Original scientific paper – *Izvorni znanstveni rad*

GIS-Based Decision-Support Program for Planning and Analyzing Short-Wood Transport in Russia

Yuri Gerasimov, Anton Sokolov, Timo Karjalainen

Abstract – Nacrtak

Extraction of short-wood from harvesting operations is becoming common practice in Russia. Logging companies are faced with a large number of options for short-wood transport, but they have limited knowledge of logistics potential. Developed GIS-based decision support program is a unique tool assisting logging companies in making comprehensive decisions on organizational options for the most suitable short-wood transport. Application of the program allows to increase efficiency when introducing cut-to-length technology in Northwest Russia, decrease wood transport costs and improve utilization of short-wood truck fleet. Testing of the program and comparison of alternative delivery plans show that the efficiency of short-wood transport can be increased by 40%. This program could also be used for other applications, such as road planning, fuel supply or logistics in silviculture, and also provides an excellent opportunity to convey knowledge gained through research to the companies in a clear and practical way.

Keywords: Russia, logging, cut-to-length, logistics, delivery plan, truck fleet, optimization, GIS, MapInfo

1. Introduction – *Uvod*

In Russia, logging operations are traditionally divided into three stages: harvesting, transport and work at the central processing yard. Wood harvesting is conducted according to full-tree, tree-length or cut-to-length methods. These methods are different regarding the applied technology and namely delimbing and cross cutting taking place at the stump, road-side or central processing yard (Karvinen et al. 2006). Although the lack of appropriate domestic machinery hinders the implementation of cut-to-length method, it is becoming increasingly common in Russia due to technology transfer from the Nordic countries. The reasons for increasing popularity of cut-to-length method have been as follows: better suitability of this method to other fellings than just clear-cutting, smaller environmental impacts, cleaner wood, less requirements for road-side landings compared to full-tree and tree-length methods (Gerasimov 2004). For example, in the Republic of Karelia and Leningrad region, approximately 70% of harvested wood is already logged with cut-to-length method, whereas its share in other regions of Russia is considerably smaller, at the level of the whole Russian Federation it is approximately 30% (Gerasimov et al. 2005). Methods of wood transport depend on the used harvesting methods: wood is transported either directly to the end user from the road side storage or via intermediate storages or central processing yard. It is quite easy to manage logistic issues related to traditional tree-length method as all tree-length wood from cutting areas is transported to one central processing yard. Application of the cut-to-length harvesting method or using of the processor at a road-side storage require more attention on wood transport logistics as different timber assortments or short-wood from cutting areas should be delivered directly to several customers: pulp mills, sawmills, wood-based boards mills, wood terminals, and railway stations. The short-wood logistics is complicated and can not be realized by current tree-length approaches effectively (Sikainen et al. 2005). Logistical approaches for short-wood transport are not yet well developed in Russia. Software and tools developed in countries having long experience of cut-to-length method and short-wood logistics, namely Finland and Sweden (Andersson et al. 2007, Forsberg et al. 2005, Fjeld and Hedlinger 2005, Uusitalo 2005, Hedlinger et al. 2005, Helstad 2006), are not necessarily applicable in Russian conditions. This is due to the specific organizational structure of Russian logging companies, which include a transport department with own vehicle fleet, garages and repair workshops. Russia also has specific requirements for axle load of trucks, own standard of round-wood, category of roads, poor state and maintenance of roads, seasonality of road availability, uneven distribution of logging during the year, etc. Moreover solutions are usually company specific, so that tailored programming tools need to be developed for improving planning and optimization of wood transport in operational and tactical tasks.

2. Objectives of the program – *Smjernice programa*

The objective is to develop a GIS-based decision support program for planning and analyzing short-wood transport for a logging company level in Russian conditions. The program should give the logging company comprehensive information about the benefits and limitations of different short-wood transport options. The logging company should get sufficient information to make sound short-term and long-term decisions. Development of the program has been supported by the latest research results that have been produced as part of the »Intensification of forest management and improvement of wood harvesting in Northwest Russia« project (web-address of the project is http://www.metla.fi/hanke/3384/subproject-2.htm#background) as well as some other projects.

The economic feasibility of logging operations that provide short-wood is a critical element for the development of forestry and wood harvesting in Russia (Karjalainen et al. 2005). The decision support program also acts as a set of guidelines for logging companies since it takes economical aspect into consideration, draws attention to the lack of short-wood trucks and gives recommendations for organizational management of logistics (i.e. delivery planning, locations of garages and temporary wood terminals) when required.

3. Problem set – *Problematika*

The problem in the short-wood transport is to define delivery plans, which allows maximizing wood removals and rationalizing the usage of short-wood truck fleet in a logging company. The term delivery plan means an output schedule for truck fleet for a given time period, including for example places and time for loading and unloading, and type of transporting assortments.

Let us formalize the short-wood transport problem. The logging company has several operation units: cutting areas, customers, railway stations and garages (Fig. 1). The following data are known: allowable and actual short-wood storages at roadsides, daily productions in cutting areas by assortments, and their accessibility for wood transport in winter or all-seasons. The company has valid wood trade contracts with some customers and monthly delivery volumes by assortment are known for each customer.

The type of assortment depends on tree species, use (sawlog, pulpwood, energy wood), size or dimensions (diameter and length), and quality of wood (domestic or export requirements). The size of an assortment can be specified by limiting values (minimum, maximum), tree species can be specified directly (pine, spruce, birch, aspen and other) or given as a general information (coniferous, deciduous, any). Moreover, a customer may accept unsorted roundwood. In such a case, two different assortments in the cutting area can be equal raw material in the mill and vice versa. Therefore the procedure of assortment identification has to distinguish between assortments nomenclatures in cutting areas and at customer.

All cutting areas and customers are connected by road and/or railway. Trans-shipment from trucks to railway wagons is organized in terminals at railway stations. Wood from cutting areas to mills or terminals is delivered by short-wood trucks. The number of trucks and their characteristics (model, carrying capacity, etc) are established. Each truck registers in a concrete garage. There can be several garages. Geographical information system (GIS) should be used to locate and connect cutting areas, terminals, customers and garages.

4. Program structure – *Struktura programa*

4.1 Overall structure of the program – Sveobuhvatna struktura programa

Decision support program has been constructed in MapInfo environment using Map Basics for coding and Microsoft Excel for reporting, i.e. with very common software.

MapInfo environment provides the possibility to build a program with user interfaces and custom dialog boxes with MS Excel. An overview of the pro-

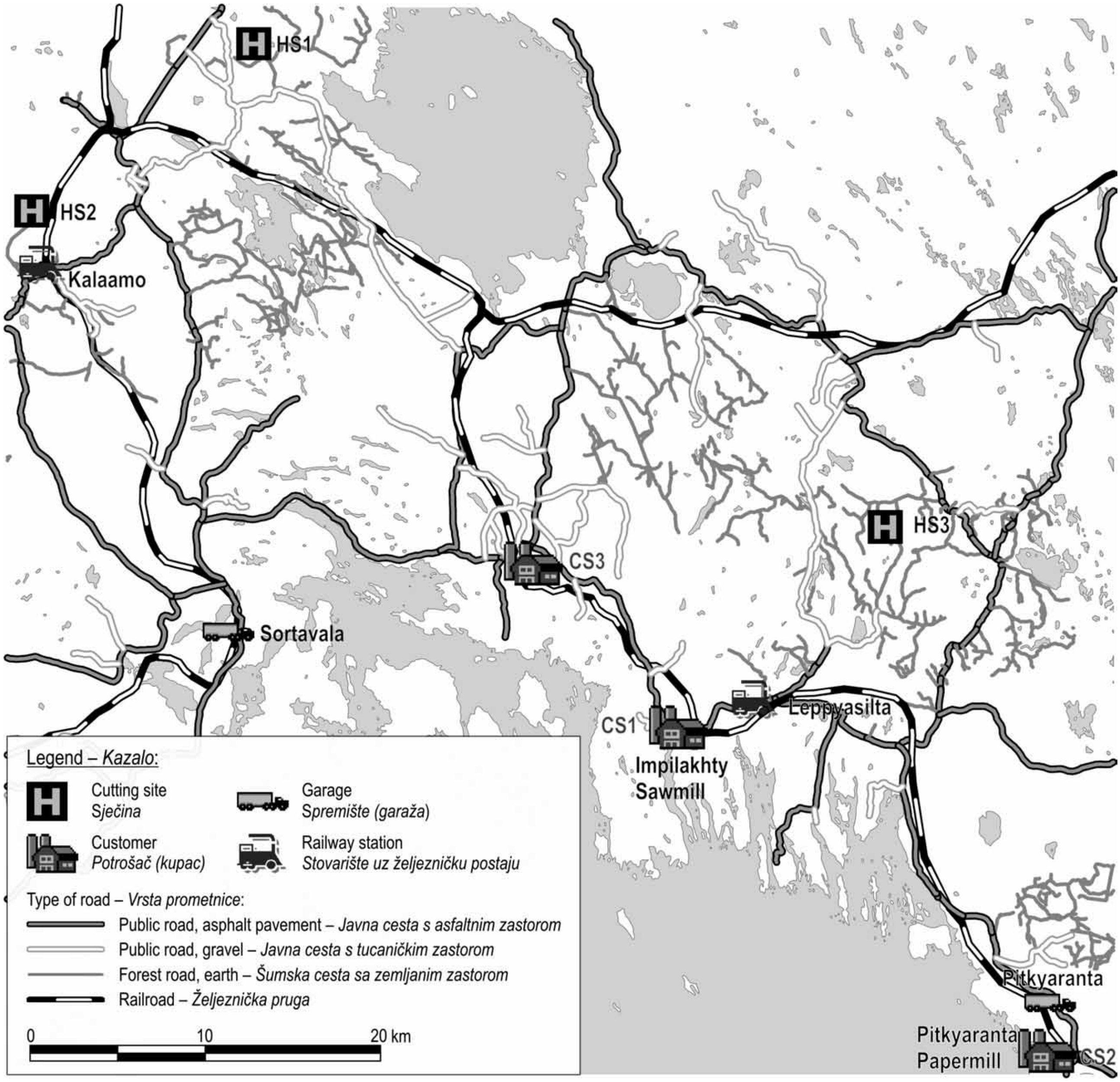

Fig. 1 Example of logistic management units of a logging company
Slika 1. *Primjer logistike organizacijskih jednica poduzeća za pridobivanje drva*

gram structure and its most important components is presented in Fig. 2.

Data module includes information about roads and their quality, locations of logistic management units (i.e. cutting areas, customers, truck garages, and railway stations) and their characteristics. The user can easily manage data with a user friendly interface.

The second part of the program is *Graph* module. In this module the user can generate a layer of roads including logistic management units. Several submodules have been created for the managing graph (construction, editing, deleting, and adding).

The module of *Optimal Routes* helps the user to search with heuristic optimization method better variant of short-wood transporting route.

The module of *Optimal Delivery Plan* helps the user to optimize by dynamic programming daily tasks for each truck.

The *Reporting* module contains reports of optimal routes and delivery for short-wood transport for the logging company.

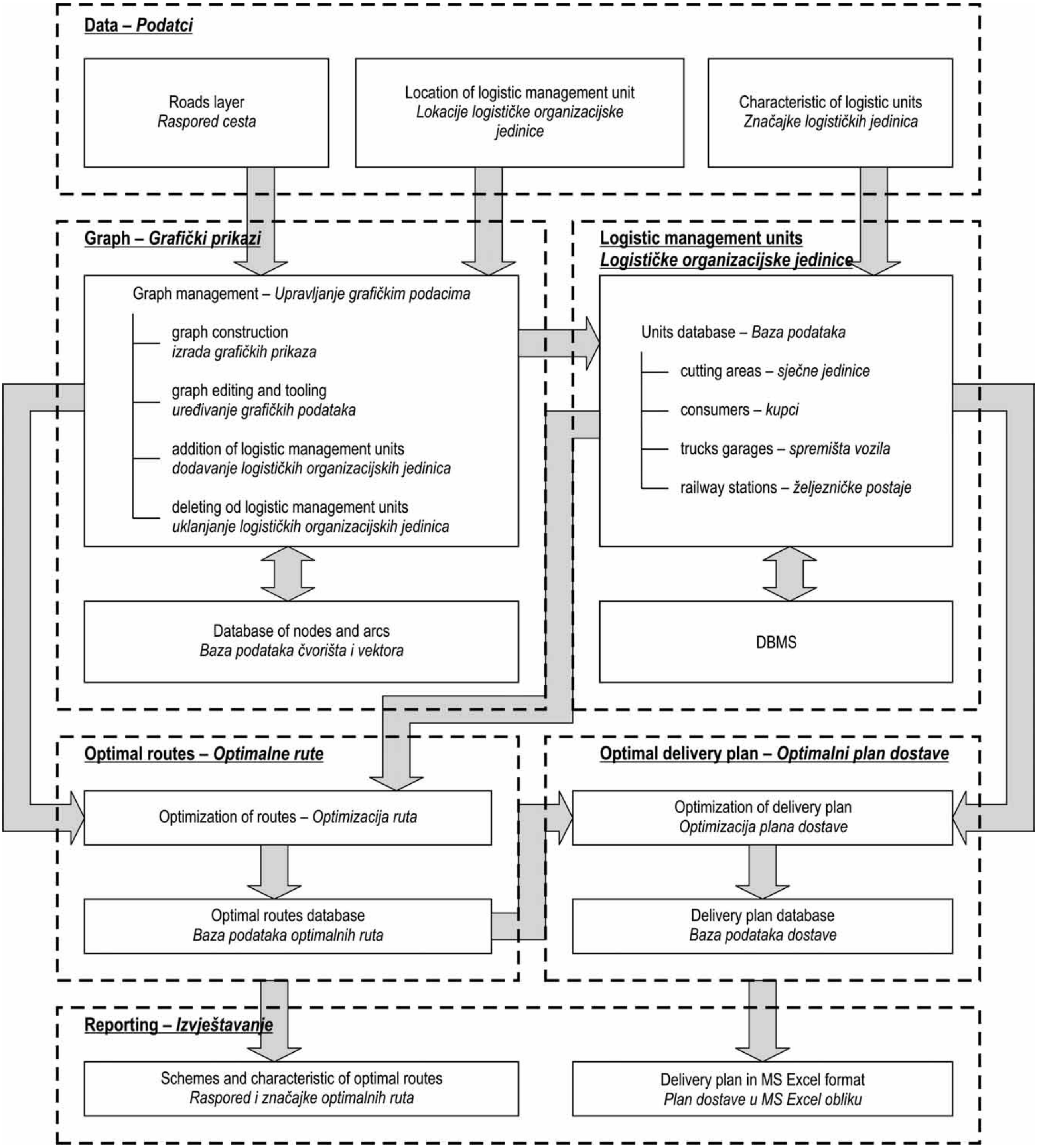

Fig. 2 An overview of the program structure
Slika 2. *Pregled strukture programa*

4.2 Data – Podatci

Data required for planning and analyzing short-wood transport include:

⇒ Road maps in MapInfo format

⇒ Location of logistic management units (cutting aresas, customers, railway stations, garages)

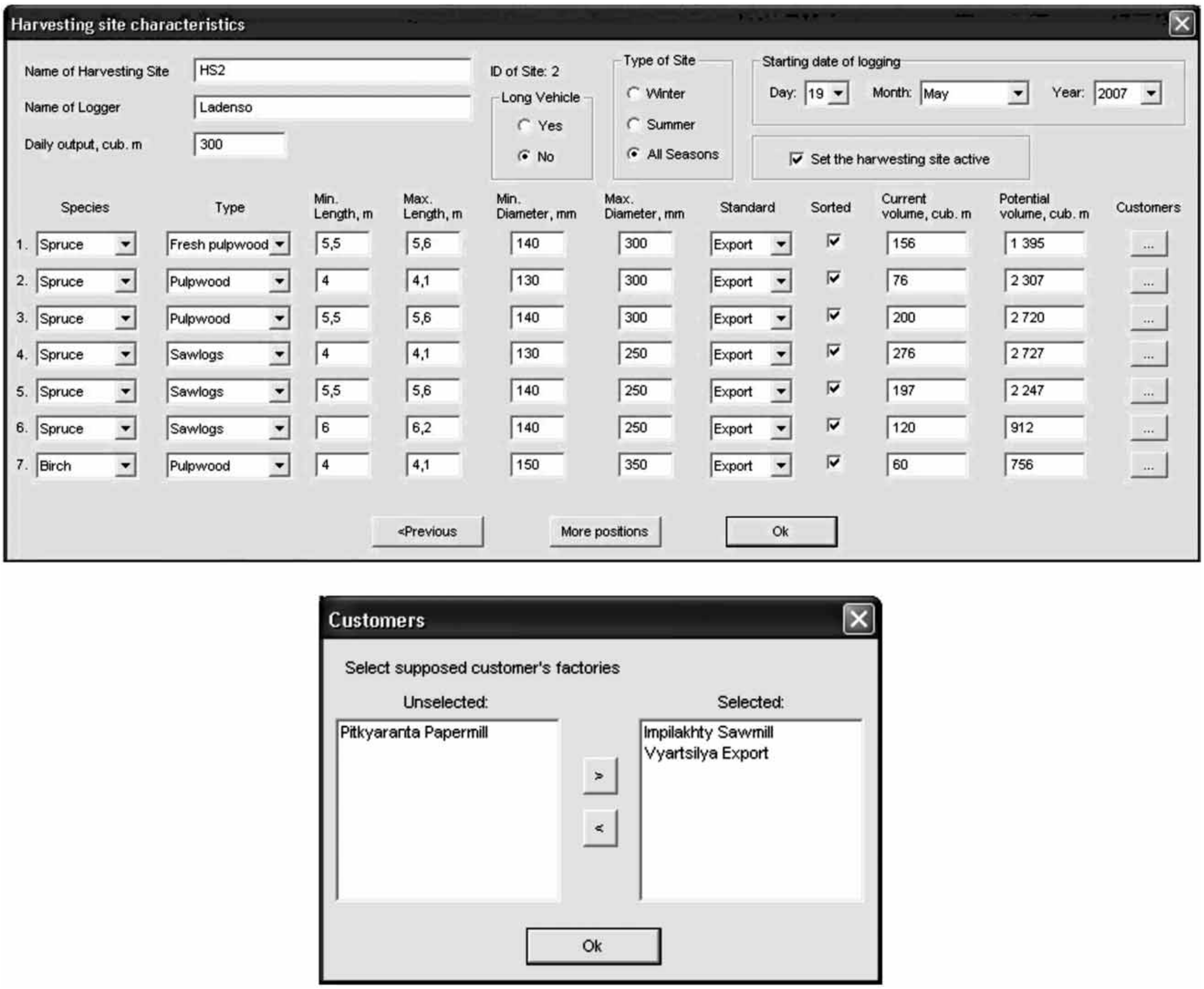

Fig. 3 Screenshots for a cutting area
Slika 3. *Zaslon računala pri odabiru značajki sječine*

⇒ Characteristics of logistic management units

Cutting areas (Fig. 3): starting date of logging; type of cutting site (winter, summer, the whole year round); type of producible assortments and their characteristics: tree species, size, and quality class; average production of daily logging; growing stock by assortments: actual cut and allowable cut; possibility to use heavy trucks with trailer; possible customers for each assortment.

Customers (Fig. 4): type of customer (local customer means that direct delivery by truck is possible, remote customer means that trans-shipment from trucks to railway wagons is needed); distance from railway station to remote customer; type of used assortments and their characteristics: tree species, size, quality class; monthly contracted deliveries by assortment.

Garages (Fig. 5): number of registered trucks; characteristics of each truck: model, trailer or semi-trailer availability, registration number, carrying capacity, average time for loading and unloading.

Railway station: name, code; costs of trans-shipment from trucks to wagons via terminal per m^3

⇒ Wood transporting costs and trans-shipment costs at terminals are taken into account when searching optimal routes.

4.3 Graph – Grafički prikazi

Before searching optimal routes, the initial layer of roads has to be transferred into the graph. The first step is the creation of the layer of nodes. Nodes

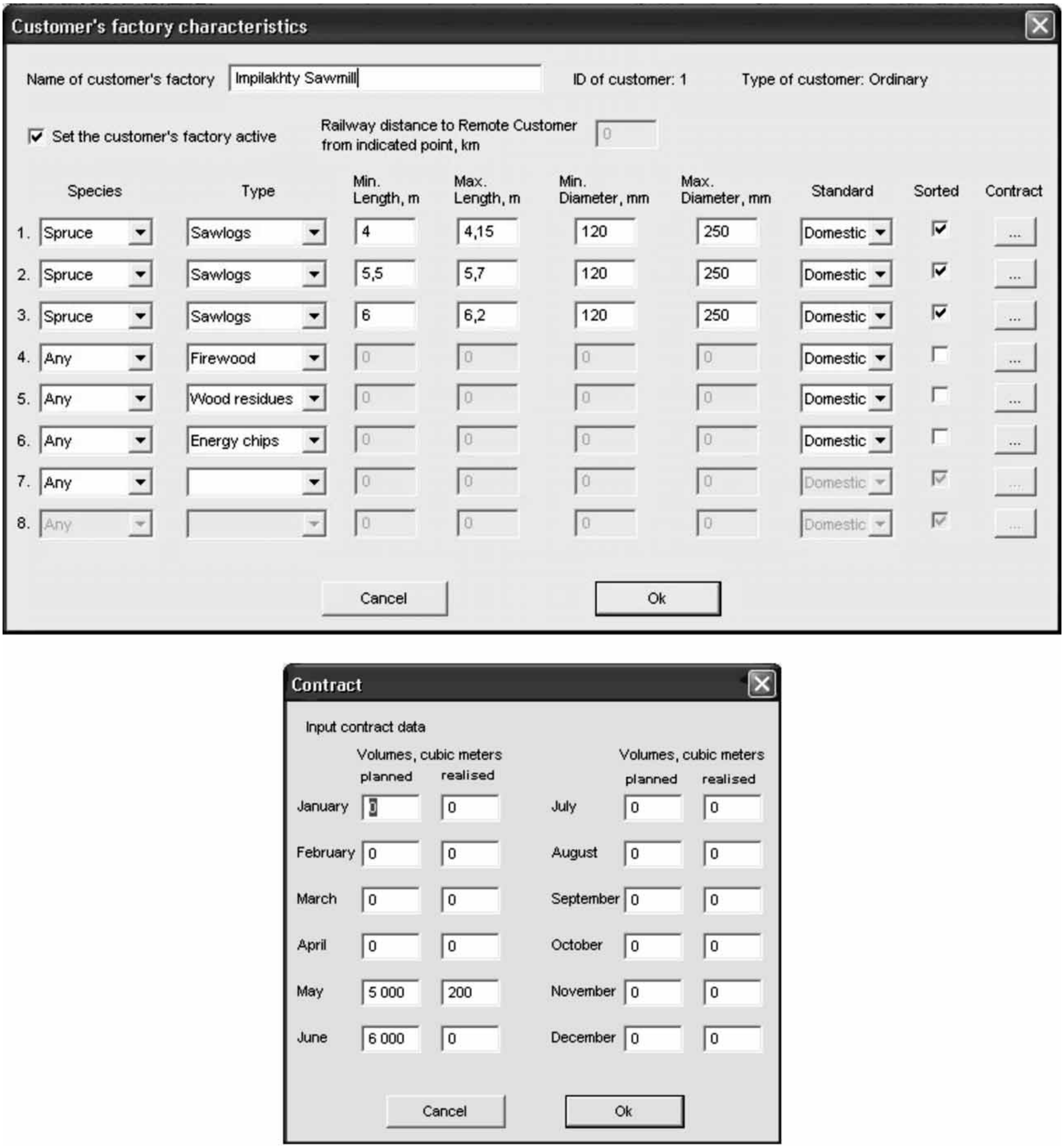

Fig. 4 Screenshots for a customer
Slika 4. *Zaslon računala pri podešavanju podataka o kupcu*

are numbered and saved in the database. The next step is the creation of the layer of arcs – every road is transferred into several independent segments. The starting and the ending points of segments coincide with dotty objects of the layer of nodes.

Type of the road, number of starting and final dots, arc length and computed time of moving are entered into database for each arc. The user has to put down the average speeds of all types of roads for the calculation of moving time.

If the user knows the specific properties of the road sections – their state, complicated turns, and other factors affecting speed – the program has special tools for specifying them. Fig. 1 shows an example of the graph including logistic management units of a logging company.

4.4 Search of optimal routes – *Utvrđivanje optimalnih ruta*

The search of optimal routes helps to find the route with the lowest transport costs. Relative or absolute wood transport costs per 1 m^3 by different types of roads and trans-shipment costs at the terminals have to be established.

Estimation of moving time and costs between the logistic management units are important elements for optimization. Moving time depends on the distance and the average speed of moving along the road, under different condition. Usually several paths can be used for moving.

There are several approaches to optimal route searching (Dijkstra 1956, Hart et al. 1968, Stefankis and Kavouras 1995, Jonsson 2003, Huurinainen and Ikonen 2007). The Dijkstra algorithm is the most simple and precise one. Moreover, an absolute optimum can always be reached. Application of the Dijkstra algorithm for this task showed that the algorithm does not work properly when there is a huge number of nodes in the graph. Therefore an original heuristic method based on the Dijkstra algorithm was applied, allowing taking into account all nodes of the graph for every step of the algorithm (Appendix).

All routes and their characteristics are saved in the database and downloaded from there when queries are repeated. This saves time significantly during calculation of new alternatives for the delivery plan of the same graph.

4.5 Search of optimal delivery plan – *Određivanje optimalnoga plana isporuke*

The synthesis of the delivery plan can not be solved by classical approaches (Andreev and Gerasimov 1999). This problem may be classified as »open« and »without end«. The process of the delivery plan calculation for every truck stops and the procedure for return to the garage starts because shift ends; lack of short-wood in cutting areas, obligations of wood trade contracts already performed. The original algorithm based on dynamic programming was developed for these tasks (Sokolov and Gerasimov 2004).

The criterion for optimization is wood transport per shift for every truck. Total time of the truck moving is minimized during limited shift without non-technological stops. The established optimal decision directly corresponds to maximum wood transport per shift, i.e. number of runs. During conditional optimization on every step of the dynamic programming for every current cutting area in turn sets customers with minimum total moving time. Moving time is calculated from the beginning of the shift to the arrival to the current cutting area.

During unconditional optimization (from the end to the beginning) the plan with maximum runs is defined. If several alternative plans with the same number of runs are defined then the plan where the

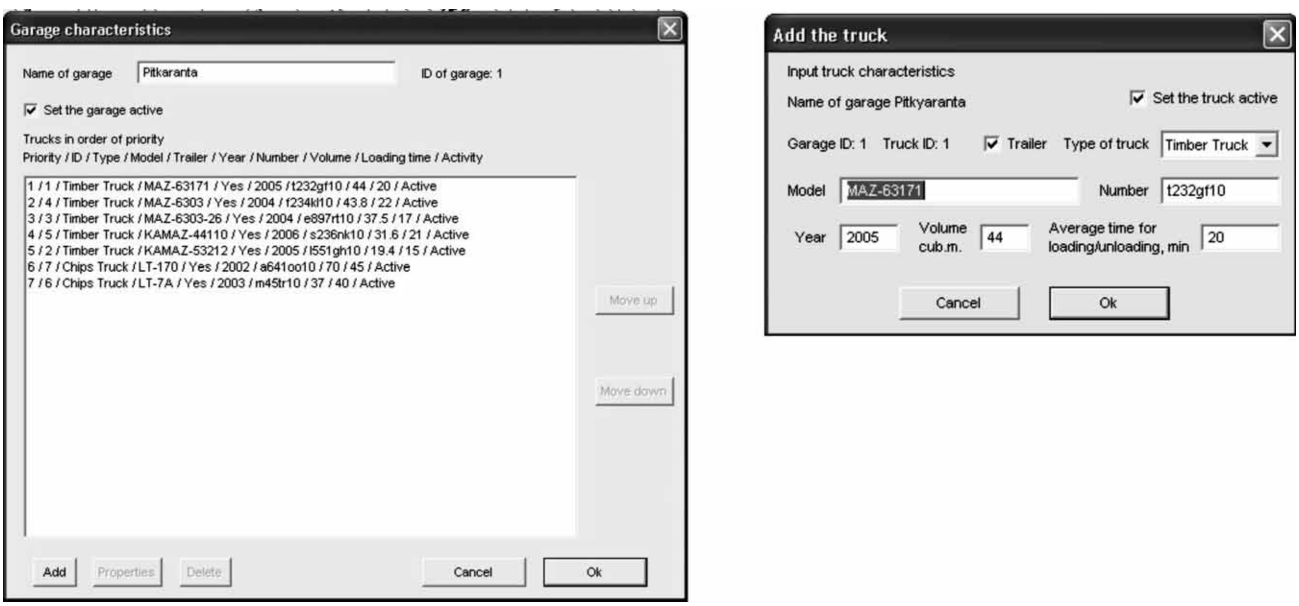

Fig. 5 Screenshots for a trucks garage
Slika 5. *Zaslon računala pri podešavanju podataka vozila*

Name of Garage: Garage1												ID of Garage: 1			
Arrival Date	Shift	Arrival Time	Departure Date	Departure Time	Destination	Distance, km	Long Vehicle	Species	Type	Min. length	Max. length	Min. diam.	Max. diam.	Sorted	Standard
Timber Truck Volvo-FH12 with trailer; Number: b185bo98; Volume: 52 cub.m															
10.8.2007	1	8:00	10.8.2007	8:56	HS2	34,15	+	Conifers	Sawlogs	4	6	260	420	+	Export
10.8.2007	1	9:46	10.8.2007	10:19	Terminal	7,1	+	Unloading							
10.8.2007	1	11:09	10.8.2007	12:00	HS1	29,77	+	Conifers	Sawlogs	4	6	260	420	+	Export
10.8.2007	1	12:50	10.8.2007	15:06	Sawmill1	41,64	+	Unloading							
10.8.2007	1	15:56	10.8.2007	16:19	Garage	29,1	+	Return							
Total distance 142 km. Total volume 104 cub.m															
Timber Truck Volvo-FH12 with trailer; Number: b184bo98; Volume: 52 cub.m															
10.8.2007	1	8:00	10.8.2007	9:07	HS1	50,22	+	Conifers	Sawlogs	4	6	260	420	+	Export
10.8.2007	1	9:57	10.8.2007	10:48	Terminal	29,77	+	Unloading							
10.8.2007	1	11:38	10.8.2007	12:29	HS1	29,77	+	Conifers	Sawlogs	4	6	260	420	+	Export
10.8.2007	1	14:19	10.8.2007	15:34	Sawmill1	41,64	+	Unloading							
10.8.2007	1	16:24	10.8.2007	16:48	Garage	29,1	+	Return							
Total distance 181 km. Total volume 104 cub.m															
Timber Truck Volvo-FH12 with trailer; Number: b187bo98; Volume: 52 cub.m															
10.8.2007	1	8:00	10.8.2007	9:07	HS1	50,22	+	Conifers	Sawlogs	4	6	260	420	+	Export
10.8.2007	1	9:57	10.8.2007	11:13	Sawmill1	41,64	+	Unloading							
10.8.2007	1	12:03	10.8.2007	14:03	HS3	52,03	+	Conifers	Sawlogs	4	6	260	420	+	Export
10.8.2007	1	14:53	10.8.2007	15:53	Sawmill1	52,03	+	Unloading							
10.8.2007	1	16:43	10.8.2007	17:06	Garage	29,1	+	Return							
Total distance 225 km. Total volume 104 cub.m															
Timber Truck Volvo-FH12 with trailer; Number: b188bo98; Volume: 52 cub.m															
10.8.2007	1	8:00	10.8.2007	9:07	HS1	50,22	+	Conifers	Pulpwood						Export
10.8.2007	1	9:57	10.8.2007	10:48	Terminal	29,77	+	Unloading							
10.8.2007	1	11:38	10.8.2007	12:29	HS1	29,77	+	Birch	Pulpwood						Export
10.8.2007	1	14:19	10.8.2007	15:10	Terminal	29,77	+	Unloading							
10.8.2007	1	16:00	10.8.2007	16:24	Garage	30,39	+	Return							

Fig. 6 An example of a delivery plan
Slika 6. *Primjer plana isporuke*

truck is back to garage as late as possible is selected (use of truck is maximized).

The assortment with the highest priority is selected if alternative types of assortments are allocated for transport from the optimal cutting area to optimal customer. The assortment priority is moved in corresponding user's dialog (characteristics of cutting area or customer).

All trucks are included in the total list by garage according to user's priority. Trucks priority is set in corresponding user's dialog (characteristics of garage). The first plan is calculated for the first truck in the list, then for the second one (for undelivered wood) and so on. In case of several garages, the first plans are calculated for the first trucks of all garages. Next plans are calculated for the second trucks of all garages and so on as long as there is wood to be delivered.

The results are saved as Microsoft Excel file, every sheet in the file is a delivery plan for all trucks of a single garage.

5. Efficiency of delivery plans – *Učinkovitost planova isporuke*

5.1 Testing – Testiranje

The efficiency of the developed program was tested in the actual logging process. Three delivery plans were compared for a logging company operating in the Republic of Karelia. The company provided forest inventory and infrastructure information and thus the following map layers were created: roads (5 types of quality), forest stands, and cutting areas. The »basic« delivery plan (Plan 1) was made in a traditional way without program support. Two delivery plans (Plan 2 and Plan 3) were made with the program. The difference between the second and third delivery plan is that in the third plan (Plan 3) the trucks change the drivers on the route without retuning to the garage in every shift.

The delivery plans were created for four consecutive working days using two shifts per day for the same conditions of logistic management units (cutting areas, customers, routes, fleet, etc). There were five trucks based in one garage, four cutting areas, and four customers (three sawmills and one wood terminal). Capacities for short-wood trucks were 50–52 m^3 depending on the model (Volvo, Scania). Daily outputs in cutting areas were 140–420 m^3 depending on the site, the actual cut per cutting area was 5,000–15,000 m^3. A half of the actual cut is coniferous sawlogs including 9% of small size spruce sawlogs, 18% – coniferous pulpwood, 22% – birch pulpwood, 10% – energy wood (Gerasimov et al. 2005).

5.2 Performance indexes – Indeksi učinkovitosti

Delivery plans were compared using the following performance indexes: total work time (hours), total run (kilometers); total number of runs, total volume of wood transport (m^3), total cargo run (kilometers), required number of trucks, fleet utilization rate per shift, index of loaded distance; index of operation work (m^3/km).

Fleet utilization rate per shift is calculated as follows:

$$k_u = \frac{t_p}{t_s \cdot n} \qquad (1)$$

where:

t_p total work time per day, hours
t_s total length of shift, hours
n number of working trucks, units

The fleet utilization rate per shift has somewhat different meaning than standard fleet utilization rate. This rate shows truck utilization within a shift, i.e. how effectively trucks are utilized in the delivery plan. If the truck was standing idle during a day, it was excluded from the calculation. The most efficient delivery plan means the least working trucks for the same daily short-wood transport or, vice versa, the biggest short-wood transport for the same number of working trucks.

The index of loaded distance means the ratio between the total cargo run and the total run.

The operation work shows how much short-wood is delivered per 1 km of the total truck's run.

5.3 Results – Rezultati

Comparison of the results between delivery plans when applying the basic method (Plan 1) and the program (Plans 2 and 3) are presented in Table 1. The change in the indexes (in percents compared to the basic Plan 1) is shown in parentheses.

Optimization of the schedule using the program with Plan 2 shows that the total delivered wood volume increases from 2740 m^3 to 2997 m^3 (+9%). The total run is the same, but the total working time decreases by 17%. The required fleet is the same, 5 short-wood trucks. The fleet utilization rate decreases slightly (-4%), the index of loaded distance increases by 22%, the total volume of transporting roundwood per km increases by 9%.

Optimization of the schedule using the program with Plan 3 shows that the total delivered wood volume increases from 2740 m^3 to 3000 m^3 (+10%). The total run decreases from 7382 km to 5743 km (-22%), the total working time decreases from 307 h to 234 h (-22%). It reduces the required fleet from 5 to 4 trucks. The fleet utilization rate increases by 19%, the index of loaded distance increases by 30%, the total volume of transporting roundwood per km increases by 42%.

6. Discussion and conclusion – *Rasprava i zaključci*

Developed decision support program can be used for planning and analysis of short-wood transport. One logging company was asked to provide the actual data for testing the program. Different transport options were then presented to the logging company, and feedback was received for further development of the program.

Testing of the program and comparison of alternative delivery plans show that the efficiency of short-wood transport can be increased by 40%. Application of the program allows computer based processing of delivery plans and thus provides possibilities for producing several alternatives and taking into account possible changes both inside and outside the organization. And most importantly, the program makes it possible to optimize transportation operations.

The program may not be able to find global optimum in some cases. Testing shows, however, that

Table 1 Comparison between the basic delivery Plan 1 and delivery Plan 2 and Plan 3 made with the decision support program

Tablica 1. *Poredba osnovnog plana (plan 1) i preostala dva plana isporuke (plan 2, plan 3) nastala kao rezultat programa za pomoć pri donošenju odluka*

Plan – *Plan*	Total working time, h *Ukupno vrijeme rada, h*	Total run, km *Ukupna udaljenost, km*	Number of runs *Broj turnusa*	Total volume, m^3 *Ukupni drvni obujam, m^3*	Total cargo run, km *Ukupna udaljenost vožnje opterećenoga vozila, km*	Required number of trucks *Potreban broj kamiona*	Fleet utilization rate *Stupanj iskorištenosti flote vozila*	Index of loaded distance *Indeks udaljenosti opterećenoga vozila*	Operation work, m^3/km *Operativan rad, m^3/km*
1	307	7382	53	2740	2212	5	0.754	0.300	0.371
2	255 (-17%)	7382 (0%)	58 (+9%)	2996 (+9%)	2697 (+22%)	5 (0%)	0.728 (-4%)	0.365 (+22%)	0.406 (+9%)
3	239 (-22%)	5743 (-22%)	58 (+9%)	3000 (+10%)	2872 (+30%)	4 (-20%)	0.895 (+19%)	0.499 (+66%)	0.526 (+42%)

Plan 1 was made in a traditional way without program support, the trucks return to the garage in every shift.
Plan 2 was made using the program, the trucks return to the garage in every shift.
Plan 3 was made using the program, the trucks change the drivers on the route without retuning to the garage in every shift.

Plan 1 izrađen je tradicionalnim načinom bez pomoći računala, vozila (kamioni) vraćaju se u spremište na kraju svake radne smjene.
Plan 2 izrađen je uz pomoć programa, vozila se vraćaju u spremište na kraju svake radne smjene.
Plan 3 izrađen je uz pomoć programa, promjene vozača na trasi puta bez vraćanja u spremište na kraju svake radne smjene.

problems appear only in the case of complicated graphs with chaotic structure. In reality forest road networks are not located randomly. They have certain directions, and therefore the developed algorithm for searching optimal routes can be considered reliable.

Mathematical programming has been used as the main tool for optimization. Coding of algorithms has been done in a simple Map Basic environment. Obviously such universal algorithmic languages as C++ or Visual Basic would provide better processing speed and flexibility of the program.

Extraction of short-wood from harvesting processes is becoming more common practice in Northwest Russia, particularly in Karelia, Leningrad, Pskov and Novgorod regions. Short-wood transport is also expected to increase in other parts of Russia. Application of cut-to-length harvesting method would allow to increase productivity of wood harvesting and thus to improve the economics of logging operations. At the same time, harvesting of forest resources by cut-to-length method causes less environmental impacts than traditional methods and improves the ecological state of forest sites both in the short and long term.

Review of the existing logistic methods and approaches applied in Russia show that logging companies are using different approaches. These approaches do not provide the basis for economic analysis. Moreover decision making is strongly based on the experience of logistic manager without software support. Approaches are suitable for companies which utilize traditional tree-length technology and one central processing yard. Introduction of the Nordic cut-to-length technology requires more attention to wood transport logistics as roundwood from cutting areas has to be delivered directly to several customers, terminals, and railway stations. GIS-based decision support program has been developed to assist logging companies in decision making related to planning, utilization and optimization of vehicle fleet. Searching of optimal routes could also be used for other applications, i.e. forest road planning, fuel supply, seedling transportation, etc.

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Appendix – *Dodatak*

Heuristic algorithm uses four arrays which have *N* numbers. *N* means number of nodes of the graph. Array *B* keeps the current shortest distances from the initial point to the corresponding node. Array *C* keeps the number of the next to the last point on the current shortest way from the initial point to the node. Array *S* keeps the marks of node consideration. The mark can have three meanings: 0 – the node is not considered, 1 – the node is included in consideration list, and 2 – if the node has already been considered. Array *H* keeps the heuristic estimation of transport costs per m^3 from the tested node to the final point of the route. The Manhattan method was used for the calculation of transport costs on the hypothetical road consisting of perpendicular segments: the first segment is located along a parallel and the second segment along a meridian (Benkert et al. 2006).

The algorithm consists of the following steps:

1. Let i to go from $i = 1$ to N. Give value 0 to $S(i)$ and value i to $C(i)$.
2. Give for *B* transport costs per 1 m^3 from initial point to every node of the graph. If the arc from the initial point to the considered node is absent, *B* is infinite.
3. Give for *H* heuristic transport costs per m^3 from the tested node to the final point of the route.
4. Give meaning 0 to element array *C* which corresponds to the initial point of the route.
5. Make active status for the initial node of the route.
6. Give meaning 2 to element array *S* which corresponds to the active point of the route.
7. Define the list of nodes of the graph which are connected with active node by arcs and value of elements array *S* less than 2.
8. Give $S(k) = 1$, if $B(k) > B(j)+A(j,k)$ than $B(k) = B(j)+A(j,k)$ and $C(k) = j$ for all nodes found on previous step list. Where k – number of the node from the concerned list; j – number of the active node; $A(j,k)$ – transport costs per 1 m^3 by the arc from node j to node k.
9. Among nodes from the list obtained in step 7 find the node with minimal sum of values of elements of arrays *B* and *H*. Make this node active.
10. If the active node is the final point of the route go to step 12.
11. Go to step 6.
12. Insert the final node into the route.
13. Calculate the value of array *C* for the final node. Let value is z.
14. Insert the node with number z into the route.
15. If $C(z) = z$, then go to 18.
16. $z = C(z)$
17. Go to 14.
18. Calculate the route in reverse order, from the last inserted node to the first inserted node.

Due to the fact that only several nearest nodes are checked in every cycle of the algorithm, the processing time does not depend on the number of nodes. The processing time depends on the distance between the initial and final points of the route, measured both in arcs and degrees of graph branching. In comparison with the Dijkstra algorithm the processing time has decreased a hundred times.

The double-ply search provides for the decrease of probability of errors. The search goes from the initial point to the final point and after that back from the final to the initial point. The next best route is selected if the searching results are not similar. This option increases the processing time by two times, but eliminates the possibility of mistakes.

Sažetak

Računalni program temeljen na GIS-u kao potpora odlučivanju pri planiranju i raščlambi transporta kratkoga drva u Rusiji

U Rusiji su šumski radovi tradicionalno podijeljeni u tri vrste: sječa, transport te radovi na stovarištu. Sječa i izradba stabala provodi se deblovnom, stablovnom i sortimentnom metodom. Te se metode razlikuju s obzirom na primijenjene postupke te mjesto kresanja grana i trupljenja debla, koje može biti u sječini, na šumskoj cesti ili na stovarištu. Nedostatak domaće mehanizacije priječi primjenu sortimentne metode, koja postaje sve uobičajenija u Rusiji zbog transfera tehnologije iz nordijskih zemalja. Ta je tehnologija pogodnija ne samo kod čistih već i kod ostalih vrsta sječa zbog manjega utjecaja na okoliš, smanjenoga udjela nečistoće na oblovini te su, među ostalim, i zahtjevi za pomoćna stovarišta manji

nego kod stablovne metode, što je povećalo popularnost sortimentne metode izradbe drva. Na primjer, u Republici Kareliji i u lenjingradskoj regiji približno 70 % drva posječeno je i izrađeno primjenom sortimentne metode, dok je udjel te metode u ostalim regijama manji, a u cijeloj Ruskoj Federaciji iznosi oko 30 %.

Jednostavna logistika prati tradicionalnu deblovnu metodu jer se sve drvo transportira na glavno mehanizirano stovarište. Primjena sortimentne metode ili uporaba procesora na pomoćnom stovarištu zahtjevnija je za logistiku zbog proizvodnje različitih sortimenata ili zbog potrebe neposredne dostave brojnim korisnicima: tvornicama celuloze, pilanama, proizvođačima drvnih ploča te na glavna stovarišta. Logistički sustavi u proizvodnji kratkoga drva složeni su i nemoguća je učinkovita neposredna primjena postojeće logistike deblovne metode. Logistički sustavi za transport kratkoga drva u Rusiji su u povojima. Računalni softver i alati razvijeni u zemljama s dugogodišnjim iskustvom u proizvodnji kratkoga drva sortimentnom metodom, kao što su Finska i Švedska, nisu primjenjivi za ruske uvjete zbog specifične organizacijske strukture ruskoga šumarstva koja uključuje transportni sektor s vlastitim voznim parkom, spremištima i radionicama, zahtjeve za osovinskim opterećenjima vozila, vlastiti standard za oblo drvo, posebnost kategorizacije prometnica, nezadovoljavajuće stanje cesta, sezonsku dostupnost prometnica, neravnomjerni prostorno-vremenski raspored sječina itd. Osim toga poslovna su rješenja obično posebnost pojedinoga poduzeća, tako da programski alati moraju biti razvijani i/ili prilagođavani za kvalitetnije planiranje i optimizaciju na razini operativnih i taktičkih zadataka.

Cilj je bio razviti GIS, sustav za potporu odlučivanju pri planiranju i raščlambi transporta kratkoga drva u ruskim uvjetima za poduzeća čija je djelatnost pridobivanje drva. Poduzeća bi trebala dobiti zadovoljavajuće informacije potrebne za kratkoročno i dugoročno donošenje prihvatljivih odluka. Ekonomska izvedivost šumarskih operacija pri proizvodnji kratkoga drva kritična je sastavnica razvoja šumarstva u Rusiji. Sustav potpore odlučivanju djeluje kao skup smjernica za poduzeća jer u obzir uzima i ekonomski aspekt, te na zahtjev upozorava na manjak kamionskih skupova i daje preporuke za organizaciju logistike (planiranje dostave, lokacije spremišta i pomoćnih stovarišta).

Za pojednostavljenje daljinskoga transporta kratkoga drva pri modeliranju daljinskoga prijevoza potrebni su ovi podaci: sječna područja, kupci, željeznički kolodvori i spremišta/garaže (slika 1). Potrebno je poznavati najveći dopušteni obujam sječa i stvarno stanje na pomoćnim stovarištima uz cestu, dnevnu proizvodnju po vrstama sortimenata i otvorenost šuma mrežom prometnica (zimi i tijekom cijele godine). Na osnovi valjanih ugovora o kupoprodaji drva poznate su tražene količine po sortimentima za isporuku na mjesečnoj razini za svakoga kupca. Veličina sorimenta može biti određena i ograničavajućim vrijednostima (minimum i maksimum). Vrsta se drva može specificirati neposredno ili može biti zadana općenito (četinjače, listače). Osim toga postoji mogućnosti da kupac prihvaća nesortirano oblo drvo. U takvu slučaju dva različita sortimenta iz sječine mogu biti jednaka po obujmu na skladištu kupca, ne znajući točno koji je koji. Zbog toga postupak identifikacije sortimenata mora omogućiti prepoznavanje i na pomoćnom stovarištu i kod kupca. Sve sječine i kupci međusobno su povezani javnim prometnicama – cestama i/ili željeznicom. Prekrcaj je drva s kamiona u željezničke vagone organiziran na međustovarištima uz željezniče stanice. Drvo se iz sječina prevozi kamionskim skupovima. Stoga je potrebno imati podatke o količini (broju) kamionskih skupova i njihovim tehničkim značajkama – model, nosivost itd. Svaki kamion vezan je uz pripadajuće spremište (garažu). Geografski informacijski sustav (GIS) koristi se za lociranje i povezivanje sječina, stovarišta, kupaca i spremišta.

Program potpore odlučivanju izrađen je u okruženju MapInfo korištenjem Map Basica za kodiranje i Microsoft Excela za izvještavanje. U okruženju MapInfo izrađeno je korisničko sučelje s uobičajenim MS Excel dijaloškim prozorima (dialog box). Pregled programske strukture i njegovih najvažnijih sastavnica prikazan je na slici 2. Podatkovni modul (Data modul) uključuje informacije o cestama i njihovoj kakvoći, lokacijama logističkih jedinica (sječine, kupci, kamionske garaže i željeznički kolodvori) te njihove značajke. Korisnik može lako upravljati podacima preko grafičkoga korisničkoga sučelja. Drugi je dio programa grafički modul (Graph module). U tom modulu korisnik može generirati sloj cesta uključujući logističke jedinice. Nekoliko podmodula stvoreno je za upravljanje grafičkim prikazima (izrada, uređivanje, brisanje i dodavanje). Modul optimalnih putova (Optimal routes) pomaže korisniku da metodom heurističke optimizacije odabere bolju inačicu transportnoga puta, a modul optimalne isporuke (Optimal delivery plan) pomaže korisniku da uz pomoć dinamičnoga programiranja svakodnevno odredi zadatak za svaki kamion. Izvještajni modul (Reporting module) sadržava izvještaje optimalnih putova i planova isporuke za transport drva.

Prije utvrđivanja optimalnih putova početni sloj prometnica mora biti grafički prikazan. Prvi je korak stvaranje sloja čvorišta. Čvorišta su pobrojena i pohranjena u bazi podataka. Sljedeći je korak stvaranje sloja krivina – svaka je cesta prevedena u nekoliko neovisnih sastavnica. Početne i završne točke sastavnica podudaraju se s točkastim objektima sloja čvorišta. Vrsta ceste, velik broj početnih i završnih točaka, duljine lukova i izračunato vrijeme prijevoza upisano je u bazu podataka za svaku krivinu. Korisnik mora unijeti prosjek brzina svih tipova cesta za izračun vremena kretanja. Ako korisnik poznaje specifična svojstva cestovnih sastavnica (dijelova cesta) – njihovo stanje, složena skretanja i druge čimbenike koji imaju utjecaja na brzinu, program ima dodatne alate za njihovu specifikaciju. Na slici 1 nalazi se grafički prikaz na kojem su uključene logističke jedinice poduzeća. Potraga za optimalnim putovima pomaže pri traženju puta s najnižim transportnim cijenama. Potrebno je zadati relativni ili apsolutini trošak prijevoza po kubnom metru koji razlikuju različite tipove cesta te cijene prekrcaja drva na stovarištima. Važne sastavnice za optimizaciju je proračun vremena vožnje i cijena prijevoza. Vrijeme ovisi o udaljenosti i prosječnoj brzini kretanja prometnicama. Obično se nekoliko različitih putova može koristiti za prijevoz.

Poznato je nekoliko pristupa pri optimalnom utvrđivanju puta. Dijkstrin algoritam je najjednostavniji i jedan od preciznijih. Osim toga uvijek se može utvrditi apsolutan optimum. Primjena Dijkstrina algoritma za ovaj zadatak

pokazala je da algoritam ne daje valjane rezultate u slučaju postojanja većega broja čvorišta. Zato su primijenjenoj izvornoj heurističkoj metodi temeljenoj na Dijkstrinu algoritmu pridružena i uzeta u razmatranje sva čvorišta grafičkoga prikaza za svaki korak algoritma (v. Dodatak). Svi putovi i njihove značajke pohranjeni su u bazi podataka i korišteni pri ponovljenim upitima. To značajno smanjuje vrijeme tijekom proračuna alternativnih planova isporuke. Uopćavanje plana isporuke ne može se riješiti klasičnim pristupima. Ovaj se problem može klasificirati kao »vječno otvoren«. Proces izračuna plana isporuke svakoga zaustavljanja kamionskoga skupa i postupak povratka u spremište počinje zbog kraja smjene, zbog nedostatka drva u sječinama, a obveze iz trgovinskih ugovora uzete su u razmatranje. Izvoran algoritam temeljen na dinamičnom programiranju već je bio razvijen za ovakve zadaće. Ukupno vrijeme kamionskoga prijevoza smanjeno je tijekom smjene ograničenoga trajanja i bez prekida rada. Pronađena optimalna odluka o putu utvrđuje maksimalni transport po smjeni te broj turnusa. Tijekom uvjetne optimizacije na svakom koraku dinamičnoga programiranja za svaku sječinu određuju se kupci za koje je utvrđeno najmanje ukupno vrijeme vožnje. Ukupno je vrijeme računato od početka smjene pa do dolaska u sječinu. Prilikom bezuvjetne optimizacije (od kraja prema početku) određen je plan koji ima najveći broj turnusa. Ako postoji nekoliko alternativnih planova s jednakim brojem turnusa, odabire se onaj kod kojega se kamion najkasnije vraća u spremište (upotreba kamiona je maksimizirana). Sortimenti najvišega prioriteta izabrani su u slučaju više inačica prijevoza od optimalne sječine do optimalnoga kupca. Izbor prioritetne vrste sortimenata je u odgovarajućem korisničkom dijalogu (značajke sječina ili kupaca). Rezultati su sačuvani kao Microsoft Excel dokument, svaki list (sheet) dokumenta je plan isporuke svih kamiona jednoga spremišta.

Razvijeni program može biti korišten za planiranje i raščlambu transporta kratkoga drva. Testirani program i usporedba alternativnih planova isporuke pokazuju da učinkovitost transporta može rasti i do 40 %. Primjena programa osigurava računalnu obradu plana isporuke i tako pruža mogućnost za izradu nekoliko zamjenskih inačica uz promjenu unutar i izvan organizacije poduzeća. Najznačajnije je to što program može optimizirati sve prometne sastavnice. Program u nekim slučajevima ne nalazi općeprihvaćeni optimum. Testiranje pokazuje da se te situacije pojavljuju u slučaju složenih problema s kaotičnim rasporedom logističkih jedinica. U stvarnosti se šumske prometnice ne postavljaju nasumično. One imaju stručno određen raspored pa se razvijeni alogoritam može smatrati pouzdanim. Matematičko je programiranje korišteno kao glavni alat za optimizaciju. Za kodiranje algoritama upotrijebljen je MapBasic. Očito je da bi univerzalni programski jezici kao što su C++ ili Visual Basic pružili bržu obradu i veću prilagodljivost programa. Donošenje odluka dosada se temelji na iskustvu šumarskih stručnjaka bez pomoćnoga softvera. Ovaj je pristup pogodan za poduzeća koja koriste tradicionalno stablovnu ili deblovnu metodu i jedno glavno mehanizirano stovarište. Uvod sortimentne metode zahtijeva više pažnje prema transportnoj logistici jer se oblo drvo iz sječina dostavlja neposredno nekolicini korisnika te na glavna stovarišta. Potpora GIS-a važna je pri planiranju, iskorištavanju i optimizaciji rada voznoga parka. Utvrđivanje optimalnih putova može se koristiti i za druge namjene, npr. planiranje mreže šumskih prometnica, pri opskrbi pogonskim gorivom, transportu sadnica itd.

Ključne riječi: Rusija, pridobivanje drva, sortimentna metoda, logistika, plan isporuke, vozni park, optimizacija, GIS, MapInfo

Authors' addresses – *Adresa autorâ*:

Yuri Gerasimov, PhD.
e-mail: yuri.gerasimov@metla.fi
Prof. Timo Karjalainen, PhD.
e-mail: timo.karjalainen@metla.fi
Finnish Forest Research Institute
Joensuu Research Unit
Yliopistokatu 6
80101 Joensuu
FINLAND

Assoc. Prof. Anton Sokolov, PhD.
e-mail: a_sokolov@psu.karelia.ru
Petrozavodsk State University
Forest Engineering Faculty
A. Nevsky av. 58
185030 Petrozavodsk
Republic of Karelia
RUSSIA

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