The Potential for Improvement of Tactical Planning of Roundwood Transport in Lithuanian State Forest Enterprises

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Existing timber transportation patterns in the Lithuanian state forest sector are based on independent deliveries from state forest enterprises. The aim of this article is to estimate the improvement potential for tactical-level planning of roundwood transport through localization of potential backhaul flows. A software system for backhaulage planning was applied, which use column generation as solution approach. The column generation is used to limit the size of the computations.

The study indicates that existing distribution of supply and demand nodes in the Lithuanian state forest sector allows a considerable potential to reduce transport output. The percent of the volume which could be included in a return or route was 50, 54 and 56 % for one, two, and four week planning horizons, respectively. The economic effect of this potential, however, varies with the assumptions of the applications. In this study, the potential reduction of transport costs varied from 7-16 %. The potential was largest for the longest planning period. Implementation of such a planning system requires coordination between forest enterprises.

Keywords: tactical planning, transportation costs, direct and backhaul transportation, planning horizon, demand and supply points

Introduction

Logistics may be defined simply as methods for planning, execution and control of operations governing material flow. Transport is one of the major logistics functions in the forest sector supply chain, where the goal is to coordinate roundwood supply with mill demand. This must be done under demands for high capacity utilization and low roundwood storage levels in a geographically dispersed supply chain subject to numerous climatic disturbances.

The division of entire wood supply process is differing from country to country. Typically it can be divided into 5 sub-processes; prognosis planning (yearly horizon), demand and supply planning (rolling 3 month horizons), delivery planning (confirmed harvesting teams production aimed for specific mills on a monthly horizon), and finally harvest and transport planning (on a weekly horizon).). The corresponding supply chain can be described in terms of three nodes (harvesting place, roadside inventory and mill inventory) and two connecting links (extraction and transport). Each link with its connecting nodes is the basis for planning of delivery, execution of supply and control of flow for both harvesting and transport operations (Fig. 1).

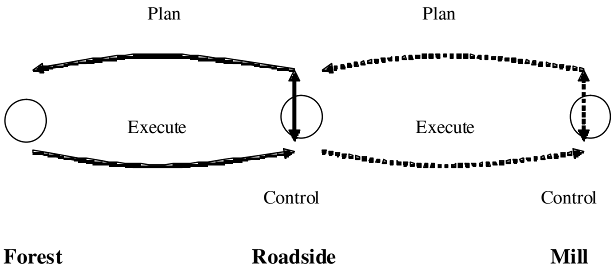

Figure 1. Logistics in forest operations. Planning, execution and control (PEC) cycles for harvesting and extraction (forest-roadside) and transport (roadside-mill) operations

These two Planning, Execution and Control (PEC) cycles are used to coordinate the rates of flow from both forest-to-roadside and from roadside-to-mill to meet varying mill demand under varying conditions.

Because transport planning is the final of 5 sub-processes in wood supply, it is subject to the greatest number of planning constraints. The high number of possible transport methods, combinations and the restrictions applied to transport planning makes it difficult to achieve an economically optimal transport organization without the help of computerized decision support tools.

The most common transport method for short distances (< 100 km) is truck transport. There are two general classes of trucks; self-loading trucks which work alone and trucks which work in groups and require a separate loader. For truck transport there are two general classes of planning functions: roundwood destination and vehicle routing. Destination aims to minimize the loaded transport distance between all forest supply nodes (active landings) and demand nodes (mills). This is done within the supply and demand restrictions imposed by the supply and demand planning. Vehicle routing aims to maximize capacity utilization of the transport fleet within the constraints imposed by destination. Different goals may be used and minimizing the unloaded distance from mill back to forest by locating backhauls is one of the most common. Typical planning horizons are less than a month for destination and less than a week for routing

Destination functions

The destination function in transport planning can be studied from different perspectives. The first is that of the large forest companies with long-term wood supply responsibilities to major mills. The second is that of forest owners associations or wood procurement groups who act as independent traders purchasing roundwood and selling to mills on shorter-term contracts on an open market. Lithuanian case is based on decentralized decisions as compared to other countries where a single company controls all transportation.

Destination of roundwood may be solved as a network model with the application of the classic transport algorithm and linear programming to minimize the loaded transport distance. This formulation may be well suited for large forest companies with long-term wood supply responsibilities to their own mills. There can be, however, important differences in the model formulation between integrated forest company and the independent trader perspective. The independent trader perspective aims to maximize the net revenue between price paid to the forest owner and the price received from the mill. Since contract prices may be specified at forest roadside or at the mill location, this must be included in the model. This means that when the price to the mill is based on delivery at roadside, the transport costs are not taken into account by the model. The prices paid to forest owners are often reduced with increasing transport distance to the nearest mill according to an agreed norm. However, prices paid by the mill, on the other hand, are determined through negotiations for each delivery contract specifying the prices for roundwood, and the delivery location.

Other important differences between destination models include the rigidity of restrictions of delivery. With the cut-to-length system it is more difficult to change the destination of wood, which is already cross-cut for specific sawmills. Pulpwood, however, is often a by-product, which is possible to deliver to a number of different customers. Deviations from the delivery plans may therefore be compensated for by purchase from other suppliers. In this case it is therefore possible to relax the constraints of delivery precision.

Vehicle routing functions

Routing of timber trucks demands the comparison of a great number of daily driving patterns and combinations. For this reason mathematical techniques creating smaller sub-problems by the use of heuristics have been common for optimal routing. These sub-problems are then easier to formulate and solve by a simpler algorithms such as the “traveling salesman” algorithm. In fact, “traveling salesman” algorithms are very sophisticated as well. However, by using heuristics it is possible to obtain high quality solutions in quick response times. More exact methods such as tree-searching or column generation followed by tree-searching are efficient methods for solving more complex problems. While general vehicle routing problems have been in use for many years, roundwood transport represents a special case where the number of restrictions is especially large. This includes, for example, factors such as the geographic movement of supply nodes (active landings) and the specificity of certain landings for certain truck types. The influence of climate on infrastructure trafficability and the effects of roundwood freshness on mill processes and product quality are also critical restrictions. There are several ways of finding solution to the TTVRP (timber transports vehicle routing problem): mathematical programming (Williamson and Nieuwenhuis 1993, Lihai 1994, Palmgren 2001), heuristic algorithms and models (Linnainmaa *et al*. 1994, Rönnqvist and Ryan 1995), simulation (Weintraub *et al*. 1996), and others. Karanta *et al* (2000) outlined a comprehensive list of needs for timber transport truck routing and scheduling on an operational level. They note that solution of this problem has many features not presented in general vehicle routing models, which makes the application of general purpose vehicle routing software compromise if practical at all. They extract 24 constraints, which are related to specific conditions in the forest sector and could be incorporated in the model. Finally the conclusion is made that "standard solutions are not feasible in solving TTVRP and the implementation of an adequate vehicle routing and scheduling system for a forest sector company calls for customized systems". Examples of successful implementation are found such as ASICAM in Chile, EPO in Finland and SMART in Sweden.

A wide spatial distribution of supply and demand nodes in a region offers ample opportunities for backhauls and potential savings of transport costs. With different patterns of node distribution clusters of supply and demand nodes will have a higher opportunity for return savings than other combinations. The transport cost savings associated with certain demand nodes can therefore make these more economically desirable destinations, even though this fact would not be shown in either a pure destination or routing solution. In these situations a destination model, which takes into consideration important backhaul flows, is recommended. Carlsson and Ronnqvist (1998) carried out such studies on tactical level by developing a model, which identifies backhauling options while optimising the roundwood flow. A typical monthly planning problem for this model is to decide the catchment's area for each industry. This means to decide which harvest areas are to supply a particular assortment to a single industry. In this type of model, increasing the number of assortments changes the catchment areas (Rönnqvist 2002).

A major difference between the different types of transport problems is the ease of implementation. Under stable conditions relatively advanced tools will function well. While under changing conditions, the number of restrictions and need for real-time operational data increases. Long-tern planning such as destination is the simplest of decision support tools while operational planning of routing is subject to the highest number of constraints. Tactical planning such as that done by Carlsson and Rönnqvist (1998) provide a more efficient roundwood flow from forest to industry by including the effect of major backhaul flows, but without filling all the more numerous operational restrictions used for solving operational routing. By specifying the destination of supply nodes the same model formulation may be used to identify major backhaul flows without taking into consideration operational assumptions and restrictions. This is a suitable level of resolution for estimating goals for improvement of tactical planning of roundwood transport in Lithuania's state forest enterprises.

The aim of this study is to identify the economic potential for cost reduction through increased backhauling in the Lithuania state forest sector. The effects of other factors on the economic potential are also examined. These factors include the length of planning horizon (weeks) as well as the trucks load size (m3), capacity utilisation (working hours) and driving speed (km/h).

Methods

The economic potential for backhauling is estimated by comparing the costs for transport work actually during a certain case and period to the costs for the same delivery, but with optimal backhauling. A program used to identify and optimize the backhaul flows was developed by Rönnqvist and based on the system described in Carlsson and Rönnqvist (1998). It goes by the name SnurrOpt. The program has since been developed for a number of specific purposes both in research and practical application. The latest application is used in an internet-based decision support system and is called Åkarweb (Eriksson and Rönnqvist 2003). The program was originally designed to make destination decisions where backhaul flows are taken into account. The program can also be used to identify and analyze potential backhaul flows without influencing destination decisions, which is the case in this study. The input data required to use the program are shown below in Table 1.

Table 1. Input data for the SnurrOpt program.

Input class	*Specification*
Volume restrictions	Volume per assortment supplied per landing (supply node)
	Volume per assortment demanded per mill (demand node)
Spatial assumptions	Landing position
	Mill position
Transport assumptions	Transport distance matrix (landing to mill)
	Transport cost function and transport saving for backhauling
Operational assumptions	Maximum route length
	Load size, driving speed, terminal time

The mathematical structure of the model originates from its primary use of improving both destination and backhauling on a tactical level. In this context the main problem is deciding which volumes shall go to which mills. For this reason the model is closely related to the linear-programming solution of the classic transport problem (TP).

In this model, the variables x_{ij} define the amount transported from supply node i (for m supply nodes) to demand node j (for n demand nodes) and c_{ij} is the

$$[\mathbf{TP}] \qquad \begin{aligned} &\min \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \\ &\textbf{s.t.} \quad \sum_{j=1}^{n} x_{ij} \le S_i, \quad i = 1,\ldots,m \\ &\qquad\quad \sum_{i=1}^{m} x_{ij} \ge D_j, \quad j = 1,\ldots,n \\ &\qquad\quad x_{ij} \ge 0, \quad \forall\ i, j. \end{aligned} \tag{1}$$

transport cost per unit. The available supply at node i is S_i and the necessary demand at node j is D_j. Given these restrictions, the objective is to minimize transport costs.

The transport problem formulation, however, assumes that the costs of individual transports are independent of each other, which is not the case in reality. To correct this, Carlsson and Rönnqvist's tactical model (SnurrOpt) divides the flow into simple and complex flow routes. A simple tour (k) is defined as a loaded transport distance from supply node i to demand node j accompanied by an unloaded transport distance back to supply node i. In contrast, a single complex tour (k) is characterized by a set of simple tours (r1, r2…rp), which are done in the order given and connected by unloaded transports.

R^c(k) = (r1, r2, r3, r4….rp)

Each simple tour (k) may be assigned a flow x_k if it belongs to the set of feasible simple tours (denoted R^s). Each complex tour (R^c) may be assigned a flow y_k assuming that it belongs to the set of feasible complex tours (denoted R^c). For both sets, the distance of each tour must be less than the limit possible to travel during one shift. For the set of complex tours, the distance traveled without load must be shorter than the loaded distance in the corresponding simple tours.

In the mathematical programming for problem solution, each tour (k) is represented by one column in the respective constraint matrices for simple and complex tours. For simple and complex tours, the matrices are defined by vectors a_k and b_k, respectively. Both matrices have dimensions m + n with the respective elements positioned at row i (for supply node constraints) and m + j (for demand constraints at node j displaced in the table by m supply nodes). Because the single complex tour (k) consists of a set of simple tours the composition of the constraint matrix column b_k is defined as:

$$\mathbf{b}_k = \sum_{l \in R^c(k)} \mathbf{a}_l. \tag{2}$$

The costs for the simple tours and complex tours are denoted by c_k and d_k, respectively. The cost for the simple tour (k) is calculated according to one-way distance from supply to demand node according the formula:

$$c_k = \alpha + \beta dist(k), \tag{3}$$

where the function includes payment for both the loaded and unloaded distance. The cost for the complex tour R^c(k) is calculated as

$$d_k = \left(\sum_{l \in R^c(k)} c_l \right) - \delta_k, \tag{4}$$

where the total cost for the loaded and unloaded distances of the corresponding simple tours (c_l) is first calculated. The total cost for the simple tours is then corrected by cost savings for the reduced unloaded transport in the complex route ($\ddot{a}_k$). The cost savings for reduced unloaded transport is defined as

$$\delta_k = \left(\left(\sum_{l \in R^c(k)} dist(l) \right) - dist_u(k) \right) \gamma. \tag{5}$$

where the saved unloaded distance is calculated by subtracting the total unloaded distance ($dist_u(k)$) of the complex tour from the sum of the loaded distances (dist(l)) for the corresponding simple tours. The resulting cost reduction for the complex tour is equal to the saved unloaded distance multiplied by the savings parameter (ć).

With these assumptions, the transport problem can be modified to take into consideration the savings of complex tour (P).

$$[\mathbf{P}] \qquad \begin{aligned} &\min \quad \sum_{k \in R^s} c_k x_k + \sum_{k \in R^c} d_k y_k \\ &\textbf{s.t.} \quad \sum_{k \in R^s} a_{ik} x_k + \sum_{k \in R^c} b_{ik} y_k \le S_i, \quad i = 1,\ldots,m \\ &\qquad\quad \sum_{k \in R^s} a_{j+m,k} x_k + \sum_{k \in R^c} b_{j+m,k} y_k \ge D_j, \quad j = 1,\ldots,n \\ &\qquad\quad x_k \ge 0, \quad \forall k \in R^s \\ &\qquad\quad y_k \ge 0, \quad \forall k \in R^c. \end{aligned} \tag{6}$$

A further specification of how different assortments and assortment groups are handled in the model is found in Eriksson and Rönnqvist (2003). Because of the large size of this model, the formulation is solved iteratively using a column generation technique. This requires the problem be divided into a master and a sub-problem. The master problem allocates flows to the different simple and complex tours within R^s and R^c while the sub-problem generates new complex tours for the next iteration. The inclusion of new columns to the master problem is based on a heuristic, which examines the reduced cost for the potential complex tours generated in the sub-problem (based on the dual information from the current LP solution). However, because the dual information of the complex tours is not available in the current LP solution, they are calculated by using the reduced costs of the simple tours. The reduced cost for the complex tour is then calculated as the sum of the reduced costs for the corresponding simple tours minus the savings in unloaded transport for the complex tour.

$$d(k) = \sum_{l \in R^c(k)} c_l - \delta_k . \qquad (7)$$

Combinations of simple tours that generate feasible complex tours are tested for possible savings. When the savings of unloaded transport for the suggested complex route are greater than the reduced cost of the corresponding simple tours, the complex route has negative reduced costs. New complex routes with negative reduced costs are included in the master problem.

After the initial solution of the classic formulation, an enumeration technique is used to generate and test new feasible complex tours. The testing continues until a specific number of tours with negative reduced costs are found. These are then included in the master problem for the next LP solution. Based on the dual information from that iteration, new routes are enumerated, tested and included. The cycle continues until no more complex routes can be found which generate savings.

Case study

The case study covered middle-southern part of Lithuania (Figure 2). The total number of enterprises in the area was 20 whereas only 13 of them used trucks for long-distance transportation. The transport data for these 13 enterprises were gathered for January of 2002. During data collection in studied state forest enterprises was observed that, currently, backhauls are more likely done accidentally and are used on very limited scale. For the studied period no backhauls were completed.

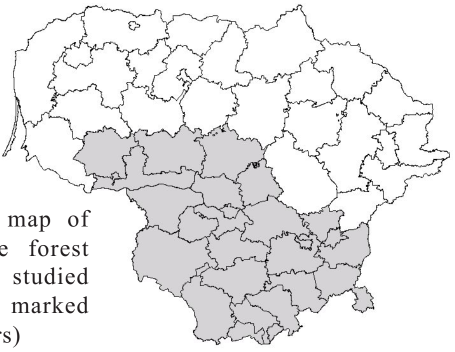

Figure 2. The map of Lithuanian state forest enterprises (the studied enterprises are marked with grey colours)

The information was available for daily activities while in calculations it was aggregated to different planning horizons:

- Planning horizon 1 week: 4 sets of one-week periods (weeks 1, 2, 3, 4)
- Planning horizon 2 weeks: 2 sets of two-weeks period (weeks 1-2, 3-4)
- Planning horizon 4 weeks: 1 four-weeks period (weeks 1-4)

The supply and demand data were analysed according to six groups of assortments: birch sawlogs (BS), pine sawlogs (PS), spruce sawlogs (SS), pulpwood (PP), palletwood (PL) and roundwood for particleboard (PB).

Currently, timber transportation in Lithuanian state forest enterprises is carried out both by themselves and contracting companies. Only state owned trucks were used in this study and total number reached 33. Seventy-five percent of these were the Russian made Kamaz. The load capacities of the trucks varied from 20 m^3 to 42 m^3. Most of them were equipped with self-loading cranes. The number of shipments for studied period reached 540. The total volume of timber delivered by the trucks reached 14 654 m^3 while the average shipment size was 27 m^3. The average transportation distance between supply and demand points was 82 km. There were few different patterns of truck routes during the day but only direct transportation routes were used in this study.

The data from each supply node was available at forest compartment level; however, the use of such detailed information significantly increases the size of the model. Due to this fact the supply node information was aggregated to the forest district level. This helped us to reduce a number of supply nodes to 111. The aggregation was made visually by finding the center point of forest area in each forest district and by attaching it to the closest road junction. It is very common in Scandinavia to use road junctions (so-called viapoints) as a base points for solving transportation problems (Karanta *et al.* 2000). Number of demand nodes reached 60. These points were represented by sawmills, wood processing factories, timber export companies, private owners and etc. The location of the demand and supply nodes are shown in Figure 3.

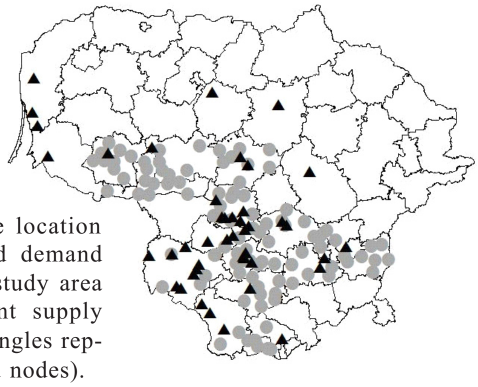

Figure 3. The location of supply and demand nodes in the study area (dots represent supply nodes and triangles represent demand nodes).

The use of the SnurrOpt model requires transport distances between all supply and demand nodes as well as the coordinates of each node. The basis for these distances was adopted current GIS database on the Lithuanian forests and road network (Databases: LMIIISC and LLTDBK-50000V). The calculations in the GIS databases were done using the ArcView GIS software. The special extension Fast Shortest Network Paths V1.0 (FSNP V1.0) was used in order to locate the shortest distances between each supply and demand nodes. The FSNP V1.0 requires three different scripts: a Network Analyst, a polyline theme representing the network and a point theme consisting of origins and destinations with unique IDs. The shortest paths are calculated after verifying the networkability of the line theme and the selected subset of origins and destinations. The primarily use of lists instead of tables leads to a better performance compared to ESRI-based script (FSNP V1.0 is at least 10 times faster). FSNP V1.0 also validates the results and fixes incorrect shapes (ESRI, 2003). The main paths are shown in Figure 4.

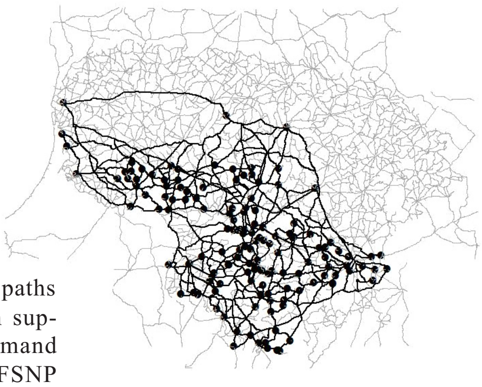

Figure 4. The paths found between supply and demand nodes by FSNP V1.0 routine

Operational assumptions

The SnurrOpt model requires a number of assumptions and restrictions in order to generating realistic backhaul output. These included: transport cost (LTL/m^3-km), average load size (m3), working hours (minutes per day), driving speed (km/hr), time spent for loading and unloading, and finally the savings for reduction of driving empty (LTL/m3-km).

The costs for wood transportation were calculated using the data from one of the studied enterprises. The average transport cost is 0.23 LTL/m^3-km while the cost savings for reduced empty driving is equivalent to 0.19 LTL/m^3-km. The distribution of costs is dominated by fuel costs (Figure 5) and it is calculated for Russian truck KAMAZ transporting timber for distance 220 km

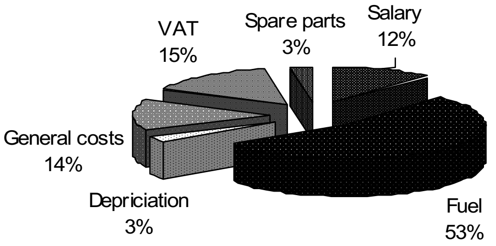

Figure 5. The distribution of operating costs for roundwood transport (Russian-built Kamaz) in Lithuania

The average load size used in the model was 25m^3. According to Lithuanian's regulations the total weight of the truck cannot exceed 40 t. Excluding truck weight (approx. 17 t) the allowed load size is equal to 23 t. Converting this figure to metric volume roundwood (1m^3=920kg of fresh timber) makes the allowable load size approximately 25m^3. Alternative calculations were also done using 35m^3 load size in order to estimate the effect of increasing load size on potential savings. The working hours of the truck was assumed to be equal to normal shift length (480 min). Alternative calculations were also done using a double shift (960 min) alternative. Assumptions on driving speed were also made. The average speed of driving used in the model was 50 km/h. Alternative calculations using a speed of 70 km/h were also made. Finally, the last assumption associated with time spent for loading and unloading was set to 60 min (Table 2).

Table 2. Operational assumptions for calculating economic potential for backhauling in Lithuanian forest enterprises

	Standard assumptions	**Alternative assumptions**
Average load size	25 m3	35 m3
Working time per day	480 min	960 min
Average driving speed	50 km/hr	70 km/hr
Loading/unloading time	60 min	

Results

The raw results of the SnurrOpt optimization are presented as a list of the different complex routes, which resulted in savings over simple routes. These are ranked from the highest volume to the least volume. The share of transported volume in these complex routes for the studied planning period varied between 40 and 60% (Figure 6). The average percent of the transported volume, which was included in a complex route was 50, 54 and 56 % for one, two, and four week planning horizons, respectively.

Because of the small volumes in some of these complex routes (less than truckload) the decision was taken to divide results into two measures. The assumption was made that economically reasonable and sufficient size of one shipment is 20m^3. This resulted in a considerable reduction of the proportion of volumes in complex routes (Figure 6). The lowest figures for transportation in route over 20 m^3 were found for one-week periods (20%) followed by two-weeks periods (25%) and four-weeks period (30%).

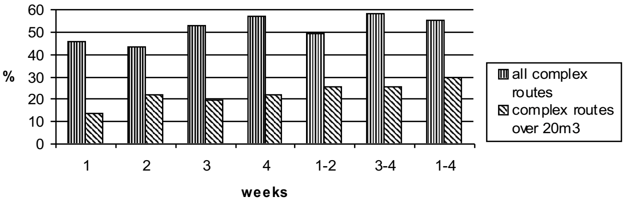

Figure 6. The percentage of transport volumes transported in any complex routes and complex routes over minimum economic size for the different planning horizons (weeks 1, 2, 3, 4, 1-2, 3-4 and 1-4)

The influence of a different minimum load size on the proportion of volumes in complex routes was also estimated and it can be seen in Figure 7. The calculations were done for week 1-4.

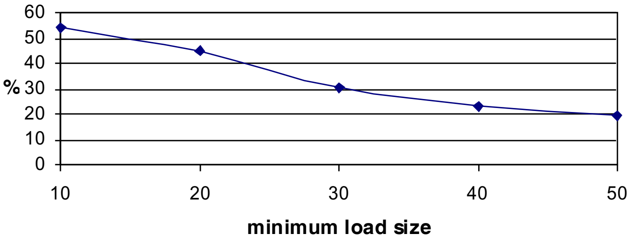

Figure 7. The influence of a different minimum load size (10, 20, 30, 40 and 50 m^3) on proportion of volumes in complex routes for week 1-4

The next step of analysis was to quantify the potential savings generated by backhauling optimization (Figure 8). The savings per complex route, when compared to the corresponding combination of simple routes, varied from a maximum of 3,1 LTL/m^3 (week 3-4) to a minimum of 2,1 LTL/m^3 (week 2). The total potential savings (all complex routes included) when seen in relation to the whole transported volume (all simple and complex routes) varied between 1,8 LTL/m^3 (week 3-4) and 0,9 LTL/m^3(week 2). Taking into account that average costs for transportation was approximately 15,6 LTL/m^3, optimization of backhauling can potentially reduce transport costs by 7-16%. On average (all three horizons) the optimization model showed the potential to reduce transport costs by 14%. The potential reductions were largest for the longer planning horizons.

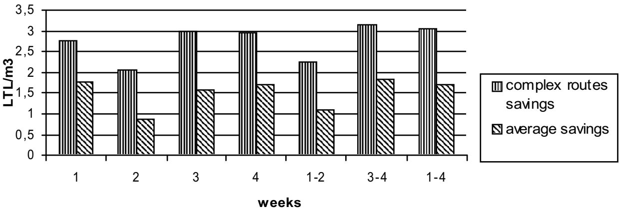

Figure 8. The potential average savings (LTL/m^3) through optimized backhauling for different planning horizons (weeks 1, 2, 3, 4, 1-2, 3-4 and 1-4). Both the average savings for the whole transported volume (sum of simple and complex routes) as well as for just the volume transported in complex routes are shown.

Estimation the influence of changing assumptions on potential savings was next study step. These are shown in Table 3 and alternative combinations of load size, working hours and driving speeds are included.

Table 3. The variation in potential savings (LTL/m3) from optimized backhauling with varying assumptions (load size 25/35 m^3, working time 480/960 minutes per day, driving speed 50/70 km/h). The standard assumptions assume 480 working minutes per day and an average driving speed of 50 km/h

	all complex routes		complex routes > 20m3		
	load size 25 m^3				
Assumptions	% of volume in route	Savings for route LTL/m3	% of volume in route	Savings for route LTL/m3	average savings LTL/m3
480 min 50 km/h	55,4	3,1	45,6	3,1	1,7
960 min	63,0	3,8	52,6	3,7	2,4
70 km/h	60,4	3,5	50,2	3,4	2,1
	load size 35 m3				
480 min 50 km/h	53,1	1,8	44,3	1,8	1,0
960 min	60,1	2,2	51,4	2,2	1,3
70 km/h	57,8	2,1	47,2	1,9	1,2

The assumption having the greatest effect on potential savings was working hours (Figure 9). The increase from 480 min (single shift) to 960 min (double shift) resulted in a 13 % increase in the volume in complex routes and a 41% increase in total savings per

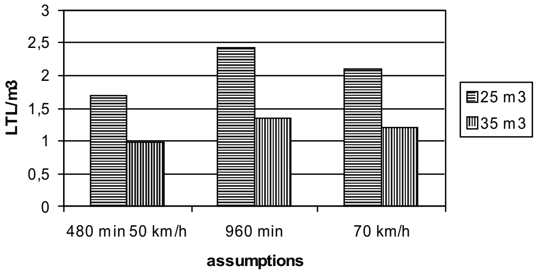

Figure 9. A comparison of the average saving of transport costs for optimized backhauling (LTL/m^3) given standard assumptions (480 min, 50 km/h) as well as increased load size, working hours and driving speed

m^3. The use of higher driving speeds also increased potential savings. The effect of increasing speed by 20 km/h (from 50 km/h to 70 km/h) increased the volume in complex routes by 9 % and the potential savings by 24 %. Increasing load size, however, has the opposite effect. Increasing average load size from $25m^3$ to $35m^3$ decreased the volume in complex routes by 4 % and the potential savings by 42 %.

Discussion

The study indicates that existing distribution of supply and demand nodes in the Lithuanian state forest sector gives a considerable potential to reduce transport costs. The economic effect of this potential, however, varies with the assumptions of the applications. With the standard assumptions, the calculated values for average reduction of transport costs varied between 7-16 %. The calculated values were found to decrease with shorter planning horizons. The decrease has been observed in many studies and its explanation is logical; the fewer the number of alternative supply and demand nodes, the lower the potential for finding better alternatives through optimization. This leads us to the effects of an important limitation of the study. As it was mentioned in the introduction chapter, many of the studied state forest enterprises were using the services of third parties to do long distance deliveries. In some cases the customers themselves transported timber. Due to this reason, only state forest enterprises deliveries were included in the study. This actually underestimated the number of available supply and demand nodes, thereby leading to an underestimation of the savings potential.

The study estimated the potential savings of transport costs from optimized backhauling. The optimization model SnurrOpt to identified complex routes with cost savings over simple routes. While the average savings for complex routes varied from the 2-3 LTL/m3, the savings for the total transport volume (simple and complex routes together) depends on the proportion of the total volume transported in complex routes. This proportion depends, in turn, on how large volumes the complex route must contain in order to be counted as a realistic alternative. In this study, setting this limit to just under one truck load reduced the proportion of volume transported in complex routes from 55 to 45 % (a 20 % relative decrease). Allowing any complex route to be included in the savings calculations therefore overestimates the realistic potential for savings.

Given the potential for underestimation of potential for savings because of a underrepresented nodes in the system and overestimation because of overrepresented backhauls the average savings calculated in this study should be seen as a maximum or goal value. Other studies in Sweden show typical potentials varying between 2 and 7 % (Holmgren 1999, Arvidsson & Carlsson 1998, Forsberg 2001, Lindwall 2003). The assumptions of these studies, however, are that only half of the actual savings are used in the program (a negotiated result between forest companies and with independent truck owner/operators). In the present study, all trucks are owned by the forest enterprises where the operators are employed and all savings, therefore come to the advantage to the forest enterprise organizations who are paying for and planning transportation.

The economical potential for transportation costs was also evaluated by changing certain parameters such as: load size, working hours and driving speed. The influence of larger load size demonstrated decrease in savings. This case can be explained by the fact that larger load size automatically results in lower transportation costs per t-km. Both cases of increase in working hours (960 min) and driving speed (70 km/h) demonstrated higher potential savings when compared to the standard assumptions. The increase in percent of volume in route wasn't very significant and reached 13% and 9% for increased working hours and driving speed, respectively. Nevertheless, potential savings were significantly higher for these two parameters and encountered 41% and 24%, respectively.

The effect of increase in working hours can be explained by the truck driver ability to drive longer distances during double shift compared to single shift resulting in lager potential savings. The similar logic is for increase driving speed, where higher driving speed enables truck driver to drive longer distances during the same shift and leads to higher savings compared to average speed used in the study. Both of these savings effects are caused by generation of higher proportion of complex routes.

Not all operational conditions influencing transport have been included as restrictions in the optimization model. This is because SnurrOpt is designed for tactical and not operational planning. During the tactical planning assets are balanced against demand while operational planning mainly concerns with actual movement of logs from supply to demand nodes. Variations in operational conditions are difficult to predict and on the other hand to incorporate into the model. Karanta *et al* (2000) have a comprehensive list of constraints for this purpose. These will represent additional factors further reducing the proportion of volumes possible to transport in complex routes. One important factor, which wasn't incorporated into the used optimization model and could additionally reduce transportation costs, is the distance from the base (starting point of the truck in the morning) to supply point. The truck drives this distance every time if we have a direct transportation. Having route transportation the truck does not need to come back to the base after first delivery since he is making second delivery directly afterwards. Historical data showed that average distance from a base to supply point was equal to 26 km. Optimization program is locating first supply point and last demand point close to each other. Due to this fact the empty driving is reduced additionally by 26 km. avoiding driving from the first demand point back to the base. By assuming that these savings are possible only having full load (>20m^3) the transportation costs additionally can be reduced by 0,15 LTL/m^3. Nevertheless, conclusion can be made that existing both geographical distribution of timber resources and customers, and existing assumptions demonstrated a potential for reducing transportation costs in the Lithuanian state forest sector. The remaining work concerns how to develop and implement a common transport planning system. A good example of such successful implementation could be Akarweb planning system (Eriksson and Rönnqvist 2003). Establishing a coordination unit of state forest enterprises transportation systems can lead to the solution of this task. It will enable coordination of timber flows and will synchronize transportation performance. Investigation of a possibility of establishing such unit could be a topic for a new study.

References

ESRI, 2003. (http://arcscripts.esri.com/details.asp?dbid=11742) 2003-05-10

Bergdahl, A. 2002. Optimal destination of saw timber in northern Sweden . important factors for potential cost reduction. MSc. Thesis nr 53 , SLU Dept. of Silviculture, Div. for Forest Technology, 43 p.

Carlsson, D. & Rönnqvist, M. 1998. Tactical planning of forestry transportation with respect to backhauling. LiTH-MAT-R-1998-13.

Dykstra, D. 1992. Mathematical programming for natural resource management. McGraw-Hill Inc. New York.

Epstein, R., Morales, R., Serón, J. and Weintraub, A. 1999. Use of OR Systems in the Chilean Forest Industries. Interfaces, 29 (1): 7-29.

Eriksson, J., Rönnqvist, M. 2003. Transportation and route planning. Akarweb – a web-based planning system. Proceedings of 2nd Forest Engineering Conference. Sweden (2003): 48-57.

Fohlin Å and Silver, M. 1997. Kvantitativa modeller för lokalisering av sågverk. Luleå Tekniska Universitet, Institutionen för Industiell ekonomi och samhållvetenskap. Licentiatuppsats 1997:42. K – 3,4,5.

Haartveit, E. & Fjeld, D. 2000. Interregional variations in transport net geometry – an analysis of wood procurement areas for norwegian sawmills. In: Sjöström, K (ed) Logistics in the forest sector. Timber Logistics Club, Helsinki 2000, p. 165-188.

Karanta, I., Jokinen, O., Mikkola, T, Savola, J., Bounsaythip, C. 2000. Requirements for a vehicle routing and scheduling system in timber transport. In: Sjöström, K. (ed) 2000. Logistics in the forest sector. Timber Logistics Club. Helsinki (2000), p. 235-251.

Linnainainma, S., Savola, J., Jokinen, O. 1994. EPO A knowledge base system for wood procurement management. Paper from the 7th Annual Conferernce onm Artificial Intelligence, Montreal (1995): 107-113.

Palmgren, M. 2001. An approach to log truck scheduling. In: Palmgren & Rönnqvist (eds). Logistik och optimering inom skogsindustrin. Workshop Åre 11-14 mars 2001. LiTH-MAT-R-2001-16: 95-106.

Rönnqvist, M. & Ryan, D. 1995. Solving truck dispatch problems in real time. Proceedings of the 31st Annual Conference of the Operational Research Society of New Zealand. Wellington, NZ (1995) 165-172.

Weintraub, A., Epstein, R., Morales, R., Seron, J., Traverso, A. 1996. A truck scheduling system improved efficiency in the forest industries. Interfaces 26 (1996): 1-12.

Winston, W. L. 1995. Introduction to mathematical programming: applications and algorithms, Duxbury Press.

Örtendahl, A. 2001. An analysis of pulpwood transactions with the NETRA transport optimisation program. MSc. Thesis SLU nr. 50 SLU Dept. of Silviculture, Div. for Forest Technology, 35 p.

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ВОЗМОЖНОСТЬ УЛУЧШЕНИЯ В ТАКТИЧЕСКОМ УРОВНЕ ПЛАНИРОВАНИЯ ТРАНСПОРТИРОВКИ КРУГЛОГО ЛЕСОМАТЕРИАЛА В ГОСУДАРСТВЕННЫХ ЛЕСНЫХ ПРЕДПРИЯТИЯХ ЛИТВЫ

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Резюме

В настоящее время в секторе лесов Литвы существующая моделъ перевозки древесины основана на независимых перевозках из государственных лесных предприятий.

Целъ этои статъи оценитъ возможные улучшения в тактическом уровне планирования, изпользуя обратные потоки. В иследовании изполъзована программа обратных рейсов и скопления транспортных колон. Осреднение колон изполъзовано для ограничения велечин вычесления.

В исследовании выявлены существующие точки распределения спроса и предложения в государственном секторе лесов Литвы. Установлены потенциалъные возможности уменшения расходов на перевозки. Процент объема древесины, который может бытъ включен в обратные рейсы при периодов плариновання одной двух и четырех неделъ, составили 50%, 54%, 56%. При этом потенционалъное уменьшение расходов на транспортировки колебалось между 7-16%. Самая большая экономия получена при долгосрочных периодах планирования. В этом случае требуется координация мехду лесными предприятиями.

Ключевые слова: тактическое планирование, расходы транспорта, прямая и обратная транспортировка, период планирования