending on the environment, there are different partially mechanized logging techniques. These differ in performance and cost. Circumstances permitting – such as a sufficient condition of the forest floor – a highly mechanized logging system for fully mechanized logging may be used. The machines most often used are harvesters and forwarders. There are also several different methods and machines that may be utilized here.

Timber extraction in forest extraction is the transport of wood from the logging place to the lumber stack at the forest road. As with logging there are both partially and fully mechanized methods to timber extraction. In partial mechanized methods, a variety of forestry tractors take over the extraction of woods. Most common are cable skidders and crane skidders. In the fully mechanized method, forwarders are used for timber extraction.

2.2.2 Wood Transport

The process of wood transport involves the fetching of logs in the forest (from the lumber stack) and their transport to the warehouse. Trucks are mainly used for transport. Here again different vehicles of varying performance and cost can be used depending on purpose and load capacity. Most often long-log and short-log trucks with their own loading crane are used. Aside from using different transport methods, different transport scenarios can also be implemented. Among those are the direct transport from the lumber stack to the processing plant (saw mill) and the broken transport using “truck points” or interim warehouses. When truck points are used, the logs are initially loaded onto off-road trucks and then moved to trailers at pre-defined spots. Only performance and cost of each variant are decisive for the later simulation study.

2.2.3 Storage

After logging the timber is initially stored in lumber stacks alongside navigable forest roads. Neither special storage technology nor special personnel are needed at this point. Stacking is an interim storage for direct transport and further storage in a central or decentralized warehouse, respectively. Layover times of the logs depends on the performance of the means of transport and the strategy. During the simulation study, it is necessary to always be able to adapt this arbitrarily. Storing logs in stacks for too long can lead to quality reductions through insect or fungal infestation. Using centralized or decentralized storage means transporting the logs to their pre-determined storage areas.

2.2.4 Wood Processing

The logs are processes in a central mill in the Harz region. The logs delivered are stored at the mill at a central storage area. Then they are processed into sawn lumber and other products using a variety of methods. Within the framework of this article, the intralogistics of the final processing are not considered. The sink is the storage area of the mill. Potential processing bottlenecks can be controlled by the intensity of the input flow. For the sake of completeness, the processes are taken over into the following process chain (cf. Figure 1).

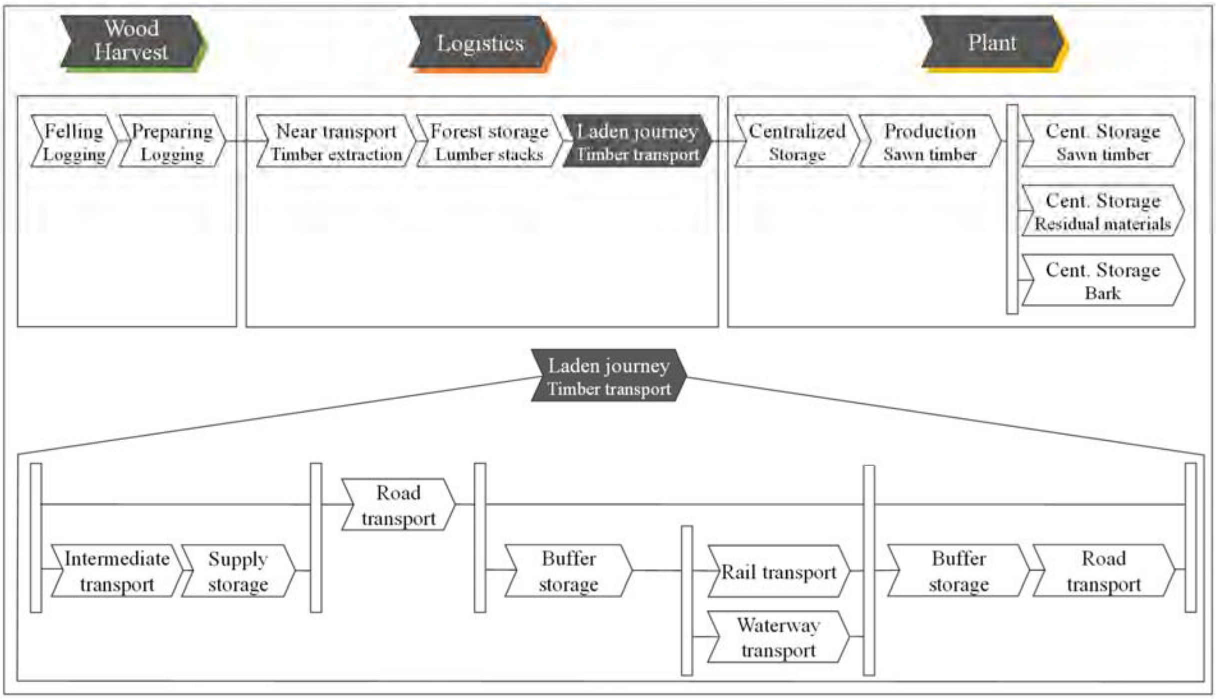

Figure 1: Process chain of a wood logistics process.

2.3 Methodical Approach

Modeling is based on the process chain model, as depicted in Figure 2, as well as on the relevant performance and cost indicators. The simulation is undertaken in the simulation environment ExtendSim. Based on the data available and the strategic objective a mesoscopic approach is chosen. The system elements illustrated in Figure 2 are parametrized with stochastic attributes, like weather influence, crop shortage or amount of unusable biomass. In the model, upper and lower bounds for performance deviations of system elements have been set (e.g. +10 to -5 percent). The simulation selects a percentage value within this range at random and applies it to the individual model objects. Each model object has its own occurrence probability and uncertainty range, allowing for possibly changing output sizes per time period. Each funnel in Figure 2 basically encompasses the following:

- input parameters: capacity and harvest yield
- and simulation output parameters: inventory/stock, performance, and costs.

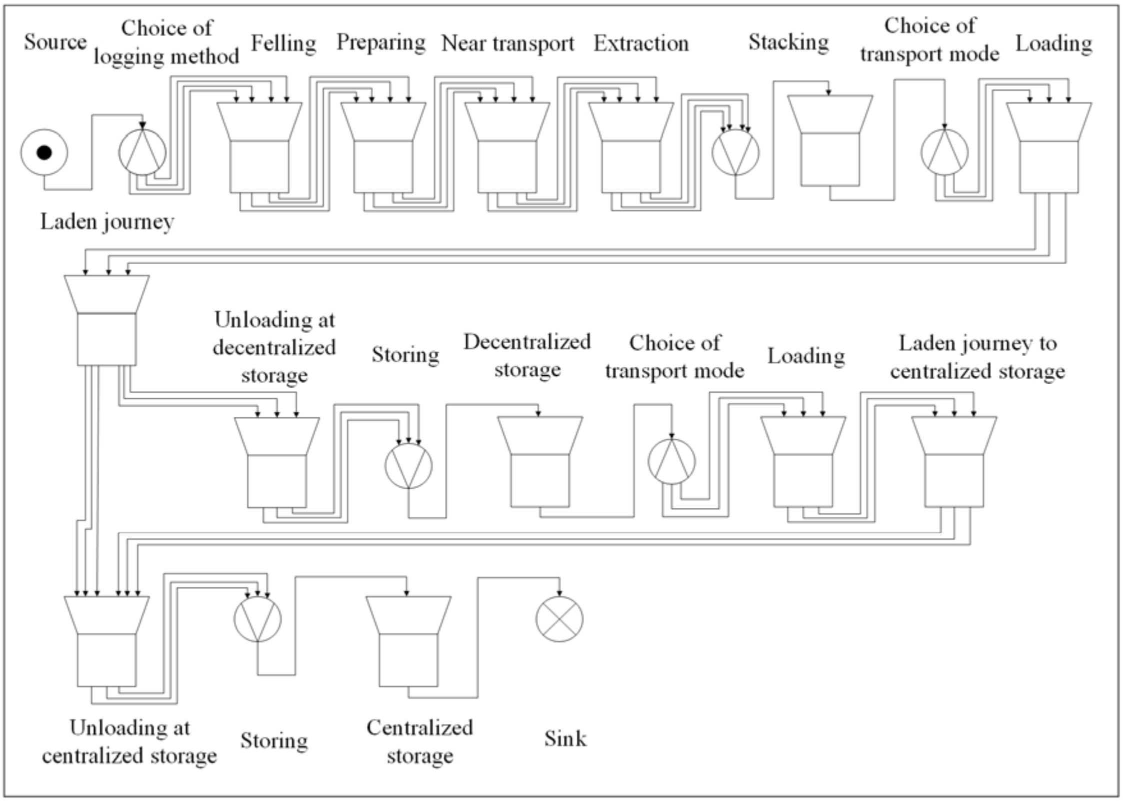

Figure 2: Implementation in simulation environment.

The methodical approach is chosen following Kühn (2006) and structured in the following phases:

- task definition,
- system analysis,
- model formalization,
- implementation,
- experiments and analysis,
- data acquisition (running in parallel), and
- data preparation (running in parallel) (Norm VDI 3633).

The following framework requirements are considered (excerpt):

- Only logistical processes and the costs incurred thereby are considered. Other necessary processes, such as machining and manufacturing are excluded.
- Saw-ready round timber and pulpwood share the same central storage location.
- Semi-trailers are used preferably for the transport from lumber stacks to the central storage location, due to their high loading capacity and favorable transport costs. Logging trucks are used when the capacity of semi-trailers is not sufficient.
- Wood arriving at the central storage location can be processed in the same month.
- A time period represents one month. This is used to calculate costs and performance as similar as possible to reality. Furthermore, only fixed time periods are used for the calculation.

3 SCENARIO DEFINITION & MODEL VERIFICATION

3.1 Scenario Definition

To represent the flow of raw materials an ideal normal state is defined. This normal state forms the basis for the validation of the model and is used to compare other scenarios to demonstrate changes in the flow of raw materials, costs, and performance. To ensure the comparability of different scenarios only single parameters are changed between the scenarios.

3.1.1 Ideal Normal State

The ideal normal state is characterized by processes identical to those forecasted by the regional project consortium. In detail this leads to meeting harvest yields as well as performance and costs corresponding to calculations. Also, capacity limits are not reached. The processing volume (throughput) in the factory (functioning as a sink) is equivalent to the prognosis. Therefore, the stock level reaches zero at the end of the season (September).

3.1.2 Crop Shortage

Crop shortage leads to part of the crop not being harvested as projected. This can happen, for instance, when weather conditions do not allow harvesting or part of the crop is infested by parasites or fungi. The shortfall needs to be harvested in the remaining other months. This scenario is used to assess the effects of crop shortfall on stock levels and production as well as on total performance and costs.

3.1.3 Reduction of Processing Volume

In this scenario, it is simulated that the projected processing volume is not reached and furthermore decrease over the five-year period. The crop size on the other hand sty constant. This situation could arise, for example, when the marked demand decreases but the plant is contractually bound to accept a predefined amount of raw material. This scenario is used to study the effects of excess inventory and to calculate appropriate storage capacities.

3.1.4 Capacity Limitations

In the ideal normal state capacities are always available. What happens if specific processes lead to capacity restrictions is studied in this scenario. Capacity limits can arise when strategical machines or transportation breaks down (the results for this scenario are not discussed in detail here).

3.2 Model Verification and Validation

For verification, the simulation results of the normal state scenario are compared with results from the network projects consulted. The restrictions are that the central storage has a maximum capacity of 55,682 solid cubic meter (m^3f) and the stock amount is reduced to zero by September, off-setting the annual logging amount with the amount processed annually. Figure **3**: Stock development crop shortage vs. normal state.Stocks increase in both the central (CS) and decentralized storage (DS), but the border of 55,682 m^3f is not exceeded in the central storage.

Validation checks whether the model’s behavior while attaining targets is in accordance with the mapped system (Rabe, Spieckermann, and Wenzel 2008). It must be ensured that data attained is valid. This is guaranteed by using our own data from previous research projects. In addition, we must make sure that data transfer to the concept model and finally to the simulation tool is consistent. All data transfers have been conducted with due diligence and in consultation with experts for mesoscopic modelling and wood procurement. In addition, all assumptions made were questioned critically by experts.

4 RESULTS

4.1 Scenario Crop Shortage

In the scenario of a crop shortage, the harvest amount in November and December is reduced by 75 percent compared to the normal state. The missing amount must be compensated from January to March. The processed amount is untouched. We will examine how the new material flow develops and whether the shortage has any influence on production. The logging and processing amount during a crop shortage is shown in Table 2.

Table 2: Logging and processing amount during crop shortage.

	Logging amount (m³f)			**Processing amount (m³f)**		
Month	Round timber	Industrial timber	Total	Round timber	Industrial timber	Total
October	70,000	8,000	78,000	31,500	4,800	36,300
November	23,625	2,700	26,325	31,500	4,000	35,500
December	15,750	1,800	17,550	14,000	1,600	15,600
January	81,375	9,300	90,675	24,500	2,400	26,900
February	91,875	10,500	102,375	28,000	2,800	30,800
March	67,375	7,700	75,075	31,500	4,400	35,900
April	-	-	-	31,500	4,000	35,500
May	-	-	-	31,500	3,200	34,700
June	-	-	-	31,500	3,200	34,700
July	-	-	-	31,500	3,200	34,700
August	-	-	-	31,500	3,200	34,700
September	-	-	-	31,500	3,200	34,700
Total			**390,000**			**390,000**

A change in the logging amount influences the stock development in both the central and decentralized storage. As shown in Figure 3 stock growth is postponed in the crop shortage scenario, as expected. Only in January does the central storage reach its maximum capacity and the decentralized storage starts gaining stock in December. Beginning in March the stock development is equal in both scenarios and continues in the same way until the end of September.

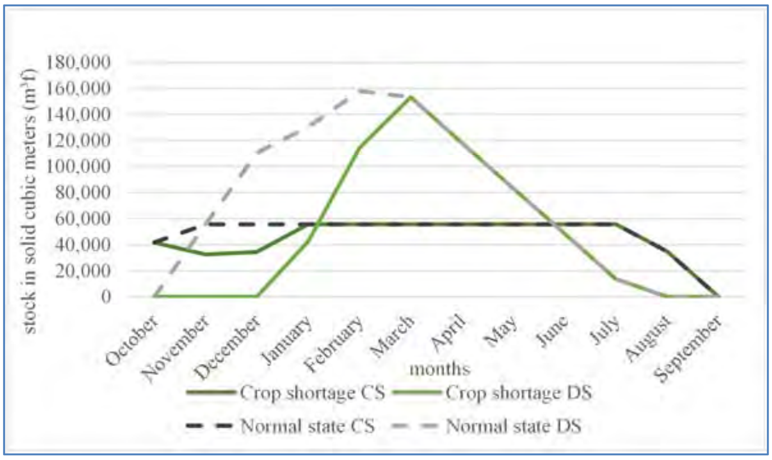

Figure 3: Stock development crop shortage vs. normal state.

As the annual logging amount is unchanged, the total sum of cost and performance is at the same level. The minimal deviation is caused as more material must be transported from stacks to the central storage than during normal state. However, there is a marked difference in the distribution of performance and cost over the year, cf. Figure 4.

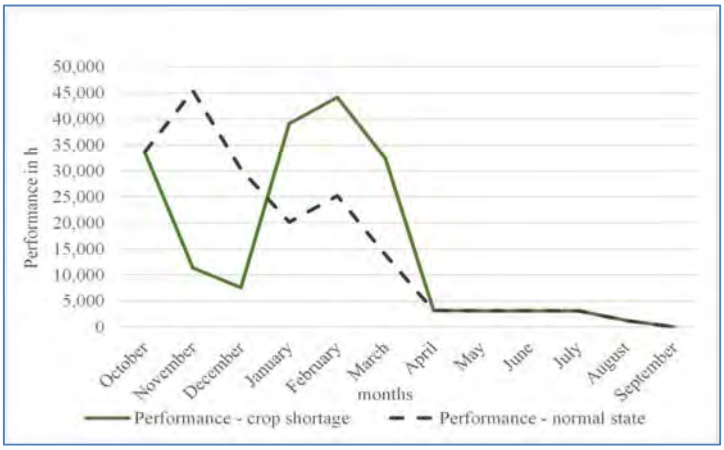

Figure 4: Performance development crop shortage vs normal state scenario.

During a crop shortage, the performance peak moves significantly from November to February (cf. Figure 4). In contrast to normal state, the main part of the wood amount is logged and transported during the last three months of the season. This has a direct effect on the stock development in both the central and decentralized storage (cf. Figure 3). No decentralized storage is needed during the first three months, and the central storage is only fully utilized in January. Despite a crop shortage of 75 % in the two performance-intensive months, there is no deficit in the plant. With a stock of 32,000 m³f there is a safety stock of at least a month during the weakest month.

Due to the movement of the performance peak there are two primary challenges for the logistics planner. First of all, during the first three months much fewer resources are needed than originally planned for. As crop shortages are usually unplanned and occur in the short term, resources such as personnel and machinery must be paid for nevertheless. A possible measure would be to refrain from using expensive fully mechanized harvesting methods. As the needed resources exist and there is no deficit in the plant, the main focus is the utilization of resources. These can work with minimal performance during the first two months. The second challenge is the increased resource use during last three months. In contrast to November and December, more personnel and machinery is needed than originally planned. The aim during this time is to reduce the needed resources as far as possible. A possible measure is an increased utilization of fully mechanized harvesting methods. Harvesters and foresters need almost 50 percent less time for the harvest than using the partially mechanized methods with a machine saw operator. Figure 4 displays the effects of these measures on the performance development of the original crop shortage and the normal state.

4.2 Lowering the Processing Amount

In this scenario, the annual processing amount of the normal state is lowered by 10 % while the logging amount is constant. The new annual processing amount of 351,000 m³f is valid in the years 1 through 5. The reduction is distributed equally over all months, cf. Table 3. This creates an overlap among the storage. The aim of this scenario is the development of measures and solutions to lower performance (operating hours) and cost.

Table 3: Logging and processing amounts while lowering the annual processing amount by 10 %.

	Logging amount (m³f)			**Processing amount (m³f)**		
Month	Round timber	Industrial timber	Total	Round timber	Industrial timber	Total
October	70,000	8,000	78,000	28,350	4,320	32,670
November	94,500	10,800	105,300	28,350	3,600	31,950
December	63,000	7,200	70,200	12,600	1,440	14,040
January	42,000	4,800	46,800	22,050	2,160	24,210
February	52,500	6,000	58,500	25,200	2,520	27,720
March	28,000	3,200	31,200	28,350	3,960	32,310
April	-	-	-	28,350	3,600	31,950
May	-	-	-	28,350	2,880	31,230
June	-	-	-	28,350	2,880	31,230
July	-	-	-	28,350	2,880	31,230
August	-	-	-	28,350	2,880	31,230
September	-	-	-	28,350	2,880	31,230
Total			**390,000**			**351,000**

Due to the overlap, there is a stair-like development of the stock in the decentralized storage. The central storage only reaches its maximum capacity during October of the second year and stays at maximum capacity until the end of the fifth year. Free capacities in the central storage exist only at the beginning (October) and end (September) of the first year. Starting with the second year the material flow runs the same way every year. Only the stock increases annually. The stock development is shown in Figure 5.

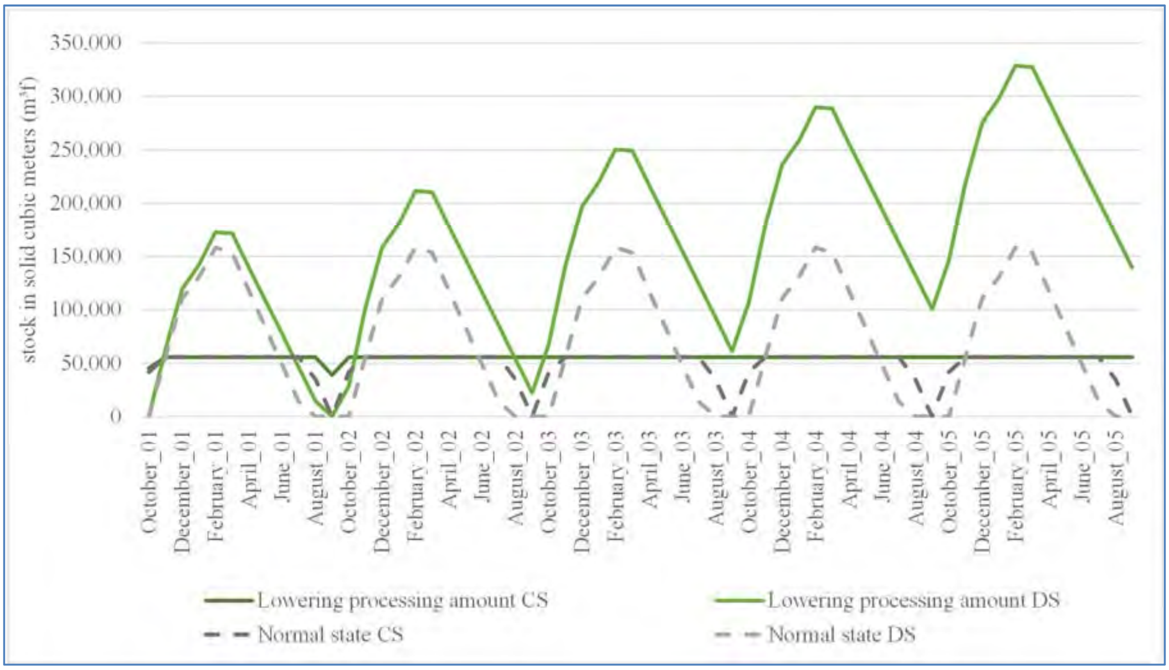

Figure 5: Stock development: Lowering the processing amount vs normal state.

The uniform development of stock is mirrored in cost and performance. When the processing amount is lowered, the annual performance eventually settles at 185,154 h and the number of trips at 36,343, beginning in the second year. The annual cost stays at 17.4 mn € from year three. Compared to the normal state this results in a cost reduction despite an increase in performance, cf. Table 4.

Table 4: Annual cost and performance while lowering the processing amount (LPA) and during normal state.

	Costs per Year	**Performance per year**	**Number of trips per year**
Year 1 (LPA)	17,695,952 €	183,665 h	34,937
Year 2 (LPA)	17,590,190 €	185,154 h	36,343
Year 3 (LPA)	17,419,454 €	185,154 h	36,343
Year 4 (LPA)	17,419,454 €	185,154 h	36,343
Year 5 (LPA)	17,419,454 €	185,154 h	36,343
Normal state	17,591,874 €	182,370 h	33,714

Although the annual cost of both scenarios differs only marginally, there is a marked shift in cost drivers. Figure 6 shows the distribution of annual cost for the normal state and the levelled scenario. The cost of logging and timber extraction are the same in both cases. In the area of transport logistics, the cost for load trips from the stack to central storage are lowered from 3.3 mn € (normal state) to 2.2 mn €. However, total costs for interim storage in the decentralized storage during the lowering of processing amounts go up 27 %.

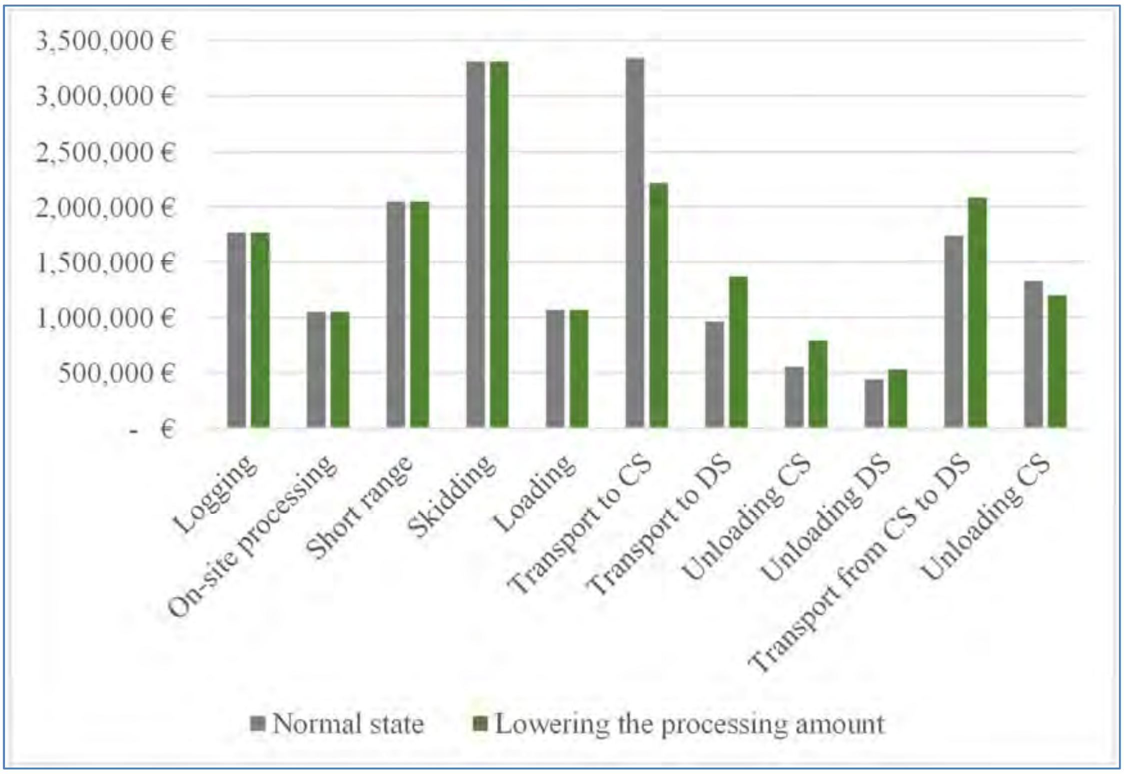

Figure 6: Annual cost of normal state and during the lowering of the processing amount.

In contrast to a crop shortage, a lowering of the processing amount has no influence on wood harvesting and extraction. But the influence on stock development and transport logistics is even stronger. By restricting the central storage, the decentralized storage grows continually by 39,000 m³f per year. One of the consequences is the central storage being filled to capacity beginning in year 2. The number of trips from the stack to the central storage is reduced by 15.5 %, while the trips from the stack to the decentralized storage and from the decentralized storage to the central storage increase by 67.7 % and 19.7 %, respectively. Thus, the focus of transports shifts from direct delivery to interim transport via the decentralized storage.

5 SUMMARY

We can conclude that the model, as described, is already capable of mapping all strategic processes with sufficient exactness to determine strategic measures. Especially during planning, a variety of measures for potential environmental conditions can be developed to be able to react quickly. A mesoscopic approach is used to model the complete wood processing value chain. Strategical decisions can be made based on the simulation results, even without detailed operational data. The degree of detail of the current model is already sufficient to be used when planning weekly transports. This, however, requires additional raw data. Every planner would be able to develop scenarios and examine potential measures on their own, after short training.

By mapping the complete wood processing value chain onto a simulation model, we could prove that a continuous raw material stream can be guaranteed despite a discontinuous harvest (harvest period from October to March) and additional weather influences (cf. crop shortage scenario). Further steps, beyond this case, will be the adaptation of the model to other raw material supply chains.

REFERENCES

Asikainen, A. 2010. “Simulation of Stump Crushing and Ruck Transport of Chips”. *Scandinavian Journal of Forest Research.* 25: 245-250.

Kühn, W. 2006. *Digitale Fabrik: Fabriksimulation für Produktionsplaner*. München: Carl Hanser Verlag.

Mobini, M., T. Sowlati, and S. Sokhansanj. 2011. “Forest biomass supply logistics for a power plant using the discrete-event simulation approach”. *Applied Energ*y 88, 4: 1241-1250.

Pufky-Heinrich, D., M. Leschinsky, and G. Unkelbach. 2012. “Neue Strategien: Holz als Rohstoff für die chemische Industrie”. *Chemie & more* No. 06/2012:10-13.

Rabe, M., S. Spieckermann, and S. Wenzel. 2008. *Verifikation und Validierung für die Simulation in Produktion und Logistik. Vorgehensmodelle und Techniken.* Berlin, Heidelberg: Springer Verlag.

Schenk, M., J. Tolujew, and T. Reggelin. 2008. “Mesoskopische Simulation von Flusssystemen - algorithmisch steuern und analytisch berechnen”. In *Beiträge zu einer Theorie der Logistik,* edited by P. Nyhuis, 463-485.Berlin: Springer Verlag.

Tolujew, J. and T. Reggelin. 2008. “Mesoskopische Simulation: Zwischen der kontinuierlichen und ereignisdiskreten Simulation”. In *Advances in Simulation for Production and Logistics Applications,* edited by M. Rabe, 585-594. Stuttgart: Fraunhofer IRB Verlag.

Norm VDI 3633. 2000. *Simulation von Logistik-, Materialfluss- und Produktionssystemen - Blatt 1: Grundlagen*. Berlin: Beuth Verlag.

Windisch, J., K. Väätäinen, P. Anttila, M. Nivala, J. Laitila, A. Asikainen, and L. Sikanen. 2015. “Discrete-event Simulation of an Information-based Raw Material Allocation Process for Increasing the Efficiency of an Energy Wood Supply Chain”. *Applied Energy* 149: 315-325.

AUTHOR BIOGRAPHIES

OLIVER MEIER is a scientific researcher at the Department of Logistics Systems at the Institute of Logistics and Material Handling Systems at the Faculty of Mechanical Engineering at the Otto-von-Guericke University Magdeburg, Germany. In addition, he is employed by the Fraunhofer IFF,

Magdeburg. He holds a degree in business informatics. His current research topics are modeling and simulation as well as resource and raw material logistics. His e-mail address is oliver.meier@ovgu.de.

HENNING STRUBELT is a senior lecturer at the Department of Logistics at the Institute of Logistics and Material Handling Systems at the Faculty of Mechanical Engineering at the Otto-von-Guericke University Magdeburg, Germany. He holds a doctoral degree in engineering for his research on ramp-up management for job production. His current research areas include sustainable supply chain design, lean ramp-up, and material provision concepts for multi-model production. His e-mail address is strubelt@ovgu.de.

SEBASTIAN TROJAHN is a scientific researcher at the Department of Logistics Systems of the Institute of Logistics and Material Handling Systems at the Faculty of Mechanical Engineering at the Otto-von-Guericke University Magdeburg, Germany. He is also a employed by the Fraunhofer IFF, Magdeburg. He holds a doctoral degree in engineering for his research on location decisions for decentralized plants. His research interests include analysis and optimization of logistics processes, energy efficiency in logistics, and resource and raw material logistics. His e-mail address is sebastian.trojahn@ovgu.de.