Wood supply chain optimization: Case studies of logging companies in Russia

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Abstract:
A decision support system on a logging company level, which was developed in the field of wood harvesting supply chain, is described. The system has been used in a number of cases, and three of them are described in this paper. The cases were selected aiming to present different planning levels: operational, tactical and strategic. Planning horizons were 4 days, 3 months and 1 year correspondently. The cases studies have been made in logging companies located in Northwest Russia with annual harvest about 250,000 m^3 each. The cases range from 5 to 24 trucks, 8-10 wood assortments, 4-129 supply points and 4-5 demand points. The results show that system can be used in solving the wide range of case studies on the company level, including the truck routing, the choice of equipment utilization level, the choice of transport method, and the infrastructure investments. The potential savings are in the range 14-25%.

Keywords: wood logistics; cut-to-length harvesting; wood-to-energy; decision support system

1 Introduction

An illustration of the cut-to-length (CTL) harvesting supply chain integrated wood-to-energy valid for a logging company is shown in Figure 1. The assortments obtained from wood harvesting can be classified according to their use. Sawlogs, pulpwood, energy logs and logging by-products are the major parts of the assortments. Each group can be divided into several subgroups according to their species, qualities and dimensions. The harvesting leaves some by-products in the form of tops and branches. The logging by-products are left for around a year in the harvesting area (or roadside) for drying and are then chipped or bundled. Then, after storage at the intermediate wood terminal (if necessary), the assortments can be transported to customers (sawmills, pulp mills, plywood mills, heating plants etc).

There are different levels of planning in wood supply chain, which depend mainly on the planning horizon (Rönnqvist, 2003; Gunnarsson, 2007). The strategic level often describes decisions that concern several years or decades. Tactical planning is often connected to annual decisions, but it could be for shorter or longer periods, depending on the considered problems. The operative planning could span over a couple of months or involve daily planning. The differences in time for each level depending on the type of problem are not clearly defined. In the wood harvesting supply chain at the Russian logging company, the strategic planning involves decisions from a year up to a decade. Strategic decisions include investment planning and infrastructure planning (Table 1). The tactical planning could be from a quarter of year to a year. Tactical decisions include annual production planning related to the budget processing, route structure and equipment utilization. The operative planning includes decisions up to three months. The operative decisions include detailed production planning and truck dispatching. Different planning horizons and decisions have different needs for supporting tools.

I – the harvesting site
III – the intermediate wood terminal
II - the roadside storage at a supplier
IV - the gate at a customer

Figure 1: Cut-to-length harvesting supply chain integrated wood-to-energy

Table 1: Levels of planning in wood supply chain at the Russian logging company

Planning level	Horizon	Harvesting decisions	Road decisions	Transport decisions
Strategic	1-10 yrs	Leasing area potentials Choice of harvesting method Equipment investments	Infrastructure investments Equipment investments	Choice of transport method Equipment investments
Tactical	3 months-1 yrs	Annual harvesting volumes Harvest unit scheduling Equipment utilization Choice of equipment utilization level	Temporary truck access roads Upgrading and maintenance of permanent road	Transport delivery plan Choice of equipment utilization level
Operational	1 day – 3 months	Detailed harvesting plan		Truck routing

Within the area of production planning problems, the levels often depend on the assortments. Usually, operative planning in production problems depends on the use of working shifts, times, or daily planning. Tactical planning is often annual, and the strategic level concerns several years. The long horizons within wood harvesting are due to the long rotation times of trees. MEDFOR, a planning tool for strategic decisions in a horizon of 50 years, is described in Epstein et al. (1999). Another model for strategic harvest planning can be found in Gunn and Rai (1987). A system based on simulating conditions in forestry, which is used primarily for the strategic planning of harvesting over large harvest areas, was developed in many countries. These systems are intended to be aids in decision operations, such as how much to harvest each year, proportions of thinning and final harvesting, and in which order to work the areas.

For making tactical decisions, the OPTIMED tool by Epstein (1999) can be used for supporting harvest planning for a period of two to five years. Harvest scheduling, road access and adjacency constraints are considered simultaneously. They address the tactical planning problem with a tabu search method. The design of the tabu search method is further discussed in Richards and Gunn (2003). A harvest-planning model for the short term can be found in Karlsson et al. (2003), where a planning period from four to six weeks was considered and harvest schedules for the different harvest crews were decided. A model integrating long-term harvest planning with short term harvest planning can be found in Nelson et al. (1991).

With regard to routing problems, the operative level often involves daily decisions about the routes. The tactical level in routing problems can be from a few weeks up to a few months, and the strategic level considers decisions of one year or longer periods (Weintraub et al., 1996). An operative and computerized system to support daily truck scheduling decisions is developed, and the system has been implemented in Chile. Decision support system RuttOpt by Andersson et al. (2008) has been used in a number of case studies. The cases range from 10 to 110 trucks and with a planning horizon between 1 and 5 days. Another approach to the problem of optimizing daily transports within forestry is used in Palmgren et al. (2003), where the aim was to find efficient routes for all the trucks involved.

2 Material and Methods

The decision support system (DSS) is developed for routing and scheduling harvesting machines and trucks in a logging company. This DSS has been constructed in a MapInfo environment using C++ for coding and Microsoft Excel for reporting. The system is made up of a number of modules. An overview of the DSS structure and its most important components is presented in Fig. 2 (Gerasimov et al., 2008).

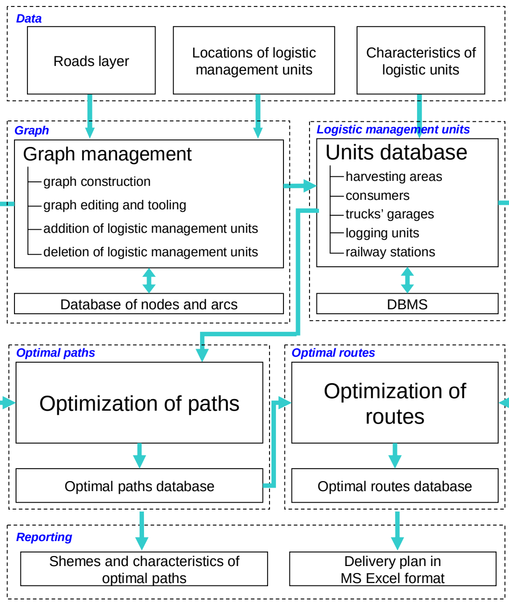

Figure 2: DSS structure and its most important components

The Data module includes information about roads and their quality, locations of logistic management units, and their characteristics. The second part of the DSS is the Graph module. In this module the user can generate a layer of roads including logistic management units. The Optimal paths module helps the user to search, with a heuristic optimization method, for the best variants for transportation routes. The

Optimal routes module helps the user to optimize, with dynamic programming, daily tasks for each truck. The Reporting module contains reports of optimal routes and delivery for CTL transportation for the logging company.

The problem was logically divided into two consecutive stages, which are the optimization of paths and the optimization of routes. The output of the first stage produces optimal paths between existing logistic management units with the minimal wood transportation costs per 1 m^3. The output of the second stage is a routes plan with the maximum wood transportation per shift for the operational truck fleet.

The developed routing algorithm is based on a dynamic programming method. The route calculation process for each vehicle is suspended and it is inserted back into the garage due to one of the following three reasons: the end of shift is happened; lack of wood on road-site storages in harvesting areas; contractual obligations with customers are fulfilled.

2.1 Problem description

The Vehicle Routing Problem (VRP) can be defined as a problem of finding the optimal routes of delivery or collection from one or several *depots* to a number of *customers,* while satisfying some constraints. The VRP plays a vital role in distribution and logistics. Huge research efforts have been devoted to studying the VRP since 1959 where Dantzig and Ramser have described the problem as a generalized problem of Travelling Salesman Problem (Liong et al., 2008). The VRP is an important combinatorial optimization problem. Maffioli (2003) has reported that the use of computerized methods in distribution processes often results in savings ranging from 5% to 20% in transportation costs. Barker (2002) describes several case studies where the application of VRP algorithms has led to substantial cost savings.

In classical VRP, the customers are known in advance. Moreover, the driving time between the customers and the service times at each customer are usually known (Madsen et al., 1995). The classical VRP can be defined as follow: Let $G = (V, A)$ be a graph where $V = \{1...n\}$ is a set of vertices representing *customers* with the *depot* located at vertex 1, and A is the set of arcs. With every arc (i, j) $i \neq j$ is associated a non-negative distance matrix $C = (c_{ij})$. In some contexts, c_{ij} can be interpreted as a *travel cost* or as a *travel time.* When C is symmetrical, it is often convenient to replace A by a set E of undirected edges. In addition, assume there are m available vehicles based at the depot, where $mL < m < mU$. When $mL = mU$, m is said to be *fixed.* When $mL = 1$ and $mU = n - 1$, m is said to be *free.* When m is not fixed, it often makes sense to associate a fixed cost f on the use of a vehicle. The VRP consists of designing a set of least-cost vehicle routes in such a way that:

(i) each customer in $V\backslash\{1\}$ is visited exactly once by exactly one vehicle;
(ii) all vehicle routes start and end at the depot;
(iii) some side constraints are satisfied.

The problems that need to be solved in real-life situations are usually much more complicated than the classical VRP. One complication that arises in forestry practice is that different assortments must be picked up at a number of customers (supply points), and brought to a number of customers (demand points) during a shift. An empty vehicle has to start a route from a depot and come back in the end of a shift. This problem is a modification of well-known VRP with Backhauls (VRPB) (Ropke and Pisinger, 2006; Bianchessi and Righini, 2007). The problem can be divided into two independent VRPs; one for the delivery (linehaul) customers and one for the pickup (backhaul) customers, such that some vehicles would be designated to linehaul customers and others to backhaul customers.

2.2 Problem formulation

The fleet of V vehicles departs from a depot to perform only sequential deliveries of A types of assortments from B backhaul supplier (harvesting site) locations to L linehaul customer (mill) locations. Planning period is N shifts within D days and M months. Linehaul customers' demands follow are known contractual volume of each assortment at mill gate (on a monthly base). Backhaul customers' supplies follow the known initial stock and daily production of each assortment at a harvesting site (on a daily base). They are assumed statistically independent. Let u_{ab} and u_{al} variables that describe the supply and demand for each supplier and customer. Exact demand (supply) for a customer (supplier) is revealed only when the vehicle arrives at the customer (supplier) for the first time. This research assumes the failure of a vehicle route when the end of shift occurs. Because of changing in supplies/demands, a vehicle route will fail when remaining supplier's supply or customer's demand for the suitable assortments are under vehicle capacity. Upon route failure, the vehicle must return to the depot to change the driver and wait the next shift. The problem objective is to find routing policies that meet demands of each customer, the travel cost is minimized or the amount of wood transportation per shift is maximized. To satisfy this objective, the routing policy also can prescribe returns to the depot before the vehicle scheduled time is depleted (i.e. proactive returns).

The problem can be formulated as follows:
$a = \{1, 2, ..., A\}$ is a set of assortments;
$v = \{1, 2, ..., V\}$ is a set of vehicles;
$l = \{0, 2, ..., L\}$ is a set of linehaul customers, node 0 represents the depot;
$b = \{1, 2, ..., B\}$ is a set of backhaul customers;
q_{va} is the vehicle v capacity associated with assortment a;
$t(l,b)$ is delivery time between customers l and b;
u_{alm} the maximum load of assortment a that has to be carried in linehaul customer l during month m;
u_{abd} the maximum load of assortment a that has to be carried from backhaul customer b during day d;
u the shift duration;
r_{abd} remaining supply capacity of assortment a associated with backhaul customer b within day d;
r_{alm} remaining delivery capacity of assortment a associated with linehaul customer l within month m;
t_v remaining time to the end of shift associated with vehicle v;
X_{vla} the number of deliveries of assortment a by vehicle v associated with linehaul customer l.

The mathematical formulation of the problem is:

$$Maximise \quad \sum\sum\sum q_{va} X_{vla} \qquad (1)$$

Subject to

$$r_{abd} <= u_{abd} \text{ for } a = 1, ..., A, \ b=1, ..., B, \text{ and } d=1, ..., D \qquad (2)$$

$$r_{alm} <= u_{alm} \text{ for } a = 1, ..., A, \ b=1, ..., L, \text{ and } m=1, ..., M \qquad (3)$$

$$r_v <= u \text{ for } a = 1, ..., V. \qquad (4)$$

The objective function (1) is the volume of assortments, which is delivered by the fleet of vehicles during the planning period. The constraint (2) ensures that the total daily load from a backhaul customer does not exceed the maximum supply capacity for each assortment associated with each day. The constraint (3) ensures that the total monthly load in a linehaul customer does not exceed the maximum demand capacity for each assortment associated with each month. The constraint (4) ensures that the travel time of a vehicle does not exceed the shift duration.

2.3 Algorithm

The VRP was formulated as a dynamic programming problem. The algorithm for each vehicle maximizes the amount of wood transportation per shift. Formally, the task of minimizing the total time of motion of the vehicle during a limited time of shift with the absence of delays (stops are not provided by technology). The obtained optimal solution directly corresponds to the maximum volume of wood transport per shift, i.e., the number of delivered loads, because the greater the number of truck loadings, the less time on the motion in conditions of limited shift.

For each linehaul customer the critical time of truck arrival is determined by the formula:

$$t_c(s) = T - t_l - t_r(s) \qquad (5)$$

Where s – the state of the system corresponding to truck location at this customer; T - duration of the shift; t_l - time of unloading; t_r(s) - moving time from this customer to the garage.

In the conditional optimization at each step of dynamic programming the target customer is determined for each current customer aiming at the fact that the total time elapsed from the beginning of the shift to arriving at current customer has to be minimal.

The problem of conditional optimization is solved for the active linehaul customer:

$$\tau_i(s) = \min\{\tau_{i-1}(u) + t(s,u) + t_l\} \qquad (6)$$

where τ_i (s) - the time from the beginning of the shift to the arrival at the active linehaul customer; i - step number of dynamic programming; s - the state of the system corresponding to the truck location at the active linehaul customer; $\tau_{i-1}(u)$ - conditionally minimum time from the beginning of the shift to arriving at the backhaul customer u, obtained in the previous step of dynamic programming; u - the desired conditional optimal action (the backhaul customer from which, at the given step, takes place conditionally optimal deliver the timber assortment to the active linehaul customer); t (s, u) – moving time from the backhaul customer u to the active linehaul customer.

The problem of conditional optimization is solving for the active backhaul customer:

$$\tau_i(s) = \min\{\tau_{i-1}(u) + t(s,u) + t_l\} \qquad (7)$$

where $\tau_i(s)$ - the time from the beginning of the shift to the arrival to the active backhaul customer; i – the step number of dynamic programming; s – the state of the system corresponding truck location at the active backhaul customer; $\tau_{i-1}(u)$ - conditionally minimum time from the beginning of a shift to arriving at the linehaul customer u, obtained at the previous step of dynamic programming; u - the desired conditional optimal action (the linehaul customer, from which conditionally optimal decision, at this step, to make a run to the active backhaul customer); t (s,u) – moving time from the linehaul customer u to the active backhaul customer.

In the unconditional optimization the route from the end to the beginning of is scanned, which was maximum number of delivered loads. If there are several alternative routes with the same number of delivered loads, the closest route to the garage in the end of the shift is selected.

In case of alternative timber assortments intended for the carriage from the optimum harvesting area to an optimal customer, the timber assortment with a higher priority is selected. The priority is set in the interface dialogues that define the characteristics of the consumer and the harvesting area. Timber assortment with a higher priority should be on lines of dialogue above, with a lower - below.

All available vehicles are included in the overall list. In the beginning, the route of the first truck in the list is defined, then - for the second (for the remaining volume of undelivered wood), etc. It is also an implemented priority: the higher priority has the truck listed first. The first truck is set by the user in the interface dialogue for garages. If there are several garages, the first truck from the first garage is selected, then for the first truck from the second garage, etc. Later in the same order are considered second trucks, third and so forth until all trucks are be considered or all available for supply timber is delivered.

The results of the algorithm are stored in the form of a book Microsoft Excel, each sheet of which is the plan of routes and schedules drawn up for a garage (for all trucks belonging to this garage). The plan indicates the points of departure and destination, the distance between them, times of arrival and departure, as well as the characteristics of the transported wood (Gerasimov et al., 2008).

3 Results

The efficiency of the developed DSS for operational, tactical and strategic planning was tested at three case studies in the Republic of Karelia and the Leningrad region (see Fig. 3). Each case study has been done at a different logging company. The logging companies provided the necessary information about harvesting areas, production, and infrastructure. The general information on the size of the case studies is shown in Table 2. Delivery routes were compared by using the following performance indexes (Table 3): total work time (hours), total distance (km), total number of truck loads, total volume of wood transportation (m^3), total loaded distance (km), required number of trucks, fleet utilization rate per shift, index of loaded distance, and index of operation work (m^3/km). All simulations have been performed on a standard personal computer.

Figure 3: Case study locations

Table 2: Comparable overview of the case studies

	Case study 1	Case study 2	Case study 3
Planning level	Operational	Tactical	Strategic
Task	Truck routing	Choice of equipment utilization level	Choice of transport method Infrastructure investments
Horizon	4 days	3 months	1 year
Total supply volume, 1000 m^3	3	80	272
Number of trucks	5	13	24
Number of assortments	10	9	8
Number of backhaul customers	4	63	129
Number of linehaul customers	4	5	5
Number of intermediate terminals	-	-	6

Table 3: Results from case studies

Plan	Required trucks [units]	Total working time [h]	Total distance [km]	Number of truck loads	Total volume [m^3]	Total loaded distance [km]	Fleet utilization rate	Index of loaded distance	Operation work [m^3/km]	Transporting cost [€/m^3]
Case study 1: Operation level										
Basic	5	307	7,382	53	2,740	2,212	0.754	0.300	0.371	-
Advanced 1	5	255	7,382	58	2,996	2,697	0.728	0.365	0.406	-
Advanced 2	4	239	5,743	58	3,000	2,872	0.895	0.499	0.526	-
Case study 2: Tactical planning										
Basic	13	13,474	622,453	2170	80,025	308,211	0.858	0.495	0.129	7.3
Advanced	6	10,349	449,648	1728	80,325	223,389	0.864	0.497	0.179	6.3
Case study 3: Strategic planning										
Basic	24	37,231	709,898	10869	314,031	296,217	0.477	0.417	0.442	6.0
Advanced	8	30,222	584,310	8184	270,072	252,143	0.636	0.432	0.462	4.5

3.1 Case study 1: Operational planning

The first company operates in the Republic of Karelia harvesting about 250,000 m^3 of wood per year. All wood comes from company's leased forests located in the southern part of Karelia. The most of coniferous sawlogs is delivered to two local sawmills, pine pulpwood to local pulp mill, and birch and spruce pulpwood to the company's terminal at the railway station for the further export. The company undertakes both forest operations and transport using fully mechanized CTL systems and modern trucks.

The case is taken from this company and covers five trucks based in one garage, four backhaul customers (harvesting areas), and four linehaul customers (three mills and one wood terminal). The capacities for the CTL trucks were 50–52 m^3, depending on the model. The daily outputs of harvester-forwarder chains in harvesting areas were 140–420 m^3, depending on the site, and the actual cut per harvesting area was 5,000–15,000 m^3. Half of the actual cut was coniferous sawlogs, including 9% small size spruce sawlogs, 18% coniferous pulpwood, 22% birch pulpwood, and 10% energy wood. The purpose was to test the DSS and compare this to the manual results covering the four days. Three solutions of delivery routes were created for four adjacent working days using two shifts per day for the same logistic management units' conditions (harvesting areas, customers, paths, fleet, etc). The Basic delivery routes were done in a traditional way without DSS support. Two advanced delivery routes were constructed with the DSS. The difference between the second and third delivery routes is that in the third plan the trucks change drivers on route without returning to the garage after every shift.

The comparison of the results is presented in Table 3. Optimization of the schedule using the DSS according to Advanced 1 plan shows that the total delivered wood volume increases from 2,740 to 2,997 m^3 (+9%). The total distance is the same, but the total working time decreases by 17%. The required fleet is the same: five CTL trucks. The fleet utilization rate decreases slightly (–4%), the index of loaded distance increases by 22%, and the total volume of transported wood per km increases by 9%. Optimization of the schedule using the DSS according to Advanced 2 plan shows that the total delivered wood volume increases from 2,740 to 3,000 m^3 (+10%). The total distance decreases from 7,382 to 5,743 km (–22%), and the total working time decreases from 307 to 234 h (–22%). This reduces the required fleet from 5 to 4 trucks. The fleet utilization rate increases by 19%, the index of loaded distance increases by 30%, and the total volume of transported round wood per km increases by 42%. All these changes also have input in the economics of the total operations, either decreasing the costs or increasing income.

3.2 Case study 2: Tactical planning

The second company operates in the Leningrad region harvesting about 250,000 m^3 of wood per year. All wood comes from company's leased forests located in the eastern part of Leningrad region. The most of coniferous sawlogs is delivered to two local sawmills, birch sawlogs to plywood mill, and pulpwood to the company's terminal at the railway station for the further export. The company buys services for both forest operations and transport. The company's contractor's use fully mechanized CTL systems in wood harvesting and different trucks with crane in transport.

Two delivery routes were created using different CTL vehicle fleets for the same logistic management units' conditions changing of the equipment utilization level aiming at decreasing transport costs. The Basic plan of delivery routes was done for an existing vehicle fleet (7 harvesters, 7 forwarders, 13 trucks) with DSS support. The Advanced plan of delivery routes was done with the DSS for an optimal fleet in wood transport (6 trucks). The delivery routes were created for three winter months using two shifts per day. There were 63 harvesting areas and five linehaul customers (four sawmills and one wood terminal). Capacities for short-wood trucks were 30–50 m^3 depending on the model. Daily outputs of harvester-forwarder chains in harvesting areas were 60–90 m^3 depending on the site.

The comparison of the results for the delivery routes is presented in Table 3. Optimization of routes using the DSS according to the advanced plan shows that for the same total delivered wood volume the total distance decreases from 622,453 to 449,648 km by –28% and the total working time decreases from 13,474 to 10,349 hours (–23%). It reduces the required fleet from 13 to 6 trucks. The fleet utilization rate increases, the index of loaded distance increases slightly, and the total volume of transported wood per km increases by 39%. Also the Advanced plan decreases the transport cost by 1.0 €/m^3 or 250,000 €/yr.

3.3 Case study 3: Strategic planning

The third company operates in the Leningrad region harvesting about 270,000 m^3 of wood per year. All wood comes from company's leased forests located in the northern part of Leningrad region. Most of spruce sawlogs is delivered to local sawmills, and pine sawlogs and pulpwood to the company's terminals at the railway stations and the river port for the further export. About 6-8 intermediate wood terminals at all weather roads nearby the harvesting areas are used during the wintertime. The company undertakes both forest operations and transport. Fully mechanized CTL systems in wood harvesting and Russian trucks with crane in transport are used. Additionally the company buys forest operations and transport services in wintertime.

Two delivery routes were created using different CTL vehicle fleets for the same logistic management units' conditions changing of transport method aiming at avoiding the use of intermediate terminals in wintertime. This change might decrease transport costs significantly. However CAPEX €1 million would be required into the infrastructure (about 100 km of forest roads upgrading). The Basic delivery plan was done for an existing vehicle fleet (9 harvesters, 9 forwarders, 24 trucks) via intermediate wood terminals in wintertime with DSS support. The second advanced plan of delivery routes was done with the DSS for an optimal fleet in wood transport (8 trucks) avoiding intermediate wood terminals in wintertime (direct transport from harvesting areas to customers). The delivery plans were created for one-year horizon using two shifts per day. The total harvested volume was about 270,000 m^3. There were about 60 harvesting areas and five linehaul customers (one sawmill, three wood terminals at railway stations, and one wood terminal at river port). Capacities for short-wood trucks were 26–33 m^3 depending on the model. Daily outputs of harvester-forwarder chains in harvesting areas were 125–250 m^3 depending on the site.

The comparison of the results for the delivery routes is presented in Table 3. Optimization of routes using the program according to the Advanced plan shows that the total run decreases from 709,898 km to 584,310 km (–18%), and the total working time decreases by 7,000 hours. It reduces the required fleet from 24 to 8 trucks. The fleet utilization rate and the index of loaded distance increase slightly, and the total volume of transported round wood per kilometer increases by 5%. In addition, Advanced plan decreases the transport cost by 1.5 €/m^3 or about €0.4 million per year. The payback time of the needed infrastructure investments (€1 million) is within 3 years.

4 Discussion

CTL harvesting has become increasingly common in Russia due to technology transfer from the Nordic countries. There are many reasons for the increasing popularity of the CTL systems. However, there are some obstacles. One of them is that the logistic approaches for CTL operations are not yet well developed. DSS developed in countries with long experience of CTL harvesting are not necessarily directly applicable to Russian conditions. This is due to the specific organizational structure of Russian logging companies. Russia also has specific requirements for traffic, its own standards for wood, categories of roads, poor state and maintenance of roads, and so on. Moreover, solutions are usually company-specific, and thus tailored programming tools need to be developed to improve the planning and optimization of wood procurement for operational and tactical tasks (Gerasimov and Karjalainen, 2008).

This DSS gives the logging company comprehensive information about the benefits and limitations of different CTL options. A logging company gets sufficient information to make sound short-, medium- and long-term decisions. Improvement of economic feasibility of CTL and wood-to-energy operations is a critical element in the development of forestry in Russia. Good productivity and thus economics of the whole CTL chain can be further improved in the logging companies, since DSS takes economic aspects into consideration, warns of lack of trucks, and gives recommendations for organizational management of logistics (i.e. wood harvesting and delivery planning, need for temporary wood terminals) when required.

The developed GIS-based DSS is a tool to assist the logging companies to make comprehensive decisions on organizational options for CTL harvesting and logistics most beneficial for them. Application of the program allows efficiency to be increased when introducing CTL and wood-to-energy in Russia, wood harvesting and transport costs to be decreased, and utilization of the CTL machinery fleet to be improved.

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