Roundwood Handling at a Lithuanian Sawmill – Discrete-event Simulation of Sourcing and Delivery Scheduling

MINDAUGAS PUODŽIŪNAS[1]* AND DAG FJELD[2]

[1]*Agricultural University of Lithuania, Faculty of Forestry, Department of Forest Management, Studentų 13, Akademija, Kaunas district, Lithuania; email: pumis@iname.com; tel: (+370) 698 46425*

[2]*Swedish University of Agricultural Sciences, Faculty of Forestry, Division of Forest Technology, 90183 Umea, Sweden*

Puodžiūnas, M. and Fjeld, D. 2008. Roundwood Handling at a Lithuanian Sawmill – Discrete-event Simulation of Sourcing and Delivery Scheduling. *Baltic Forestry*, 14 (2): 163–175.

Abstract

Roundwood receiving and sorting are the first in a long series of operations which require coordination to ensure high capacity utilization for sawmill. Variation in these operations can also cause queuing and reduced capacity utilization for wood transporting companies and delays in measurement and payment for suppliers. Two factors – sourcing and delivery scheduling have potential for reducing variation in roundwood receiving.

The aim of this study is to estimate the effects of roundwood sourcing and delivery scheduling alternatives on roundwood handling at a Lithuanian sawmill. The study was done with discrete-event simulation and focuses on the unloading and sorting operations. The model was built in the ARENA simulation package.

Based on the modelling of present delivery volumes (21,000 m^3/month), better roundwood sorting and handling operations can be achieved by replacing some unfavourable import sources (giving an increase in sorter productivity from 620 to 678 m^3/day) and by improved scheduling of wood arrivals (reduction of extra log handling from 34% to 21% of loads).

Based on the modelling of planned delivery volumes (30,000 m^3/month), replacing unfavourable import sources with domestic supply gave an increase in sorter productivity from 697 to 901 m^3/day. Improved scheduling of truck arrivals reduced the percent of loads requiring extra handling from 49% to 36% with present sourcing and from 38% to 18% with increase in domestic sourcing. In most cases improved scheduling reduced truck waiting time by 50%. Both additional loader capacity, improved sourcing and improved scheduling are necessary to reach the planned production volumes of the future.

Key words: sourcing, delivery scheduling, discrete-event, queuing time, intermediate storage, sorter production.

Introduction

Roundwood receiving and sorting are the first in a long series of operations which require coordination to ensure high capacity utilization for sawmill. Variation in these operations can also cause queuing and reduced capacity utilization for wood transporting companies and delays in measurement and payment for suppliers. Two factors – sourcing and delivery scheduling have potential for reducing variation in roundwood receiving. The more even the flow of raw material provided in deliveries, the lower the extra capacity required for serving arriving roundwood as well as sorting line elements such as feeder and bins. A more even flow of wood also enables reductions in storage, extra unloading and re-loading and as well as downtime compensation for queuing for transport companies.

A mill's wood supply structure typically includes a number of different sources such as harvesting in own forests, purchased volumes from private and state forests as well as supplemental volumes imported from other countries. Typically, the possibility to influence wood flow rates is the highest for own operations. Each of the other sources may have their own peculiarities with respect to variation and delivery precision. For example, some larger sources may follow delivery agreements on an annual basis, whereas, more detail planning *e.g.*, monthly is very difficult to achieve. Private forest owners may possess relatively small areas (on average only 4.5 ha in Lithuania). This means that getting significant roundwood volumes from this source requires cooperation with a large number of forest owners, which in turn complicates the planning of deliveries considerably. In general, imports from sources with economies in transition are often characterized by instability due to frequent policy revisions. In this case, deliveries from harvesting in own forests are even more important in order to be able to counteract short-term delivery disturbances from less stable sources of the supply structure.

The factor which has the direct daily influence on roundwood handling operations at sawmill is delivery scheduling. The possibility to arrange suitable delivery schedules varies between transport systems. Truck deliveries from geographically close sources are often subject to few constraints and can be more flexible in their scheduling. Rail deliveries from remote sources, however, are subject to numerous constraints and therefore have limited possibilities to adjusting to compensate short-term demands. Regardless of transport method, an even scheduling of deliveries increases the chance of being able to unload wood directly from the carrier to the sorting line, thereby saving the extra handling costs of placing them in a separate area for unsorted storage.

Simulation methods

A number of simulation approaches can be used to estimate the effects of potential improvements on systems efficiency. Fowler (1999) suggests the use of continuous state simulation for highly aggregated state variables, while simulation of production and operations management is normally solved with the discrete-event approach. While the state of a continuous model changes continuously over time, the state in a discrete-event model changes at discrete points in time which correspond to specific events, for example the arrival of trucks at a mill. This has the implication that state changes in the model are driven by events (Cassandras 1993). Discrete-event simulation involves modelling a system as it progresses through time and is particularly useful for analyzing queuing systems. Such systems are common in the manufacturing environment and are obvious as work in progress, buffer stocks, and warehouse parts. A major strength of discrete-event simulation is its ability to model random events and to predict the effects of the complex interactions between these events (TWI Knowledge Summary 2004). Law and Kelton (1991) states that models built with this technique are easier to develop, modify and less prone to errors when compared to those developed in general purpose language. The use of a discrete-event simulation language facilitates the development of such models since many features required for mimicking the behaviour of real systems are incorporated into the language. The drawing of inferences from simulation is usually left to the user's capabilities or may be aided by an expert system where simulation is part of a larger system (Lal *et al.* 1991, 1992).

Logistics and transport

One approach to discrete-event simulation is object-oriented programming, which started in the 1980's. Arnas (2003) made a review of the use of object-oriented methods (OOM) in logistics and transportation research including transportation, manufacturing, automation, public transport, and warehousing. As a large advantage of OOM, Arnas (2003) sees visual elements. Visualisation is important in object-orientation, and is also its largest contribution. Finally, he concludes that there is a preference using object-orientation as a design tool for transportation and manufacturing systems, rather than as an analysis tool. Paolucci and Pesenti (1999) used an object-oriented approach to discrete-event simulation applied in underground railway systems for creating new time tables. Ottjes *et al.* (2006) used an object-oriented approach to constructing port container terminals in order to ascertain the resources required for efficient terminal operations. Together with Duinkerken (Ottjes and Duinkerken 1996) they constructed Tool for Object-Oriented Modelling and Simulation (TOMAS) for discrete-event simulation focused on complex control of problems in logistics and production environments.

Agriculture and forestry

De Toro (2004) used discrete-event simulation (ARENA software) for assessment of field machinery performance in variable weather conditions. Daily field operations were simulated during a series of years including the effects of daily weather on available workdays and operation sequences on individual field treatment (de Toro and Hansson 2004a). De Toro (2004) concludes that although simulation doesn't provide solutions to all problems, as it mainly detects the state of a system over time within given assumptions, the simulation model of field machinery operations developed using discrete-event simulation technique successfully enabled the estimation of timeliness costs and their annual variability over the long term.

Simulation has become a tool which can also be used in the forest sector to better understand how a system such as a company or a production line performs. Anderson and Peter (2001) and Holmstrom (unpubl. 2004) used discrete-even simulation (ARENA) for simulating log transportation networks in Canada and Sweden, respectively. Asikainen (1995, 2001) used discrete-event simulation (WITNESS) for modelling of mechanized wood harvesting systems and for studying different vessel transport systems carrying wood from islands. He concludes that discrete-event simulation is suitable for analyzing such systems because the dynamic passing of time can be modelled and systems under study can be described with high accuracy. Also random processes that affect the machine and system performance can be considered. Weintraub *et al*. (1996) carried studies on truck scheduling. The study attempted to coordinate deliveries of different products to meet demand at different mill locations and optimize truck arrivals at the mills to avoid excessive delays at the receiving mill. Barrett (2001) developed computer simulation model to represent a logging contractor's harvesting and trucking system of wood delivery from the contractor's in-woods landing to the receiving mill.

Sawmilling

Simulation models developed for analyzing sawmills include those by Adams (1984, 1988), Aune (1974), Hall and Jewett (1988), Kempthorne (1978), Pennick (1969), Wagner and Taylor (1983), and Wagner *et al.* (1989). Those models were developed using both general-purpose programming languages and special-purpose simulation languages. The general-purpose languages such as BASIC, FORTRAN and C are designed to solve a broad class of problems, not just simulations (Shannon 1975, Harrell *et al.* 1995). The special-purpose simulation languages, however, are designed to solve a particular class or type of problem and have built-in capabilities that make them easier to use than general-purpose languages when developing simulation models (Shannon 1975). Examples of special-purpose simulation languages are SLAM, SIMAN, and GPSS (Pritsker 1986, Stahl 1990, Pegden *et al.* 1995). Asikainen (1995) argues that models built with these programming languages have been proved to be complex and slow. However, recent developments in programming technique and visual interactive programming have diminished the programming effort considerably. A number of discrete-event studies have been made on the log-sawing and kilning processes (Randhawa *et al*., 1994, Dogan *et al*., 1997, Baesler *et al*., 2004, Rappold 2006). Myers and Richards (2003) used discrete event simulation for supporting wood supply chain decisions for a mill. These models were designed to improve timber-volume yield or timber-grade yield from sawlogs where final decisions are made by sawmill managers. Korpilahti's (1987) study is one of the few simulation studies of a sawmill's green yard that analyzes the handling of materials from different sources. The review of log sort yards in North America was carried out by Dramm *et al.* (2002) The study indicates that roundwood receiving in the sawmill plays an important role for log sorting operations, for capacity utilization of machinery and, consequently, for better use of the available timber resources. McNeel (1991) used simulation for sortyard operations for improved productivity and cost. LeBel and Carruth (1997) developed a simulation model for wood yard inventory variations.

Previous studies by Puodziunas and Fjeld (2002) on delivery precision in Lithuanian state forest enterprises demonstrated a rather weak connection between sawmill demand and roundwood supply. This encourages further research on the improvement potential of new sourcing scenarios for sawmills. Puodziunas *et al.* (2004) examined the potential for improved truck transport planning. This study showed increasing pressure on road transport through weight limitations, rising fuel prices and salaries and shortage of drivers and encourages research to further improve capacity utilization. Because improved scheduling of truck deliveries to sawmills influences both truck capacity utilization and wood handling operations this is another aspect also worthy of further research.

Aim

The aim of this study is to estimate the effects of roundwood sourcing and delivery scheduling alternatives on roundwood handling at a Lithuanian sawmill.

The study will be done with discrete-event simulation and focuses on the unloading and sorting operations. Later steps such as handling after sorting and sawing are not included in the study. Key output variables include the proportion of volumes requiring intermediate storage before sorting and the utilization of sorter capacity.

Materials and methods

In this study, we simulated the Stora Enso Timber Alytus Sawmill in Lithuania. Two primary scenarios were investigated: one for present consumption volumes (21,000 m^3/month) and one for planned consumption volumes (30,000 m^3/month). The mill has a sorting line with a calculated capacity of 1,500 m^3/day. It is assumed that the mill will be in operation 7 days per week and 3 shifts per day. The yard has capacity for intermediate storage of 20,000 m^3 before sorting and 35,000 m^3 after sorting. The goals for storage levels are 0 unsorted m^3 and 10,000 sorted m^3.

Norway spruce and Scots pine logs are procured from domestic sources (state forest (SP- state pine, SS - state spruce) – 52%, private forests (PP - private pine, PS – private spruce) – 8% and own forests (OP - own logging pine, OS - own logging spruce) – 5%). Supplemental pine logs are procured from import (Belarus (BP – Byelorussian pine) – 21%, Ukraine (UP - Ukraine pine) – 7%, Poland (POLP - Polish pine) – 4% and Russia (RP - Russian pine) – 3%). These are sorted into 30 bins for two species, 5 diameter classes (11.9-

24.9 cm) and 3 length classes (2.5-6 m). Daily sorting The mill yard receives roundwood logs 6 days per week from Monday to Saturday by both truck (domestic) and rail (domestic and import). Approximately 60% of the roundwood volume arrives by trucks and 40% by rail. The number of sorting reports (loads) for studied period accounted 663. The trucks have an average load size of 25 m^3 and the rail wagons have an average load size of 50 m^3. Correspondingly, the number of loads arrived by trucks accounted 487 and by wagons – 176. The entity of railway delivery is considered to be one wagon. The length of the mill's rail spur allows 15 wagons. Log handling is accomplished with two front end loaders (lifting capacity of approx. 5 m^3).

Modelling presents delivery volumes with version 1

A discrete-event model of the roundwood handling at Alytus Sawmill was built in the ARENA simulation package (described in Kelton *et al*. 1998). Two versions were developed. The first version was developed for testing sourcing and scheduling alternatives under present delivery volumes (21,000 m^3/month). It was later developed to the second version where sourcing and scheduling alternatives could be tested under both present and future delivery volumes (30,000 m^3/month). Because of the planned volume increase in the future, version 2 also has a possibility to increase loader capacity.

The basic structure of the both ARENA models is quite simple. Version 1 is shown in Figure 1. Loads are modelled as entities which are generated by arrive modules. There are 10 different arrival modules supplying wood to sawmill. These include the 6 domestic sources for spruce and pine (state forest pine and spruce, private forest pine and spruce, own logging pine and spruce) and the 4 import sources for pine (Polish pine, Byelorussian pine, Ukraine pine, Russian pine). Each source module has specific distributions of length, diameter, and time consumptions for sorting and reject frequencies. The arrival frequency per source is also specified per week day and 6 hour period (0-6, 6-12, 12-18, 18-24).

Depending on the quantity waiting to be sorted, the arriving loads either are unloaded directly to the sorting line (server module in the ARENA model) or unloaded to an intermediate storage of unsorted volumes on the ground. Unsorted loads are then moved from the intermediate storage to the sorting line when there is space on the sorter queue.

The model was calibrated primarily by comparing the ratio between modeled production and the actual

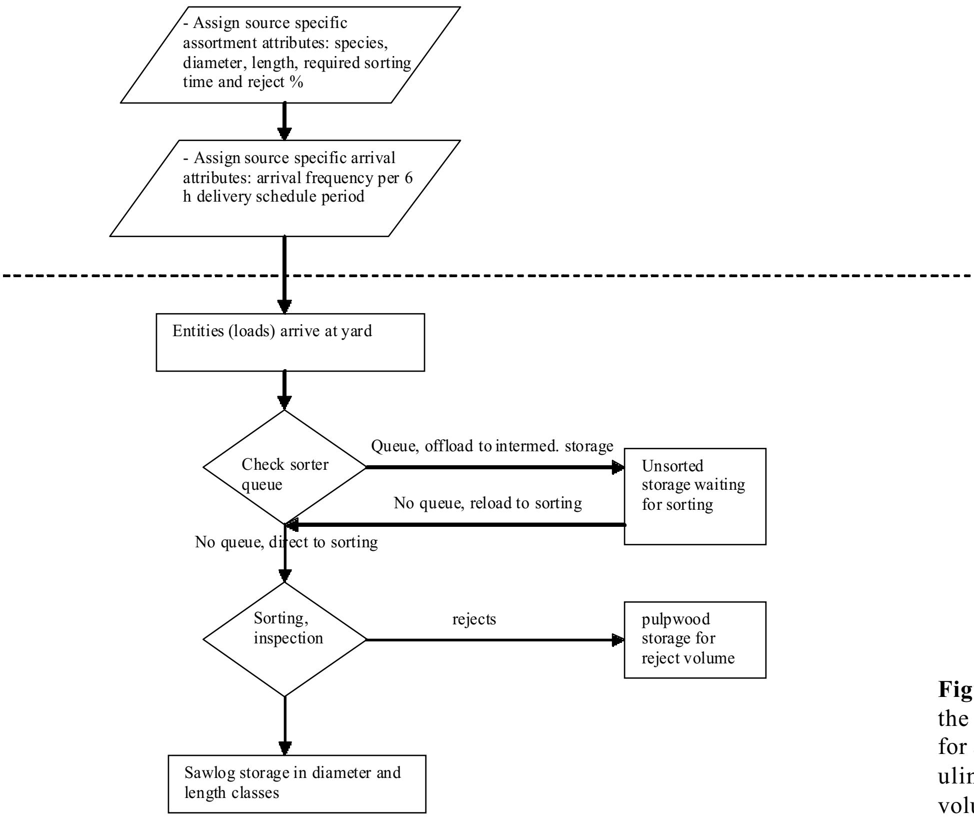

Figure 1. A simplified outline of the simulation model (version 1) for analysis of sourcing and scheduling effects at present delivery volumes

sorter production for September of 2004. The maximum capacity utilization available (%) for the sorter module was then adjusted until a one-to-one ratio was gained between modeled and actual production. The dynamics of the animated system was also observed visually and some adjustments were made to loading and unloading times as well as the limit maximum number of loads allowed in the sorter queue before intermediate storage. The typical time required for a simulation was 4.5 minutes.

Sourcing and scheduling alternatives for version 1

The first study involved running different sourcing and scheduling scenarios (Table 1) with present delivery volumes in order to compare their potential effects on sorter production and intermediate storage before sorting. There were two alternatives to the present supply structure. The first was a 100 percent

Table 1. The sourcing and truck scheduling alternatives modelled with version 1 for present delivery volumes

Monthly delivery volume (1000 m^3)	Sourcing alternative	Truck scheduling alternative (% arrivals per 6 h period)	
		1. present (2/24/56/17)	2. improved (25/25/25/25)
21	A. Present	**21A1**	**21A2**
	B. Reduced import (BP, RP) Increased domestic (SP)	**21B1**	**21B2**
	C. Reduced import (BP, RP) Increased import (UP)	**21C1**	**21C2**

reduction of import volumes of Byelorussian and Russian pine and a corresponding increase in domestic pine. The second alternative was a 100 percent reduction of import volumes of Byelorussian and Russian pine and a corresponding increase in pine import from the Ukraine. There was only one truck scheduling alternative to the present schedule. This was an even distribution of truck loads for each of the 4 arrival periods.

Modelling present and future delivery volumes with version 2

After the testing of sourcing and scheduling alternatives on version 1 of the model, the model was further developed to include future volumes (30,000 m^3/month) and increased loader handling capacity (2 loaders). The main difference in the model itself was the greater detail added to model loader handling. For utilizing two loaders control logic for priority use of loader capacity had to be developed. An extra queue was added to simulate loaded trucks waiting for unloading. Loads could then be offloaded from the truck queue to an intermediate storage of unsorted loads, first in case of a sorter queue (as with version 1) but also in case of a long truck queue (new for version 2, see Figure 2). So depending on the status of both truck and sorter queues, the loader capacity could be seized

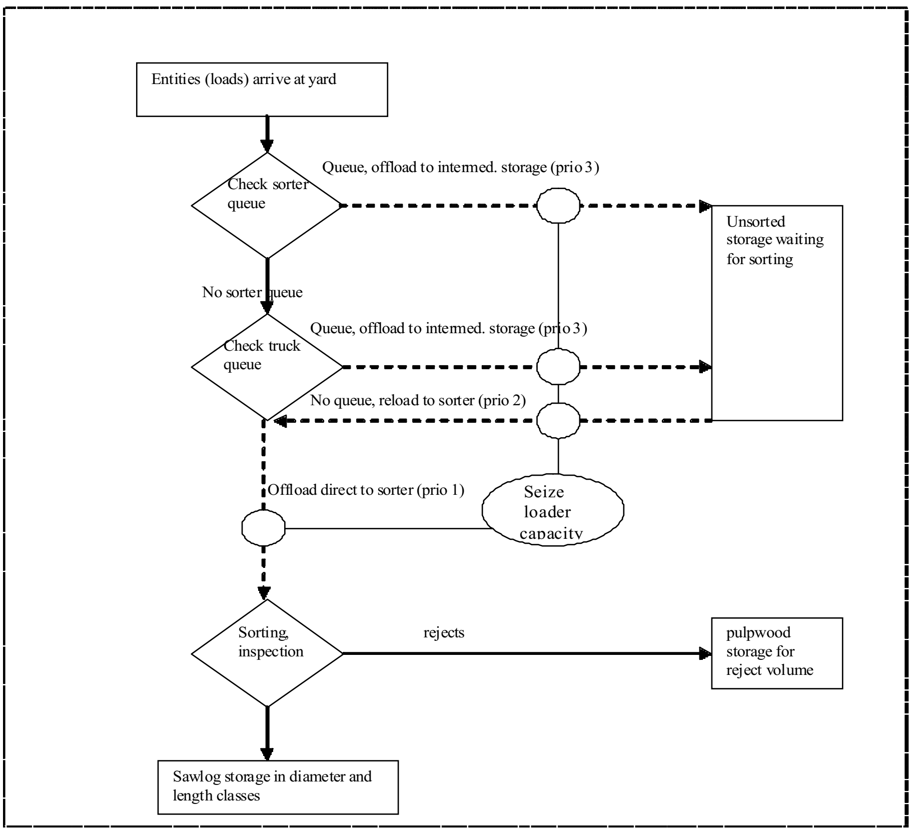

Figure 2. A simplified outline of the simulation model (version 2) for analysis of sourcing and scheduling effects at present and future volumes with increased loader handling capacity (2 loaders where prio = loader allocation priority)

for either direct unloading from arriving trucks to the sorter (capacity priority 1), reloading of the sorter from the unsorted storage (capacity priority 2) or unloading from arriving trucks to the unsorted storage (capacity priority 3).

For version 2, the maximum proportion of capacity utilization available (from the calibration of version 1 to historical production data) was reset at 100%.

Sourcing and scheduling alternatives for version 2

The second study involved running different sourcing and scheduling alternatives to compare their effects on key output variables with both present and future volumes (Table 2). In this case however, there was only one alternative to the present supply structure. This involved a 100 percent reduction of imported volumes of Byelorussian and Russian pine and a corresponding increase in domestic pine (the same as used with version 1). There was also only one truck scheduling alternative to the present schedule. This was an even distribution of truck loads for each of the 4 arrival periods (also the same as used in version 1).

Table 2. The sourcing and truck scheduling alternatives modelled with version 2 for present and future volumes

Monthly delivery volume ($1000\ m^3$)	Sourcing alternative	Truck scheduling alternative (% arrivals per 6 h period) 1. present (2/24/56/17)	2. improved (25/25/25/25)
21	A. Present	**21A1**	**21A2**
	B. Reduced import (BP, RP) Increased domestic (SP)	**21B1**	**21B2**
30	A. Present	**30A1**	**30A2**
	B. Reduced import (BP, RP) Increased domestic (SP)	**30B1**	**30B2**

Results

Daily sorting statistics collected during September 2004 is the basis for the sorter production model used in the discrete-event modelling of the Alytus Sawmill. For this reason a more detailed analysis was conducted of the underlying factors influencing the production volumes of logs approved for sawing. The results of this are shown below.

The distribution of average log diameter per source is shown in Table 3. Results show that for 9 of 10 different sources average log diameter varies within a range of 4th diameter class (150-199 mm).

The arrival times for the loads were divided into four different time intervals: from 0 to 6 hours, 6-12, 12-18 and 18-24. The distribution of the arrivals for each source is shown in Figure 3.

Truck arrivals scheduling clearly varies between supply sources. Most of the wood from the state forest enterprises arrives during the 3rd time interval (12-18). This is a result of the official working hours in the state enterprises. Arrivals from private sector are also most frequent during the 3rd time interval but with a slightly more even distribution over the other intervals. The most flexible delivery scheduling appears to come from Stora Enso's own harvesting operations (OP and OS). Most of this wood arrives during the 4th interval (18 to 24) when the possibility for unloading delays is lowest. Although they were not included in the mapping above, railway deliveries were most frequent during 2nd interval (6-12) - 60% of arrivals and 3rd interval (12-18) – 40% of arrivals.

A plot of the reject percent of each load against its average log diameter is shown in Figure 4. The figure shows that loads with average diameters less than 13 cm have a sharply increasing reject frequency.

A plot of the average reject percent per source and its respective average log size (pieces per m^3) and reject percent also shows an interesting trend (Figure 5). Figure 5 shows two potentially different groups of wood sources. One line can be used to connect all domestic sources (SP, SS, PP, PS, OP, OS) as well as Polish pine (POLP) and Ukraine pine (UA). For this line the reject percent varies from 6 to 10% for log sizes from 10 to 14 pieces per m^3. Another line can be used to connect sources of Russian pine (RP) and Byelorussian pine (BP), which differ from the first group due to the higher reject percents – 18% and 56%, respectively for the corresponding log sizes of 11 and 19 pieces per m^3.

A linear regression analysis of each load's sorting time per cubic meter (of inspected and approved sawlogs) as a function of the average log size and reject percent could explain 82% of the variation in time consumption (minutes per m^3).

$$\text{Sorting time } (min/m^3) = 0.034907\ (pieces/m^3) + 0.0023547\ (pieces/m^3 \times \text{reject } \%) - 0.0061$$

N=127 loads $R^2 = 82\%$ ($P_{pieces/m3} = 0.001$) ($P_{pieces/m3 \times reject \%} = 0.000$) ($P_{intercept} = 0.961$) $P_{regression} = 0.0001$

Table 3. The average diameter of logs approved for sawing per source including min and max values and standard deviation

Origin	SP	SS	PP	PS	OP	OS	RP	POLP	UP	BP
Average diameter,mm	171,0	167,2	159,9	159,0	160,1	163,9	166,0	162,8	164,8	107,5
Min diameter, mm	126,6	129,3	132,3	123,3	124,9	137,3	127,7	138,3	153,3	94,8
Max diameter, mm	226,5	233,1	185,8	203,0	200,7	188,8	185,8	206,3	190,4	123,0
Standard deviation	21,2	19,6	12,8	16,2	23,1	14,1	20,5	21,1	8,1	5,2

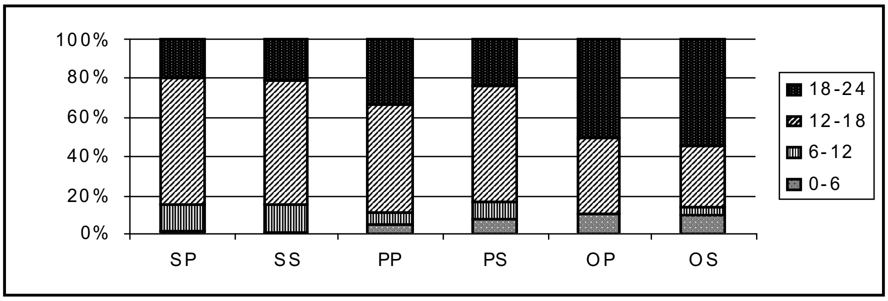

Figure 3. The distribution of truck arrivals (% of loads on y-axis) over the four delivery intervals

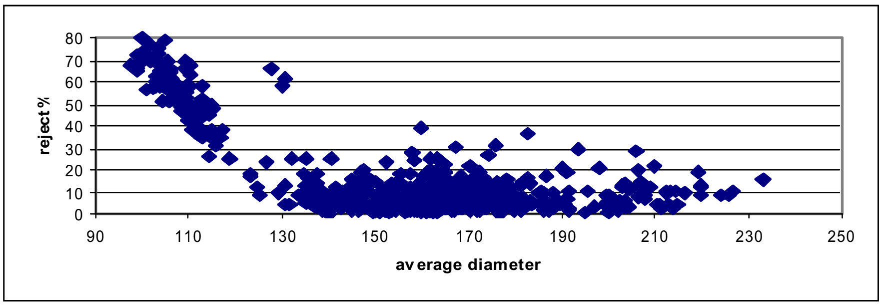

Figure 4. The relationship between the rejected percent of the sorted loads and its average log diameter

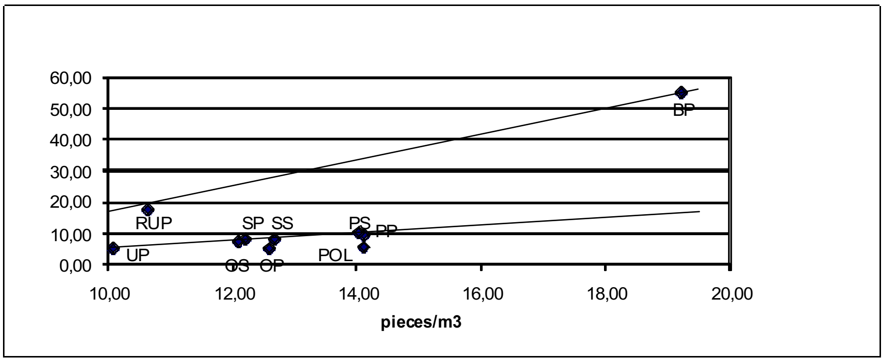

Figure 5. A plot of the average reject percent per source and their respective log volumes

Modelling sourcing and scheduling alternatives for present volumes with version 1

After calibration with the present sourcing and arrival schedule the alternatives in Table 1 were tested. Both improved sourcing and scheduling reduced the amount of intermediate storage required before sorting (Figure 6).

Improved sourcing reduced the proportion of loads requiring intermediate storage from 34% for present conditions (21A1) to 22% for increased domestic sourcing (21B1) and 15% for improved import sourcing (21C1). Scheduling improvements with present sourcing (21A2) gave a reduction from 34% to 21%. Scheduling improvements with increased domestic sourcing (21B2) gave a reduction from 22 to 5%. Scheduling improvements with improved import sourcing (21C2) gave a reduction from 15 to 5%.

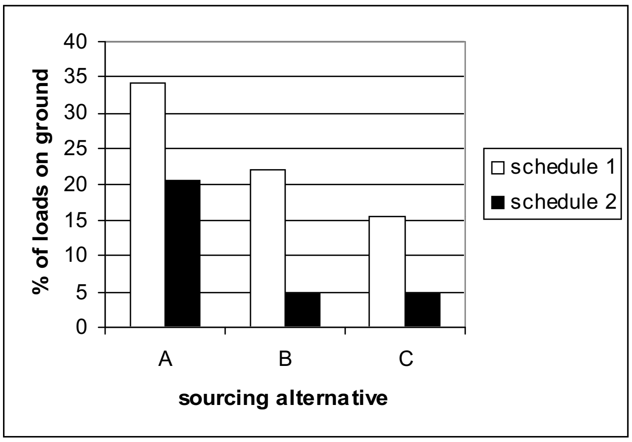

Figure 6. The percent of loads requiring intermediate storage before sorting for sourcing alternatives and scheduling alternatives. Modelling present volumes with version 1

Sorter production was influenced primarily by sourcing alternatives (Figure 7).

Improved sourcing increased the daily sorter production from 620 m^3/day with present sourcing (21A1) to 678 m^3/day with increased domestic sourcing (21B1) and to 680 m^3/day with improved import sourcing (21C1). Improved scheduling (21A2, 21B2 and 21C2) had marginal effects on sorter production.

The proportion of volume rejected after inspection was reduced from approx. 16% with the present sourcing (21A1), to 9% with increased domestic sourcing (21B1) to 8% with improved import sourcing (21C1).

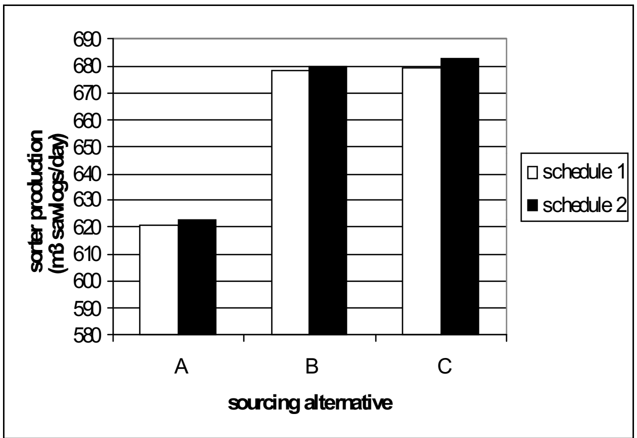

Figure 7. The average values of sorter production (m^3/day of approved sawlogs) with sourcing alternatives and scheduling alternatives 1 and 2. Modelling present volumes with version 1

Modelling sourcing and scheduling alternatives on present and future volumes with version 2

For version 2 both present and future volumes were modelled with a more detailed handling of loader capacity allocation. The present delivery volumes (21,000 m^3/month) were modelled with one loader. The future delivery volumes (30,000 m^3/month) were modelled with 2 loaders.

As was the case for version 1, modelling with version 2 also showed clear effects of sourcing and scheduling alternatives on the proportion of loads requiring intermediate storage before sorting (Figure 8).

Figure 8 shows that the percent of loads requiring intermediate storage before sorting is higher for future volumes than present volumes, even with the increase in loader capacity. For future volumes an increase in domestic sourcing reduces the proportion of loads requiring intermediate storage from 49% (30A1) to 38% (30B1). Improved scheduling of truck arrivals also reduces this proportion from 49% (30A1) to 35% (30A2) for unchanged sourcing and from 38% (30B1) to 18% (30B2) for increased domestic sourcing. For present volumes, improved scheduling reduces the proportion of intermediate storage for unchanged sourcing from 28% (21A1) to 12% (21A2) and for increased domestic sourcing from 28% (21B1) to 0% (21B2).

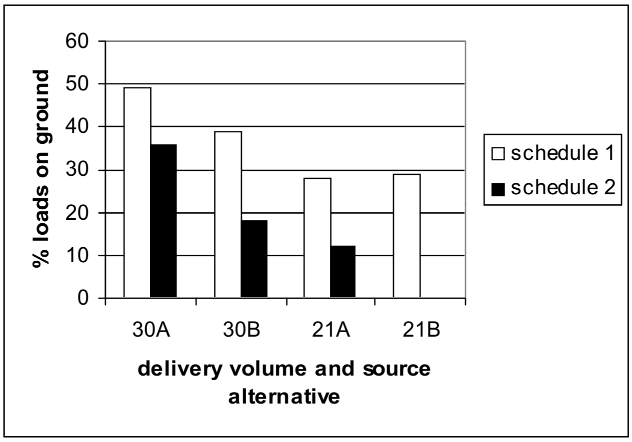

Figure 8. The percent of loads requiring intermediate storage before sorting for sourcing alternatives and scheduling alternatives 1 and 2. Modelling present (with 1 loader) and future volumes (with 2 loaders) with version 2

As was the case for the previous version, modelling with version 2 also showed clear effects of sourcing on sorter production (Figure 9). Scheduling improvements in version 2 had no effect with present volumes but did have an observable effect for future volumes.

Figure 9 shows that sorter production is higher for future delivery volumes than present volumes. However, an important note is that the only acceptable level of production is with increased domestic

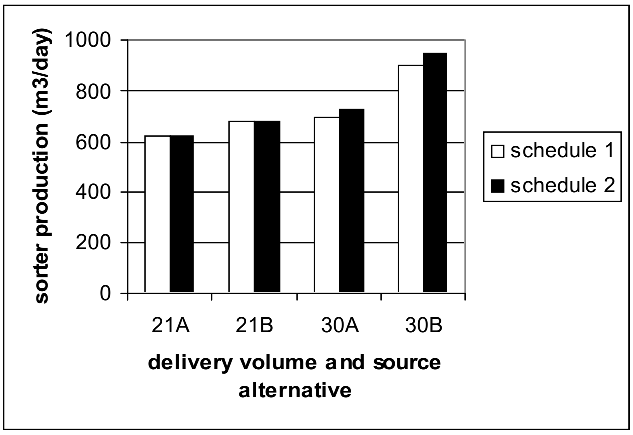

Figure 9. The daily sorter production (m^3/day of approved sawlogs) for sourcing alternatives and scheduling alternatives 1 and 2. Modelling present and future volumes with version 2

sourcing (901 m^3/day for 30B1). The daily level of sorter production with the present supply structure (697 m^3/day for 30A1) falls well short of handling the required monthly volume of 30,000 m^3, even with the increase in loader capacity. The potential for improvement through improved scheduling was noticeable for future volumes with an increase from 697 (30A1) to 725 m^3/day (30A2) for the present supply structure and an increase from 901 (30B1) to 949 m^3/day (30B2) for increased domestic sourcing.

Version 2 allowed a more detailed examination of queuing and capacity utilization. The following table (Table 4) shows both truck and storage queues as well as the capacity utilization for loaders and sorters for all the sourcing and scheduling alternatives.

Table 4 shows that capacity utilization for the sorter is 52-65% with present volumes (1 loader) and 70-75% with future volumes (2 loaders). At the same time capacity utilization for the loaders drops from 62-76% with present volumes (1 loader) to 47-50% with future volumes (2 loaders). The table also shows that running 2 loaders at present volumes (21A1) reduces the average truck queue time from 80 to 3 minutes, reduces the average intermediate storage from 18.5 to 16.8 loads but does not increase sorter production noticeably. At the same time running only 1 loader at future volumes (30A1) increases the average truck queue time from 6 to 133 minutes, increases the average intermediate storage from 164 to 240 loads and reduces sorter production from 697 to 445 m^3 per day. minutes while improved scheduling can reduce this to 2 minutes.

Discussion

Time consumption for sorting

The initial analysis of sorting data indicated that loads with average diameters less than 13 cm have a sharply increased reject frequency (Figure 5). This is logical given that the minimum top diameter for sawlogs is 11.9 cm. The particularly high proportion of rejects for Byelorussian pine (BP) and Russian pine (RP) are partially a result of the sourcing policy; these volumes are actually purchased as pulp logs in the hope of being able to sort out additional sawlogs to a low price. The regression model for sorter productivity, however, shows that both the number of logs per m^3 and reject percent are positively correlated with time consumption per unit volume for sorting. Within the typical range of log sizes (10-15 logs/m^3) and reject percent (5-20%) a change in either variable influences the daily volumes of approved sawlogs. Small log sizes require a higher number of pieces to pass the conveyor in order to get one solid cubic meter sorted, and in the case of sorting pulpwood the reject percent is even higher than for sawlogs. This combination severely limited sorter output and should be avoided in order to achieve a supply structure with a more streamlined wood flow.

Table 4. Queues and capacity utilization for all sourcing and scheduling alternatives while modeling present and future delivery volumes with version 2

	21A1		21A2	21B1	21B2	30A1		30A2	30B1	30B2
Loaders	1	**2**	1	1	1	2	**1**	2	2	2
Avg. truck queue (no and waiting time in min.)	1.56 /80	**0.06 /3**	0.88 /45	1.79 /91	0.47 /24	0.18 / 6	**3.72 /133**	0.09 /3	0.29 /10	0.07 /2
Avg. intermed. storage (no. unsorted loads)	18.45	**16,78**	12.4	11.3	5.77	164.23	**240**	141	71.5	30.7
Loader busy (% of time)	75	**39**	67	76	62	50	**81**	47	50	49
Sorter busy (% of time)	65	**66**	65	52	53	73	**49**	75	70	73
Sorter production (m^3/day)	625	**630**	623	680	685	697	**445**	725	901	949

For all alternatives of present volumes (with 1 loader) the average truck queue is considerably larger than for the future volumes (with 2 loaders). Regardless, almost all cases of improved scheduling reduce the average truck queue time by at least 50%. In the case of the improved import sourcing with an acceptable sorter production for future volumes (30 B) the present scheduling has an average queuing time of 10

Modelling sourcing alternatives

With a technical sawing capacity of 1,200 m^3 per day, sorter production is a clear bottleneck for mill production. Modelling present volumes with version 1 included 3 sourcing alternatives. The effect on sorter production was equal (Figure 7) for both increased domestic sourcing (21B) and improved import sourcing (21C). Only sourcing alternatives A (unchanged) and B (increased domestic sourcing) were kept for modelling future volumes. When modelling increased volumes with version 2 it is important to note that while increased deliveries alone (30A) did increase sorter production it was the increased domestic sourcing (30B) which enabled the sorter production to reach over 900 m^3 per day (Figure 9). Helstad's (2006) study on managing supply uncertainties in sawlogs procurement indicate that sawmills cannot apply a single or dual sourcing strategy as they are dependent on multiple suppliers. This was also the case for our studied sawmill where we had identified at least four sources of wood supply – state, private, import and own logging. Although not a variable taken into consideration in this study, the development of prices and delivery risks for imported wood also motivate increased domestic sourcing.

Modelling present volumes with version 1 showed a clear reduction of intermediate storage of unsorted volumes with improved sourcing (Figure 6). Version 2 had a more complete logic for log handling and the increased domestic volumes for improved sourcing, (delivered primarily by truck) resulted in reduced intermediate storage but slightly increased truck queue times (Table 4). Because the capacity utilization for the loaders was almost the same for both unchanged and increased domestic sourcing, the reduced storage and increased queuing is a logical result of the priority for capacity allocation (Figure 2) where first priority is given to direct loading to the sorter.

Modelling scheduling alternatives

For both modelling present volumes in version 1 and future volumes in version 2, the effects of improved scheduling were greater for intermediate storage than for sorter production. This issue is acute for sawmill as every extra movement of the roundwood adds an additional cost of approx. 1 EUR per m^3. Replacing the present arrival schedule for trucks (21A1 with 2/24/56/17 % arrivals per 6h period) with an improved schedule (21A2 with 25/25/25/25 % per 6h period) gave major reductions in all cases (21A in Figure 6 and 31A in Figure 8). The reduction was even larger for improved sourcing (21B in Figure 6 and 31B in Figure 8). This is logical given that scenario B is based on increased domestic sourcing, which means an increased proportion of loads arriving by truck and a greater number of loads influenced by the transition. This helps to explain the finding that it is first for future volumes and increased domestic sourcing that scheduling begins to have an effect on sorter production (Figure 9).

Loader handling capacity

Discussions with sawmill and wood supply personnel identified the shortage of unloading machinery as one of the possible reasons why the sorting line could be a bottleneck for sawmill production. This was the reason why version 2 of the model allowed varying loader handling capacity. The modelled increase from 1 to 2 loaders for present volumes (21A) showed a major reduction in truck queuing time (from 80 min to 3 min), however, only a minor effect on intermediate storage volumes and sorter production (Table 4). This is because the capacity allocation logic prioritizes sorter production first. Continuing with only 1 loader for future volumes (30A1), however, would not only increase queuing times to unacceptable levels but also sink sorter production to levels lower than with present volumes (Table 4).

The model made it possible to measure the effect of both sourcing and scheduling alternatives on truck waiting times (Table 4). While increased domestic sourcing resulted often in increased queuing times, improved scheduling always resulted in a major reduction of queuing times, particularly in combination with increased domestic sourcing. The scheduling of truck arrivals has also been found to be an effective way to reduce queuing times in previous studies (Korpilahti 1987, Vaatainen *et al.* 2005). An analysis by Puodziunas *et al.* (2004) on improving tactical planning of roundwood transport in Lithuanian demonstrated a potential to reduce transport costs by 14% due to backhauling. Even though the completely even distribution of arrivals (25/25/25/25 % per 6 h period) modelled in the current study is unrealistic, the results of this study show that truck queuing times can be a hinder to this development. Keeping in mind that a timber truck usually only has one driver, this limits truck working hours to one shift (480 min) and an average queuing time of 80 min (under planned delivery conditions 30A1) constitutes 17% of the total working hours. The current situation is that trucks are being forced to spend time queuing at a sorting line instead of making the next delivery. This has resulted in the wood supply unit receiving petitions from transport companies indicating dissatisfaction due to downtimes at sawmills up to 6-8 hours with resulting discontinuance of services. While compensation costs for truck downtimes were not included in this study, another negative effect of the excessive queuing seen in some scenarios are the disturbances they represent for transport planning. These disturbances both decrease the productive driving time available and prevent the realization of the potential savings possible through better planning.

Conclusions

Discrete-event simulation in ARENA was a suitable experimental method for modelling roundwood handling at the studied sawmill. The visualization of material flow made it much easier to check the dynamics of the model during the building phase. This was especially important for checking the control logic for steering series of queues and balancing handling capacity. During the building and calibration we judged that the model built mimicked the work realistically from the arrivals of raw material from different supply sources to the unloading and sorting operations. This method enabled the identification of the critical factors for wood handling and sorting operations through the simulation of alternative scenarios. Based on the analysis the following conclusions can be drawn:

1.Based on the modelling of present delivery volumes (21,000 m^3/month) in version 1, better roundwood sorting and handling operations can be achieved by replacing some unfavourable import sources (giving an increase of sorter productivity from 620 to 678 m^3/day) and by improved scheduling of wood arrivals (reduction of extra log handling from 34% to 21%).

2. Based on the modelling of planned delivery volumes (30,000 m^3/month) in version 2, additional loader capacity is required. Replacing unfavourable import sources with domestic supply gave an increase in sorter productivity from 697 to 901 m^3/day. Improved scheduling of truck arrivals reduced the percent of loads requiring extra handling from 49% to 36% with present sourcing and from 38% to 18% with increase in domestic sourcing. In most cases improved scheduling reduced truck waiting time by 50%. Both additional loader capacity, improved sourcing and improved scheduling are necessary to reach the planned production volumes of the future.

Acknowledgements

We would like to thank the managers of studied Stora Enso Alytus sawmill for a possibility to collect relevant data for this study. We also appreciate a financial support from the Royal Swedish Academy of Agriculture and Forestry.

References

Adams, E. L. 1984. DESIM: A system for designing and simulating hardwood sawmill systems Gen. Tech. Rep. NE-89. Broomall, PA: U. S. Department of Agriculture, Forest Service, Northeastern Forest Experimental Station, 71 p.

Adams, E.L. 1988. Testing DESIM for designing and simulating the operations of hardwood mills. *Forest Prod. J.,* 38(7/8): 41-45.

Anderson, A. and Peter, B. 2001. Log transportation network simulation using Arena. (unpublished).

Arnas, P.O. 2003. The uses of object-oriented methods in logistics and transportation research. Lic. En. (unpublished).

Asikainen, A. 1995. Discrete-event simulation of mechanized wood-harvesting systems. DSc thesis, Faculty of Forestry, University of Joensuu, Research Notes 38, 86 p.

Asikainen, A. 2001. Simulation of logging and barge transport of wood from forests on islands. *International Journal of Forest Engineering* 12(2): 110-128.

Aune, P.A. 1974. System simulation—A technique for sawmill productivity analysis and designs. *Forestry Chronicle,* 50(2): 66-69.

Baesler, F.F., Araya, E., Ramis, F.J. and Sepulveda, J.A. 2004. The use of simulation and design of experiments for productivity improvement in the sawmill industry. Dept. of Ind. Eng., Bio-Bio Univ., Concepcion, Chile, Vol. 2, p. 1218- 1221.

Cassandras, C.G. 1993. Discrete-event systems: modelling and performance analysis. Aksen Associates-Irvin, Boston, USA, 790 p.

de Toro, A. 2004. Assesment of field machinery performance in variable weather conditions using discrete-event simulation. Doctoral Thesis, SLU, Uppsala.

de Toro, A. and Hansson, P.-A. 2004a. Analysis of field machinery performance based on daily soil workability status using discrete-event simulation or on average workday probability. *Agricultural systems,* 79: 109-129.

Dogan, C.A., McClain, T.F. and Wicklund S.A. 1997. Simulation modelling and analysis of a hardwood sawmill. *Simulation Practice and Theory,* Vol. 5/5: 387-403.

Fowler, A. 1999. Feedback and feedforward as systematic frameworks for operations control. *Internatonal Journal of Operations & Production Management*, Vol.19/No. 2: 182-204.

Hall, R.J. and Jewett, D.B. 1988. A simulator for the design, analysis, and management of sawmills. Presented at: Forest Prod. Res. Society 42nd Annual Meeting. Forest Prod. Soc., Madison, WI.

Harrell, C.R., Bateman, R.E., Gogg, T.J. and Mott, J.R. 1995. System Improvement Using Simulation. 3rd ed. Promodel Corp., Orem, UT.

Helstad, K. 2006. Managing timber procurement in Nordic purchasing sawmills. Doctoral thesis. Acta Wexionensia Wood Design and Technology, No 93/2006.

Holmstrom, A. 2004. A discrete-event model of rail transport of roundwood at SCA Virke Nord. (unpubl.)

Kelton, W. D., Sadowski, D. A. and Sadowski, R. P. 1998. Simulation with ARENA, WCB/McGraw-Hill.

Kempthorne, K.H. 1978. Whole mill simulation of small log sawmills with head sawyers. In: Proc. Winter Simulation Conf. 2, p. 684-692.

Korpilahti, A. 1987. Puutavaratoimitusten ajoitus tehdasvastaanoton kustannusten optimoinnissa; jonoteoriaa soveltava tarkastelu. [Timing of round wood delivery in optimisation of costs of mill's wood receiving.] Metsätalouden liiketieteen lisensiaattityö. Helsingin Yliopisto, 80 p.

Lal, H., Peart, R.M., Jones, J.W. and Shoup, W.D. 1991. An object-oriented field operations simulator in PROLOG. *Transactions of ASAE,* 34(3): 1031-1039.

Lal, H., Jones, J.W., Peart, R.M. and Shoup, W.D. 1992. FARMSYS – A whole-farm machinery management decision support system. *Agricultural systems,* 38: 257-273.

Law, A.M. and Kelton , W.D. 1991. Simulation modelling and analysis. 2nd edition, *McGraw-Hill*, *Inc*, USA, 759 p.

Ottjes, J. A. and Duinkerken, M. B. 1996. Robotised inter-terminal transport of containers. A simulation study at the Rotterdam Port area. Proc. of ESS 96. *8th European Simulation Symposium.* Simulation **in** Industry, SCS.

Ottjes, J.A., Veeke, H.P.M., Duinkerken, M.B., Rijsenbrij, J.C. and Lodewijks, G. 2006. Simulation of a multiterminal system for container handling. *OR Spectrum,* 28: 447–468.

Paolucci, M. and Pesenti, R. 1999. An object-oriented approach to discrete-event simulation applied to underground railway systems. *Simulation,* 72(6): 372-383.

Pegden, C.D., Shannon, R.E. and Sadowski, R.P. 1995. Introduction to Simulation Using SIMAN. 2nd ed. McGraw-Hill, Inc., New York, 600 p.

Pennick, E.B., Jr. 1969. Monte Carlo simulation for production control. *Forest Prod. J.,* 19(5): 10.

Pritsker, A.A. 1986. Introduction to Simulation and SLAM II. 3rd ed. *John Wiley & Sons*, New York, 839 p.

Puodziunas, M. and Fjeld, D. 2002. Evaluation of supply chain strategies in Lithuanian forest enterprises: a case study. *Baltic Forestry,* 8 (2): 64-70.

Puodziunas, M., Rönnqvist, M. and Fjeld, D. 2004. The improvement potential for tactical planning of roundwood transport in Lithuanian state forest enterprises. *Baltic Forestry,* 10 (1): 79-88.

Randhawa, S.U., Zhang, G., Brunner, C.C. and Funck, J.W. 1994. A Discrete-event Object-Oriented Modeling Environment For Sawmill Simulation. *Simulation,* Vol. 62/2: 119-130.

Rappold, P.M. 2006. PhD Dissertation Activity-based product costing in a hardwood sawmill through the use of discrete-event simulation.

Shannon, R.E. 1975. Systems Simulation: The Art and Science. Prentice-Hall, Inc., Upper Saddle River, NJ, 387 p.

Stahl, I. 1990. Introduction to Simulation with GPSS. Prentice Hall, New York, 366 p.

(TWI Knowledge Summary) F:\Manufacturing - discrete-event simulation (Knowledge Summary).htm

Väätäinen, K., Asikainen, A. and Eronen, J. 2005. Improving the Logistics of Biofuel Reception at the Power Plant of Kuopio City. *International Journal of Forest Engineering,* Vol. 16/2.

Wagner, F.G., Jr. and Taylor, F.W. 1983. SPSM—A southern pine sawmill model. *Forest Prod. J.,* 33(4): 37-43.

Wagner, F.G., Seale, R.D. and Taylor, F.W. 1989. MICRO-MSUSP: An interactive computer simulation program for modelling southern pine sawmills. In: Executive Summary of 44th Forest Prod. Research Society Annual Meeting. Forest Prod. Soc., Madison, WI.

Received 08 September 2008
Accepted 30 October 2008

ПОСТАВКА КРУГЛОГО ЛЕСОМАТЕРИАЛА НА ЛИТОВСКОЙ ЛЕСОПИЛЬНЕ – ИМИТАЦИЯ ИСТОЧНИКОВ И ГРАФИКА ПОСТАВОК ПРИ ИСПОЛЬЗОВАНИИ МЕТОДА ОТДЕЛЬНОГО СЛУЧАЯ

М. Пуоджюнас и Д. Фъелд

Резюме

Принятие и сортировка круглого лесоматериала - это одна из многих операций на лесопильне, требующая хорошей планировки работ, гарантирующих степень использования всех мощностей. Изменения этих операций могут привести к большим простоям транспортных средств предприятия. Это создаёт условия задержки обмера древесины, что в итоге влечёт за собой задержку платы поставщикам.

Изменения при поставке древесины могут быть уменьшены при влиянии двух факторов – это источники поставок древесины и график привоза лесоматериала.

Цель этого исследования – установить источники поставки древесины и эффект графика принятия круглого лесоматериала на лесопильнях в Литве. Исследование было проведено, используя программу симуляции, и главное внимание было уделено операциям выгрузки и сортировки круглой древесины. Модель была создана, используя симуляционный пакет Арена.

Моделируя существующие количества поставок (21,000 м^3/месяц), приём и сортировка лесоматериала могут быть улучшены, изменяя некоторые нежелательные источники импорта (увеличилась продуктивность линии сортировки от 620 до 678 м^3/день) и усовершенствуя график поставок прибывающей древесины (дополнительные работы перегрузки круглой древесины уменьшились от 34% до 21%).

В случае планируемой поставки (30,000 м^3/месяц), продуктивность линий сортировки может быть увеличена от 697 до 901 м^3/день при отказе некоторых источников импорта древесины, меняя их на местные поставки. Улучшенный график работы лесовозов сократил количество грузов от 49% до 36%, которым нужна дополнительная перегрузка при существующей структуре поставок и от 38% до 18% увеличив поставки древесины местных источников. Во многих случаях улучшенный график привоза древесины уменьшил простои лесовозов на 50%. В будущем, желая достигнуть планируемого количества продукции, важны дополнительные мощности погрузчиков, надо пересмотреть источники поставки, отрегулировать график поставок древесины.

Ключевые слова: источники, график поставок, время простоя, промежуточное складирование, продуктивность линий сортировок