IMPROVING RAIL ROAD TERMINAL OPERATIONS IN THE FOREST WOOD SUPPLY CHAIN – A SIMULATION BASED APPROACH

Karl Etlinger[(a)], Peter Rauch[(b)], Manfred Gronalt[(c)]

(a,b,c) University of Natural Resources and Life Sciences, Institute of Production Economics and Logistics

[(a)]karl.etlinger@boku.ac.at, [(b)] peter.rauch@boku.ac.at , [(c)] manfred.gronalt@boku.ac.at

ABSTRACT
Advanced logistics and transportation concepts are required to improve the forest-wood supply chain. In this paper some terminal concepts are analyzed that show a strengthening of the railway timber transport and synergies between rail and road transport chains. A discrete event simulation model is developed in order to analyze different prevalent terminal layout configuration and to disclose potential improvements of the timber railway transportation system by proposing new terminal layouts and new railway transport options. We conduct comprehensive simulation experiments of the wood supply network with several terminals and industry sites to find out system's bottlenecks and appropriate railway operation schedules. As a result we can show that by changing the railway operation from a single wagon load to a shuttle system we can nearly double the amount of round wood to be transported.

Keywords: forest-wood supply chain, rail terminal, scenario analysis

1. INTRODUCTION
It is often claimed that the rail transport system should preferable be used for heavy and bulk materials. Austria processes approx. 25 Mio. of solid cubic meter roundwood per year and it operates more than 200 wood loading and transshipment points and a good quantity of wood industries have sidings in use. On the other hand the portion of road transport is rather high and cost pressure on railway forces railway companies to rethink their wood terminal network.

In this paper a few terminal concepts are analyzed in particular that show a strengthening of the railway timber transport and the possibilities of synergy between rail and road intermodal transport chains. For this purpose, already existing concepts in timber logistics are analyzed and the role of the railway is shown during timber transport. In a first step we carry out a detailed process analysis of roundwood (i.e. sawlogs and pulpwood) transport and its handling on dedicated wood terminals. Further, we give special emphasis on the communication interfaces of the involved actors. Through a mass flow analysis the structure of the timber transportation, both in terms of transport mode as well as the actual spatial distribution of the wood transports are evaluated. A discrete event simulation model is developed in order to analyze different prevalent terminal layout configuration and to disclose potential improvements of the timber railway transportation system by proposing new terminal layouts and new railway transport options. We conduct comprehensive simulation experiments of the wood supply network with several terminals and industry sites to find out system's bottlenecks and appropriate railway operation schedules. As a result we can show that by changing the railway operation from a single wagon load to a shuttle system we can nearly double the amount of round wood to be transported. If it is moreover possible to change the terminal layout (i.e. loading track length) we can further increase railway transport volumes.

2. TIMBER TRANSPORTATION SYSTEMS AND WOOD TERMINAL OPERATIONS
Round wood transportation may be either directly from forest to industry by truck or for some reason like long distances or high volume transport units are transshipped on dedicated wood terminals. In this case we are talking about multimodal transport (Wolfsmayr and Rauch 2014, Zazgornik et al. 2012). The log truck driver is using a truck crane to unload the logs in the terminal. If there are appropriate rail wagons available to use, which further on transport the logs to the industry, there will be a direct transhipment from truck to rail wagon. This is denoted as synchronous transhipment. However in standard operation a direct transhipment is rarely possible, so that the logs are unloaded by using some certain storage areas at the terminal. When the freight train arrives an additional operation is required for loading the freight wagons. The activities of this multimodal transport chain are shown in Figure 1.

Railroad terminal transhipment volume is mainly determined by existing infrastructure like number and length of loading tracks, storage area and handling equipment. We will describe a simulation based scenario approach for analyzing a railway based wood supply network. For a given number of industry plants we evaluate the capacity of such a network and study the effects of infrastructural changes at the terminals, different railway operational concepts and fluctuations of the available wood supply in the catchment area of the terminals.

In intermodal wood transport chains, terminals proofed to provide good services (Gunnarsson et al.

2004) and large buffer storage area is also essential for rail transport, as high volumes can be unloaded and stored in a short time slot (Rauch and Gronalt 2011). Supply chains including terminals increase year round availability resp. supply security (Ranta et al. 2012) and are seen as prerequisite to fulfill significantly increasing wood demand.

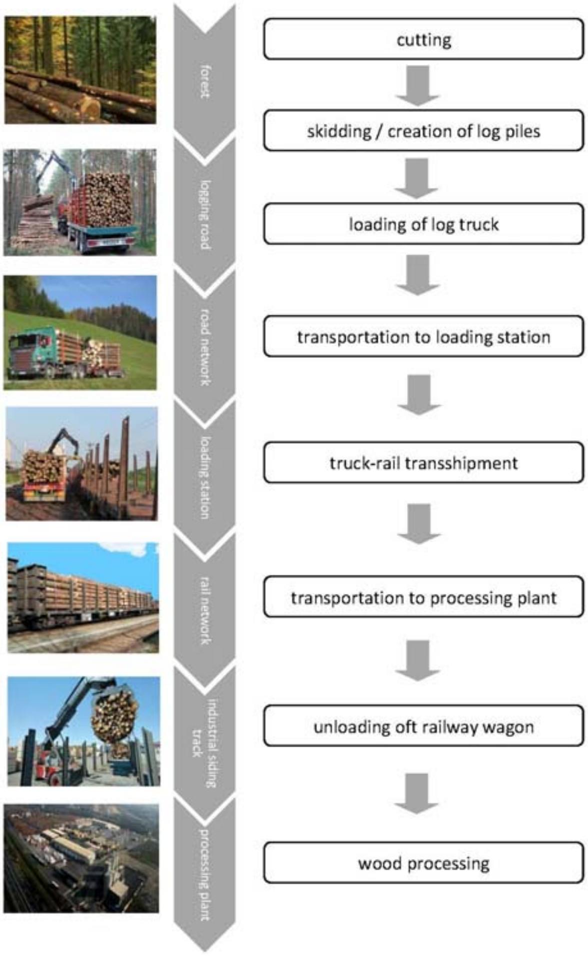

Figure 1: Multimodal round wood transport and synchronous transshipment

Next to transshipment, a train terminal can fulfill additional logistical functions or services and therefore terminals differ in terms of location, storage capacity and specific services provided (Benna and Gronalt 2008; Gronalt et al. 2012). Optimal storing capacity of a terminal is determined by seasonality of both, timber supply and plant demand, leading to a minimum amount of timber to be stored at a certain time of the year in order to ensure supply security. In Finland, domestic roundwood transport via train terminals becomes competitive at a distance of at least 200 km, from there on total costs for truck transport to the terminal, terminal costs and rail transport to the plant are lower than for direct truck transport (Tahvanainen and Anttila 2011). If an additional post road transport is included in the roundwood supply (e.g. since the plant has no own rail access), break-even point of rail transport compared to direct truck transport is reached at a distance of 300 km (Chesneau et al. 2012). Additionally, cost cutting potential of a terminal varies depending on specific timber supply chain parameters like total timber volume or regional wood harvest seasonality (Rauch and Gronalt 2010). Critical success factors for rail terminals proved to be length of loading rail, capacity and characteristic of storage area (Ranta et al. 2012), number of trains despatched per week and utilising maximum payload for each train or wagon.

The aim of the simulation model and simulation study described in the following section is to simulate a wood supply chain including four wood terminals and four wood processing plants. Two of them are sawmills, requiring the delivery of sawlogs and two are papermills which process pulpwood. We want to compare the transport chain as it is currently in use in Austria with a different approach that uses terminals for asynchronous truck-train transshipment and employs a concept of shuttle trains in contrast to the single wagon system that is used now.

We assess the two approaches under the current real life situations and develop a number of scenarios to see how the analyzed approaches react to changed transport volumes and how infrastructural adaptions influence the performance. Since there is no information about the actual capacities of the existing terminals we want to evaluate the current capacity, compare it to the capacity when a different operational concept is applied and subsequently analyze how changes in infrastructure and train concepts affect the capacity of the terminals and the whole wood supply chain network.

3. SIMULATION MODEL DEVELOPMENT

The simulation model developed covers the precarriage of round timber to wood terminals, round wood storage in terminals, transshipment to rail cars and final transport to and unloading at woodworking plants. The simulation model is used for several issues in order to improve the efficiency of this supply chain. These contain the determination of transshipment time / cycle time of round timber, stock levels at terminals over time, utilization of terminal infrastructure (storage capacity, transshipment equipment), network capacity with given terminal sizes and configurations and required terminal sizes and configurations to achieve a given network capacity. The model must be able to cope with the effects of short term fluctuations in timber supply and capacity constraints of specific terminal layouts. The simulation study includes therefore various terminal specifications and their effect on the supply network and also the effects of applying different train concepts (single wagon, shuttle train) for picking up the wood at the terminals.

To achieve the level of detail in the simulation results that is necessary to derive valid conclusions requires our model to be process-centric and on a detailed operational level. Therefore we developed and implemented a discrete-event based simulation model by using AnyLogic. In the discrete-event simulation approach, continuous real world processes are divided into an ordered sequence of events, where each event occurs at an instant in time. This simplification allows for better analysis of the modeled processes.

3.1. Model description, structure and components

The simulation model consists of four basic components that are interrelated with each other in order to represent the specific supply chain network. These components are (1) forest and precarriage, (2) terminal modules, (3) railway network and (4) plant modules. The behavior of each component depends both on its process and infrastructural input parameters, stochastic effects and the other model components. The components and their input and output parameters are schematically shown in Figure 2. All components except the railway network follow a modular principle so that they can be duplicated as often as required in order to reflect the studied supply chain. Since the railway network already presents the whole network, there is only one railway network in the model.

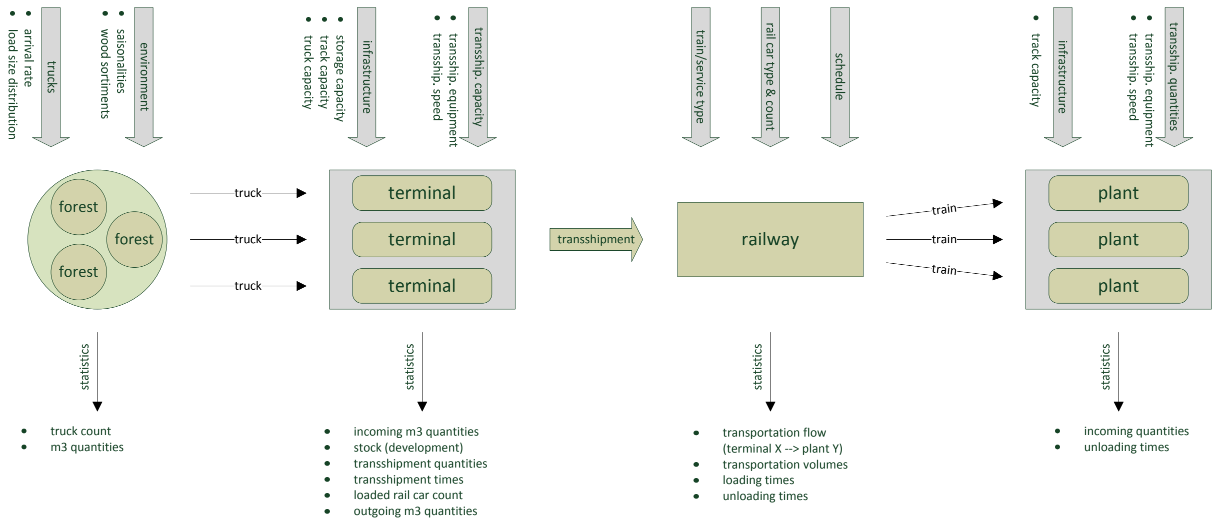

Figure 2: model components and input/output relations

(1) Forest and precarriage module

This module constitutes the starting point of the model. Its main purposes are to generate the wood supply and simulate the precarriage of the generated log-entities to its assigned terminal. All log-entities that have to be handled in the wood supply chain are generated here. Consequently all external effects that affect the wood supply and their stochastic behavior are implemented in this part of the model. These effects represent environmental impacts on the wood supply and include seasonality and weather conditions that influence the accessibility of the forest sites which serve as source for the log-entities. On creation of the log-entities, the forest module also assesses the assortment of the generated entity. The approach for the log generation works in that way, that it does not create single logs, but truckload sized batches of coherent log assortments. The batch size is determined by a truck load generator function that applies a triangular distribution to generate truck load sizes corresponding to realistic truck loads in the setting of Austrian forestry.

So the output of the forest module are log trucks that carry logs of one assortment and are associated with a certain departure time and a stochastic travel time to the terminal. Since we assume that no truck arrives at a terminal outside of its hours of operation, the arrival rate of the log creation process is set to zero if the truck leaving the forest can't reach the destination terminal within the opening hours.

(2) Terminal module

The terminal module contains all processes that take place in the terminal and therefore includes all multimodal interactions between trucks and railcars. The main functions of the terminal module are the unloading the incoming log trucks, if necessary storage of logs at the terminal and the loading of the outgoing railcars. Every terminal module has a respective forest/precarriage module assigned.

The model considers two types of wood terminals and consequently includes two types of terminal modules. While type A represents the most common type of wood terminals in Austria and the according synchronous multimodal loading processes we model asynchronous loading with shuttle train traffic as terminal type B.

Type A:

In terminal modules of type A we modeled Terminals that are used for synchronous multimodal transshipment for single wagon traffic as it is common practice in Austrian wood supply chains.

The processes in the terminal module are designed as follows. When a log truck from the assigned forest module arrives at the terminal, first it is checked if the truck can enter the terminal or the transshipment area respectively. Since most current terminals are quite small and don't have a lot of space it can be impossible for a truck to enter a terminal when there are a couple of other trucks unloading or waiting to unload. So if a truck can't enter a terminal or estimates the waiting time too long to wait it leaves and tries again at a later time.

In case no waiting is necessary the truck enters and starts to tranship the logs to the wagons provided by the railway network. Since we included a uniform distributed probability that the required wagons for the transshipment are not provided on time there is a chance that the truck has to put the logs into interim storage at the terminal area. In this case the truck unloads, leaves the terminal and returns again after a stochastic generated period of time to load the previously stocked logs onto the wagons, if now provided. The loaded wagons are then dispatched by train at the next scheduled time of service for single wagon traffic and therefore are passed from the terminal to the railway network within the simulation model.

Type B:

In contrast to type A, terminal type B is served by shuttle trains rather than single wagon traffic and therefore also has to allow for asynchronous transshipment of the round wood. Hence we modeled the layout of a type B terminal as shown in Figure **3**. Next to the traffic lane for the trucks there are loading boxes arranged (T-section shaped storage racks made of steel) that can hold the amount of round wood necessary to fill a block train. In the adjacent area between the loading box lane and the exiting traffic lane there is additional storage space for storing logs that exceed the capacity of the loading boxes.

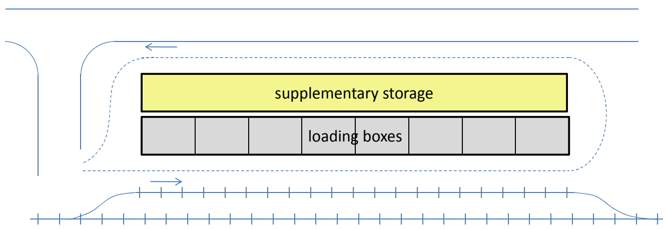

Figure 3: layout of type B terminals

The arrival and potential impossibility of entering the terminal because of too many trucks inside is modeled as in the type A module.

When a truck enters the terminal it drives to an empty loading box and unloads the logs into it. In case another truck is unloading at the same time and therefore is blocking the traffic lane, the incoming truck has to use an empty box rear to the truck already standing in the lane so it can be reached without passing the blocking truck. If that is not possible because all the reachable boxes are full the truck has to wait until the other, already unloading, truck is done and the traffic lane is cleared.

The terminal is served by shuttle trains that arrive and depart according to a fixed schedule specified in the railway network.

While the shuttle train is waiting at the siding track of the terminal, its wagons are loaded with the logs of the wood assortment assigned to this shuttle train. Which assortment has to be loaded is determined by the industrial site the shuttle train is headed for (saw logs for sawmills, pulpwood for paper mills, dummy assortment for external destinations outside of the modeled network).

For the process of loading the train, wheel loaders or log trucks with cranes are present at the terminal to load the wood from the loading boxes to the railway wagons. The loading time is modeled by a stochastic probability distribution dependent on equipment used for the transshipment.

In order to show how the entity flow is modeled, in Figure **4** a fraction of a terminal module is depicted. The grey box in the upper left corner is the connection of the module to the rest of the simulation model. Via the left and the right nodes in the box, the train entity enters, respectively departs the terminal module, whereas the log truck entity is passed on to the terminal by the bottom node. The entering truck goes to the “queueEntry” where the check if the truck can enter the terminal or has to wait is conducted. Subsequently, the truck either waits, leaves to returns at a later point in time (executed by the processes in the lower white box) or continues to the actual terminal and is set up for the transshipment process at “setupTruck”. This is followed by the check whether the truck can access an available loading box or is blocked by another truck in the traffic lane and has to wait until this truck is finished unloading (processes in the upper left box). Providing that the truck is not blocked it proceeds to a loading box, unloads the logs and leaves the terminal. During the unloading process the truck entity is separated from the carried wood which subsequently is splitted into flow units each representing one solid cubic meters of a specific wood assortment.

In case a shuttle train with empty wagons is currently present at the siding track when the truck is at the terminal and the wood assortment the truck carries matches the assortment assigned to the train, the truck transships directly to the a wagon of the shuttle train. These processes are performed in the upper right white box together with other areas of the terminal module that are not shown for reasons of clarity.

(3) Railway network.

The terminal and plant modules are embedded in the railway network which generates trains and controls the routing between the particular terminals and plants according to schedule. When a train arrives at a specific terminal or plant, it is forwarded to the corresponding module and passed back to the railway network after finishing operations at the terminal or plant module.

The railway network also controls all railway related parameters like number of trains in the network, number of railcars per train, the wood assortment the train is going to pick up at a terminal depending on the plant it is routed to next and travel times.

(4)Plant module

Since our study focuses on the processes at the terminals and the rail based shipping, there is not much emphasis on an extensive modeling of an entire industrial site. So the focal point of the plant module is the siding track of the facility. Therefore we model the arrival and departure of the trains as well as the unloading of the logs and the log storage at the facility. The unloading speed and the storage capacity are being controlled by parameters representing the transshipping equipment and the storage area available at the modeled industrial site.

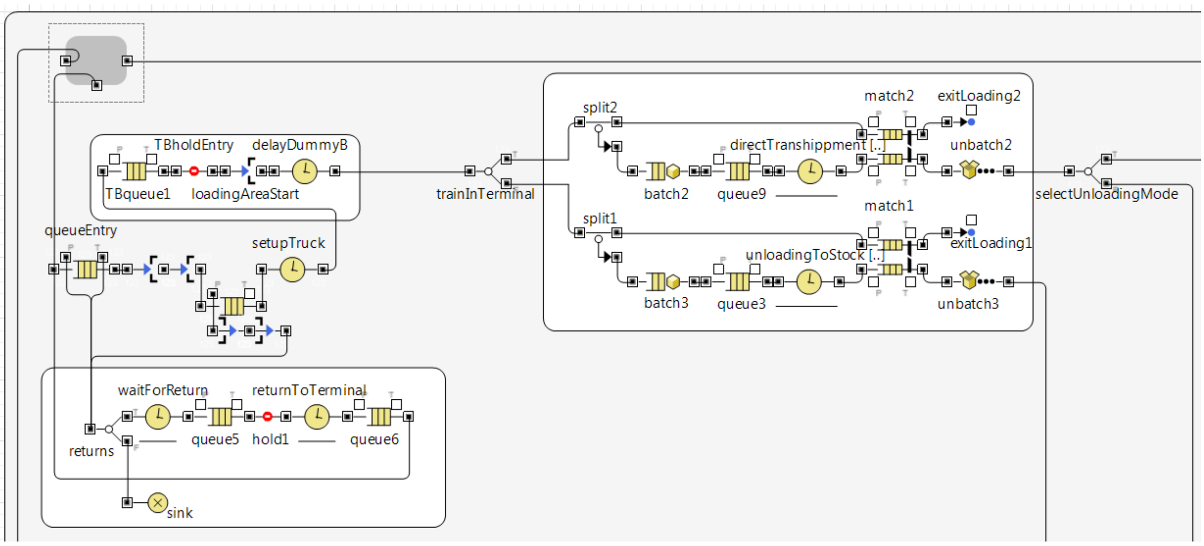

Figure 4: example for the modeling of the entity flow within a terminal module

Beyond that, the plant modules merely serve as sink for the modeled flow entities i.e. the logs. So we don't simulate the log processing at the plants. Nevertheless we included an aggregated manufacturing process, so when the parameters of the throughput of logs per unit of time at the facility are known it is possible to monitor the inventory and determine shortages of wood supply or a lack of size of the available storage area.

3.2. Simulation Study

In our case study for analyzing the competitiveness of the wood terminal network we consider four wood terminals and four production sites of the wood processing industry, specifically two saw mills and two paper mills. We deliberately consider different types of processing plants since it makes sense for wood processing companies to cooperate with each other in the area of raw material procurement (Zazgornik et al 2012). The overall procurement cooperation is realized via common buying agents.

3.2.1. Data basis and model parameters

The data we use were gathered from three sources. The quantity of logs that is handled at the terminals was provided by the operating railway company whereas the data about the quantity of wood supply that is delivered to the considered wood processing plants was provided by the buying agent of the plant operators. The information, regarding the infrastructure at the terminals as well as the processes that take place during terminal operations where either collected on site or also provided by the operating railway company.

For the parameterization of the simulation model we made following assumptions:

- There are three types of logs in our model. Two types correspond to the different wood assortments that are processed in the industrial sites. Those two types are saw logs, which have to be transported to one of the two sawmills in the model and pulpwood which is bound for one of the paper mills.
- Additionally we introduce a third assortment that doesn't represent an actual type of wood, but is a dummy assortment for logs which are assigned to demand outside of our considered supply network. These logs are transshipped in the terminals of our system but are not transported to one of the modeled industrial sites. Therefor they occupy resources at the terminals, but not in the railway network or the wood processing plants.
- In case a log truck can't enter a terminal to deliver the logs because the terminal has reached its maximum capacity, either in terms of trucks inside the terminal or in terms of storage capacity, it will wait outside the terminal for some time. This is only possible if there are not so many trucks waiting that the public street gets blocked. If the truck still can't enter the terminal after this waiting period, it leaves and comes back once after a time span which is determined by a triangular probability distribution. Is the terminal blocked again on return, the log truck will leave and deliver the logs directly to the industrial site the logs are bound for.
- Shuttle trains have fixed arrival and departure times at the terminals. Since railway

companies have to reserve the rail tracks on the whole route well in advance for a specific time window it is not possible to adjust the waiting time to the actual loading time. Therefore in the simulation it can happen, that the train is either waiting at the terminal for some time even if the loading process is already completed. The other way round if the transshipment capacity at a terminal is not sufficient it is also possible that the train has to depart before all logs could have been transshipped.

3.2.2. Scenario generation

The simulation model is used to analyze several scenarios in order to evaluate the network capacity of the supply chain under various configurations. For the definition of the different scenarios used for the numerical experiments we first identify four dimensions that influence the performance of the modeled supply chain. These dimensions are the quantity of wood that has to run through the network (volume dimension), the infrastructural dimension (available storage space, length of rail tracks and hence the maximum number of wagons at a terminal), the transshipment dimension (quantity and type of transshipment equipment) and the train concept dimension (type of railway production system). For every dimension we then define a number of one dimensional scenarios where only the parameters of this dimension are changed. This leads to following scenario types:

- Base scenario (current "real world" infrastructure and volumes).
- Volume scenarios (volume dimension).
- Infrastructure scenarios (infrastructural dimension).
- Storage capacity scenarios.
- Rail track scenarios.
- Transshipment scenarios (transshipment dimension).
- Train concept scenarios (train concept dimension).

Finally, for the scenarios that are used in the simulation runs of the numerical experiments, multidimensional scenarios are derived by combining different variations of the one dimensional scenarios.

We start our analysis with a base-scenario where the configuration of the model represents the actual state of the network i.e. the actual infrastructure at the terminals and run through the defined volume scenarios with this configuration. The results of this simulation runs provide the basis for measuring the effects of infrastructural changes considered in the later scenarios. The further scenario plan is not fixed in advanced but developed in a recurring iterative process of scenario selection, simulation run and performance evaluation. This cycle is illustrated in Figure **5**.

So after every simulation run the results are analyzed with respect to the performance of the network and the terminals and the next scenario is picked accordingly.

This is done to avoid the simulation of scenarios that are already known to provide no further information, based on the evaluation of the outcome of previously simulated scenarios.

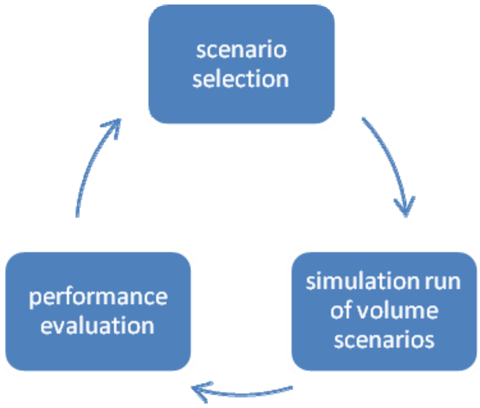

Figure 5: scenario plan definition process

Based on the "real world" transportation volume data the volume scenarios range from -20% to +320% of the actual quantities that where supplied by the analyzed network.

The infrastructural scenarios consist of different capacities of the storage space for logs and different railway track lengths at the terminals. In the transshipment scenarios different transshipment capacities are defined in dependence of the used equipment at the terminals. Finally, the train concept scenarios define different approaches regarding the rail concept and the frequency of the train schedule. The parameter for the simulation scenarios are listed in Table 1.

supplied wood	infrastructure	transshipment	train concept
actual volumes	current infrastructure	synchronous	single wagon
- 20%	upgrade 1	log truck	block train - 48h
- 10%	upgrade 2	log truck - variation	block train - 24h
+ 10%	target volume coverage	wheel loader	2 block trains
+ 20%			
+ 40%			
+ 80%			
+ 160%			
+ 320%			

Table 1 : parameter for simulation scenarios

4. NUMERICAL EXPERIMENTS AND RESULTS

In order to be able to evaluate the performance of the supply chain setting, we identify all relevant performance measures and collect all required data and statistics during the course of a simulation run. 2 lists the selected scenarios and the most important results.

The performance of the supply chain is evaluated primarily based on the throughput of the terminal network. Throughput here is defined as the percentage of generated wood volumes that can be handled by the terminal network. Correspondingly the dismissed volume is the quantity of wood that cannot be delivered via a terminal but has to be brought to the industrial site by truck because of a lack of capacity at a terminal or in the railway network.

Base-scenario

As mentioned before, the base-scenario represents the current “real world” state of the analyzed supply chain network which is composed of four terminals and four industrial sites, more specifically two saw mills and two paper mills, with the actual infrastructure and equipment.

The volume scenarios for the basic network configuration show, that volumes up to 180% of the initial quantity can be handled quite well. Just 3% of the generated wood cannot be covered by the terminal network but have to be delivered to the industrial sites by truck. Beyond the 180% the network gets noticeable overstressed.

An important foundation for the evaluation of a new supply chain concept is the finding under which configuration the same volumes of wood can be handled as in the standard concept. Simulating the same volume scenarios with the new terminal concept of asynchronous transshipment and a shuttle train service (terminal module type B) instead of synchronous transshipment an single wagon traffic (terminal module type A) in scenario 1 shows that the base volume as well as an increase by 10% can be handled quite well (98.2% and 97% throughput respectively). But with further increasing volumes, the throughput drops significantly. The higher throughput at increased volumes in the base scenario can be explained with the higher frequency of service with single wagon traffic (30 times a week in the base scenario in comparison to 14 times a week in scenario 1).

So the base volume can be handled at less effort in terms of train service with the new supply chain concept. This is also evident when looking at the average train load, which rises from 98 solid cubic meters of wood in the base scenario to 214 in scenario 1. The following scenarios analyze at what configuration higher volumes can be handled by new supply chain concept too.

Covering 180% of the base volume.

Deploying a second shuttle train in the network (scenario 2) results in a significant higher throughput than without any infrastructural modifications. The limit for an effective network operation is now at 180% of the initial volume like in the base-scenario and the development of the throughput over the volume scenarios is now very similar to the one in the base scenario. Whereas the number of performed train services is still lower (23 vs. 30).

Covering 320% of the base volume

Another interesting question is where the limits of the new supply chain concepts in terms of the handled volume are with adapted infrastructure. In scenario 3 the rail track and storage capacities at the bottlenecks are increased. This leads to an acceptable throughput of 98.2% at the 260% volume scenario, compared to a throughput of 88% in the base scenario and scenario 2. However, the network is still not very effective at 320% of the base volume (93% throughput). The throughput also hardly improves with further increases in rail track and storage capacities. This is due to the fact, that at this

		base-scenario			scenario 1			scenario 2			scenario 3		
m²-volumes	scenario	dismissed m²	through-put (%)	ø train-load (m²)	dismissed m²	through-put (%)	ø train-load (m²)	dismissed m²	through-put (%)	ø train-load (m²)	dismissed m²	through-put (%)	ø train-load (m²)
80%	S1	11	0,998	78,18	6	0,991	173,82	3	0,996	110,32			
90%	S2	68	0,998	89,38	60	0,990	194,88	12	0,996	122,12			
100%	S3	120	0,997	97,63	902	0,982	213,52	33	0,995	136,21			
110%	S4	197	0,997	106,88	3.219	0,969	229,52	74	0,995	146,96			
120%	S5	410	0,996	115,85	10.191	0,928	237,69	117	0,995	159,45			
140%	S6	1.491	0,991	135,23	28.552	0,849	253,47	578	0,993	183,60			
180%	S7	7.542	0,970	169,88	71.979	0,723	276,35	5.636	0,975	231,01			
260%	S8	47.589	0,878	222,42	159.871	0,584	319,81	46.520	0,876	299,45	5.260	0,982	334,39
320%	S9	94.332	0,803	248,87	231.665	0,516	348,69	109.219	0,772	325,73	31.711	0,930	390,33
train concept		single wagon traffic			1 shuttle train			2 shuttle trains			2 shuttle trains		
capacity increase of infastructure		terminal	track	storage	terminal	track	storage	terminal	track	storage	terminal	track	storage
		T1			T1			T1			T1		
		T2			T2			T2			T2	+1	+40%
		T3			T3			T3			T3	+3	+20%
		TSQ1			TSQ1			TSQ1			TSQ1		

		scenario 4			scenario 5			scenario 6			scenario 7		
m²-volumes	scenario	dismissed m²	through-put (%)	ø train-load (m²)	dismissed m²	through-put (%)	ø train-load (m²)	dismissed m²	through-put (%)	ø train-load (m²)	dismissed m²	through-put (%)	ø train-load (m²)
140%	S6				0	0,995	156,09						
180%	S7	473	0,994	237,09	1.907	0,986	197,96						
260%	S8	3.585	0,987	337,09	41.549	0,867	248,57	0	0,995	285,82	0	0,995	285,52
320%	S9	22.018	0,952	399,03	96.720	0,757	265,66	3.317	0,985	346,85	169	0,994	349,19
train concept		2 shuttle trains			2 shuttle trains			2 shuttle trains			2 shuttle trains		
capacity increase of infastructure		terminal	track	storage	terminal	track	storage	terminal	track	storage	terminal	track	storage
		T1			T1			T1			T1		
		T2	+3		T2			T2	+2	+40%	T2	+3	+20%
		T3	+6		T3			T3	+5	+20%	T3	+6	+20%
		TSQ1			TSQ1			TSQ1			TSQ1		
					no truck blocking			no truck blocking			no truck blocking		

Table 2: simulation results

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high volumes trucks are unloading at the terminals very frequently and therefore also block each other more often. So in scenarios 5 to 7 we assume that the terminals are designed in a way that an unloading truck doesn't block the traffic lane. Now with the same parameters as in scenario 3 and a slightly increased rail track capacity, a throughput of 98.5% can be achieved at 320% of the base volume handled by the supply chain network.

The results of the numerical experiments show that the proposed train concept of asynchronous transshipment and shuttle trains connecting terminals and industrial sites instead of single wagon traffic combined with adaptations in the infrastructure at the terminals can increase the network capacity significantly.

The simulation study also indicates that it is important to increase railway track and storage capacities in a way so that they match each other. An enlarged storage doesn't have much of a positive effect if the rail tracks limit the throughput too much and therefore just cause non-productive expenses. On the other side can a storage that is too small not provide the required buffer function in order to maximize the effectiveness of the given railway tracks, hence network capacity is lost.

An interesting finding is that the redesign of terminals in a way so trucks don't block each other while unloading can boost the throughput at terminals with high utilization even with unchanged infrastructure.

ACKNOWLEDGMENTS
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