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OPTIMIZATION OF INDUSTRIAL AND FUEL WOOD SUPPLY CHAIN ASSOCIATED WITH CUT-TO-LENGTH HARVESTING

The paper presents the results of the development and application of the computer information system for optimization of wood supply chain in Russian conditions. The system is designed to support of strategic, tactical and operational decisions in terms of logging companies applying cut-to-length technology taken into account the needs of forest bioenergy. Two case-studies in logging companies in Northwestern Russia are analyzed and discussed.

Key words: Cut-to-length method, bioenergy, logistics, wood harvesting, optimization.

Full-tree (FT), tree-length (TL), and cut-to-length (CTL) methods are applied in wood harvesting. These methods differ in relation to the technology utilized. Delimbing and bucking can take place at a stump, road-side, or a central processing yard. Although lack of appropriate domestic machinery has hindered implementation of the CTL method, it has become increasingly common in Russia due to technology transfer from the Nordic countries. Better suitability of this method in particular compared to felling other than just clear-cutting, smaller environmental impacts, work safety, cleaner wood, and less requirements for road-side landings compared to FT and TL methods have been, among other things, reasons for the increasing popularity of the CTL method [1-3]. For example, in the Republic of Karelia, 93% of the harvested wood is already logged with the CTL method.

It is quite easy to manage logistic issues related to the traditional TL method, as all wood from cutting areas is transported to a central processing yard. Applying the CTL harvesting method or use of a processor at a road-side storage requires more attention to wood logistics, as different timber assortments and possibly also energy wood from cutting areas should be delivered directly to several customers: pulp mills, sawmills, wood-based boards mills, power plants, and so on. Therefore logistic approaches used with FT and TL do not work well for CTL logistics.

Logistic approaches for CTL operations are not yet well developed in Russia. This is due to the specific organizational structure of Russian logging companies, which usually include logging and transportation departments with their own vehicle fleets (harvesters, forwarders, trucks), garages, and repair workshops. Russia also has specific requirements for the axle load of trucks, its own standards for roundwood, categories of roads, poor state and maintenance of roads, seasonality of road availability, uneven distribution of logging during the year, 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.

We introduce a decision support system (DSS) for planning and analyzing industrial and fuel wood supply chain associated with CTL operations at the logging company level for Russian conditions [4-10]. Work was carried out in the projects "Wood harvesting and logistics", financed by the European Union through the Finnish Funding Agency for Technology and Innovation (TEKES), and "Decision support system to promote the rational use of woody biomass and logging residues into bio-energy", financed by the Ministry of Education and Science of the Russian Federation. This DSS gives the logging

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

Delivery plan. The term delivery plan means an output schedule for a vehicle fleet for a given time period, including, for example, places and time for loading and unloading, and types of transportation assortments. Defining delivery plans which allow the maximization of wood removals and rationalization of the use of a vehicle fleet may become a challenge for a logging company. The logging company has several operation units: cutting areas, customers, railway stations, and garages. The wood storages at roadsides, daily production in cutting areas by assortments, and their accessibility in winter or all seasons are known. Monthly delivery volumes by assortment are known for each customer with whom the company has a valid wood trade contract.

The type of assortment depends on tree species, use (sawlog, pulpwood, fuel 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, and tree species can be exactly specified or can be given in a more generalized manner (coniferous, deciduous, any). Moreover, a customer may accept unsorted wood. 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 for assortment identification has to distinguish between assortment nomenclatures at cutting areas and at the customer's site.

The structure of the DSS. This DSS has been constructed in a MapInfo environment using C++ for coding and Microsoft Excel for reporting, that is with very common software [4, 8]. It is possible to build a DSS with user interfaces in the MapInfo environment and custom dialogue boxes with MS Excel. An overview of the DSS structure and its most important components is presented in fig. 1.

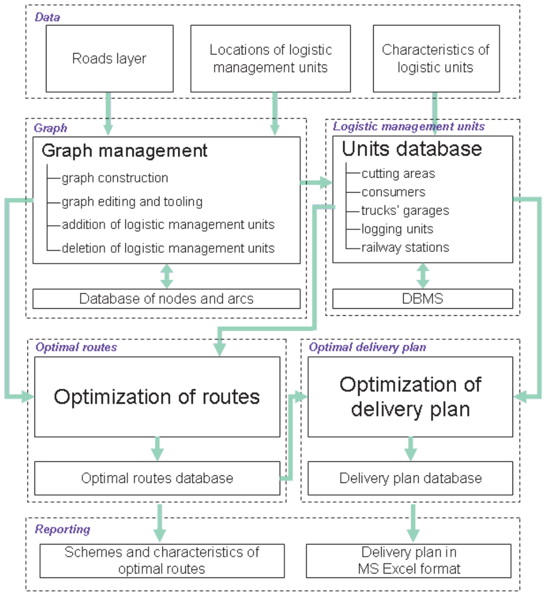

Figure 1. An overview of DSS structure.

The Data module includes information about roads and their quality, locations of logistic management units, and their characteristics. The user can easily manage data with a user friendly interface. 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 (i.e. cutting areas, customers, truck garages, and railway stations). Several sub-modules have been created for managing the graph (construction, editing, deletion, and addition). The Optimal routes module helps the user to search, with a heuristic optimization method, for the best variants for transportation routes. The Optimal delivery plan module helps the user to optimize, with dynamic programming, daily tasks for each truck. The Reporting module creates reports of optimal routes and delivery for CTL transportation for the logging company.

Thus, the problem was logically divided into two consecutive stages, which are the optimization of routes and the optimization of the delivery plan. The output of the first stage produces optimal routes between existing logistic management units. The renewal of optimal routes is needed quite seldom, for example in the event that customers, cutting areas, or road conditions change, and so on. The output of the second stage is a delivery plan which is needed for routine functions as it deals with the operational truck fleet, current wood stocks at roadsides and at mill gates, and so on.

Data required for planning and analysing CTL harvesting and logistics include road maps, location of logistic management units (cutting areas, customers, railway stations, garages) and characteristics of logistic management units:

1. Cutting areas (fig. 2): area, stock, stem volume, average forwarding distance, tree species structure, start date of logging; types of assortments to be produced and their characteristics: tree species, size, and quality class; name of logging unit and the average production of daily logging; growing stock by assortments: actual cut and allowable cut; possibility to use heavy trucks with trailers; possible customers for each assortment.

2. Customers (fig. 3): type of customer (local customer means that direct delivery by truck is possible, whereas remote customer means that trans-shipment from trucks to railway wagons may be needed); distance from railway station to remote customer; types of used assortments and their characteristics: tree species, size, quality class; monthly contracted deliveries by assortment.

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

4. Logging units: characteristics of each CTL chain (harvester and forwarder): models, capacity, and average time for moving between cutting areas.

5. Railway stations: costs of trans-shipment from trucks to wagons via terminal per 1 m^3.

Wood transportation costs and trans-shipment costs at the railway terminals are taken into account when creating optimal routes.

Before searching for optimal routes, the initial layer of roads has to be transferred onto a graph. The type of road, number of start and end dots, arc length, and computed time for travel are entered into the database for each arc. The user has to record the average speeds of all types of roads for calculation of travel time. Wood transportation costs per 1 m^3 by different types of roads and trans-shipment costs at the terminals have to be given for the calculation of transportation costs. If the user knows the specific properties of road sections – their state, complicated turns, and other factors having influence on speed – the program has special tools to specify them.

In search of optimal routes. Usually several paths can be used for travel. The search for optimal routes helps us to find a route with, for example, the lowest transportation costs or the fastest delivery. Important elements for the optimization are the estimation of travel time and costs between the logistic management units. Travel time depends on the distance and the average speed of movement along the road, which can be in different conditions, and so travel time is calculated by the summation of road section times. Numerical values for the distance and the average speed for each road section are obtained from the database of nodes and arcs. Transportation costs are calculated by summing up the road section costs.

Numerical values for the distance and wood transportation costs per 1 m^3 for each road section are obtained from the database of nodes and arcs.

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

In search of an optimal delivery plan. The criterion for optimization is wood transportation per shift for every truck [8]. The total time for truck movement is minimized during a limited shift without non-technological stops. The optimal decision directly corresponds to maximum wood transportation per shift that is the number of truck loads.

During conditional optimization, every step of the dynamic programming, for every current cutting area, provides customers with a minimum total moving time. Moving time is calculated from the beginning of a shift until arrival at the cutting area. During unconditional optimization (from the end to the beginning), a plan which has a maximum number of truck loads is defined. If several alternative plans with the same number of truck loads are defined then the plan where the truck arrives back at the garage as late as possible is selected (the usage of the truck is maximized).

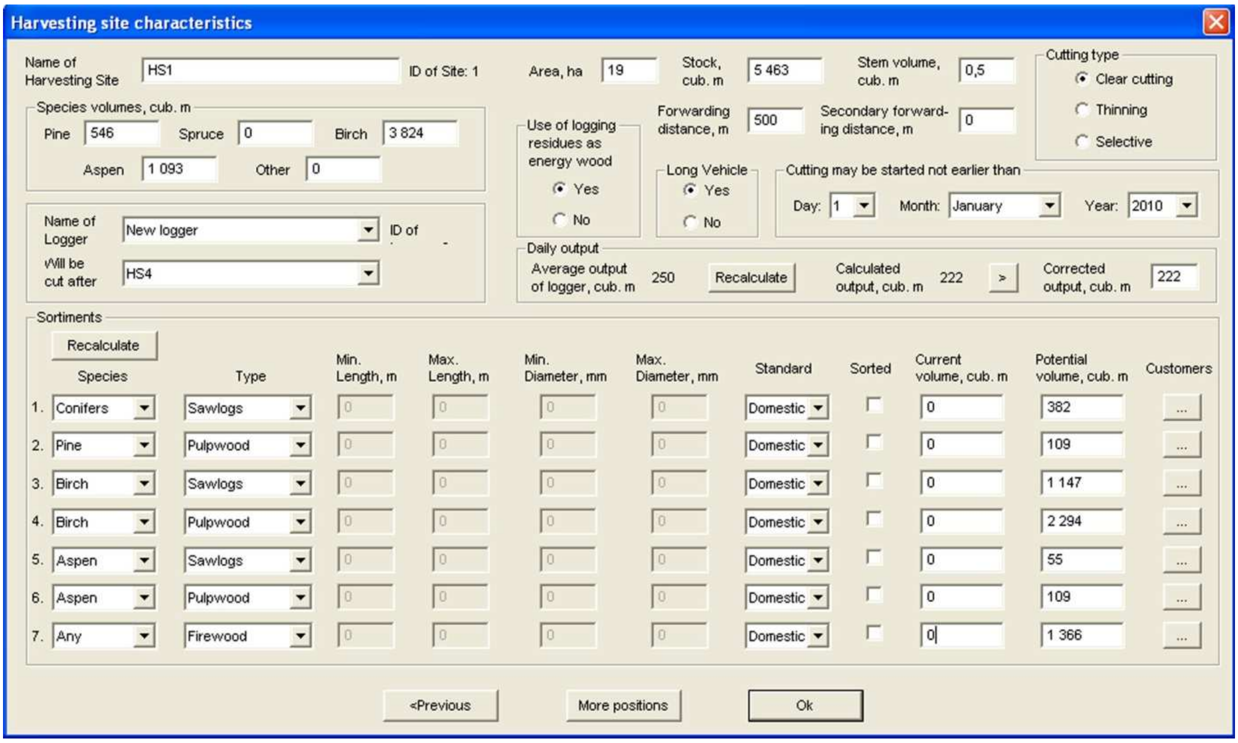

Figure 2. Screenshot for a cutting area.

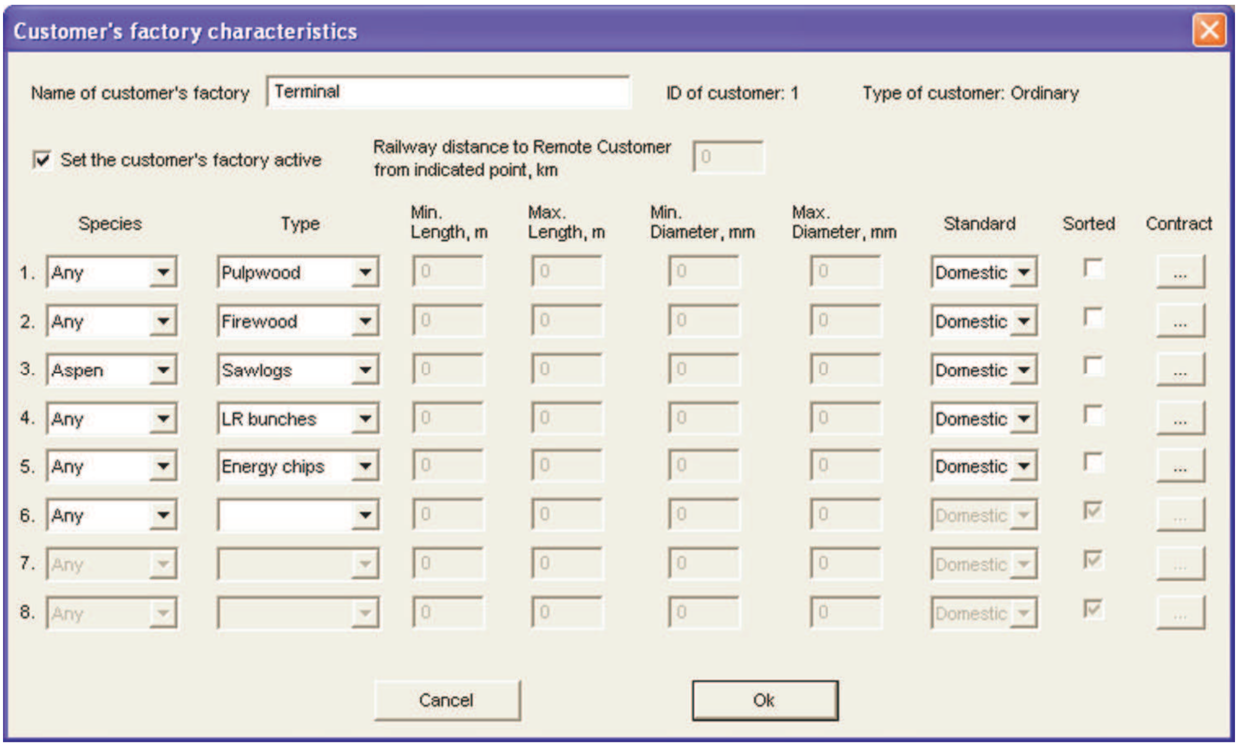

Figure 3. Screenshot for a customer

Table 1

Comparison of short term delivery plan 1 and delivery plans 2 and 3, done with the DSS

Plan	Total working time, h	Total run, km	Number of truck loads	Total volume, m^3	Total cargo run, km	Required number of trucks	Fleet utilization rate	Index of loaded distance	Operation work, m^3/km
1	307	7382	53	2740	2212	5	0.754	0.300	0.371
2	255	7382	58	2997	2697	5	0.728	0.365	0.406
3	239	5743	58	3000	2872	4	0.895	0.499	0.526

The assortment with the highest priority is selected in the case of alternative types of assortments being allocated for transportation from the optimal cutting area to an optimal customer. The assortment priority is moved to correspond to the user's dialogue (characteristics of cutting area or customer).

All trucks are included in the total list, by garage, according to the user's priority. The trucks are then prioritized in the corresponding user's dialogue (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 the case of several garages, the first plans are calculated for the first trucks of all garages. Then 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 on a Microsoft Excel file; every sheet in the file is a delivery plan for all trucks of a single garage.

Efficiency of the DSS. The efficiency of the developed DSS was tested on a real logging process in the Republic of Karelia (in short term planning, up to one week) and the Leningrad region (in long term planning, up to one year) [9]. The logging companies provided forest inventory, production, and infrastructure information. Delivery plans were compared by using the following performance indexes: total work time (hours), total run (km), total number of truck loads, total volume of wood transportation (m^3), total cargo run (km), required number of trucks, fleet utilization rate per shift, index of loaded distance, and index of operation work (m^3/km) [8].

Short term planning. Three delivery plans were created for four adjacent working days using two shifts per day for the same logistic management units' conditions (cutting areas, customers, routes, fleet, etc) (table 1). The "basic" delivery plan (Plan 1) was done in a traditional way without DSS support. Two other delivery plans (Plan 2 and Plan 3) were constructed with the DSS. The difference between the second and third delivery plans is that in the third plan (Plan 3) the trucks change drivers en route without returning to the garage every shift. There were five trucks based in one garage, four cutting areas, and four customers (three sawmills 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 cutting areas were 140–420 m^3, depending on the site, and the actual cut per cutting area was 5000–15000 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.

Optimization of the schedule using the DSS according to 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: 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 1 km increases by 9%. Optimization of the schedule using the DSS according to 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%), and the total working time decreases from 307 h to 234 h (–22%).

Table 2.

Comparison of long term delivery plans 1, 2, and 3, done with the DSS

Plan	Required number of harvesters and forwarders	Hourly productivity, cub.m/h	Required number of trucks	Total working time, h	Total run, km	Total volume, m3	Total cargo run, km	Fleet utilization rate	Index of loaded distance	Operation work, m3/km
1	7	10.5	13	13474	622453	80025	308211	0.858	0.495	0.129
2	5	10.5	6	10270	448503	77995	189161	0.912	0.497	0.174
3	5	11.9	6	10349	449648	80325	223389	0.864	0.497	0.179

This reduces the required fleet from five to four 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 1 km increases by 42%. All these changes also have input in the economics of the total operations, either decreasing the costs or increasing income.

Long term planning. Three delivery plans were created using different CTL vehicle fleets for the same logistic management units' conditions (table 2). The "basic" delivery plan was done for an existing vehicle fleet (7 harvesters, 7 forwarders, 13 trucks) with DSS support. Second and third "advanced" delivery plans were done with the DSS for an optimal fleet in wood transport (7 harvesters, 7 forwarders, 6 trucks) and harvesting operations (5 harvesters, 5 forwarders, 6 trucks). The delivery plans were created for three winter months using two shifts per day. There were about 60 cutting areas and five 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 cutting areas were 60–90 m^3 depending on the site.

Optimization of the schedule using the program according to Plan 2 shows that the total run decreases from 622 453 km to 448 503 km – 28%), and the total working time decreases by 24%. It reduces the required fleet from 13 to 6 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 35%. Optimization of the schedule using the DSS according to Plan 3 shows that for the same total delivered wood volume (80 thousand m^3) the total run decreases by –28% and the total working time decreases from 13 474 hours to 10 349 hours (–23%). It reduces the required fleet from 14 to 10 harvesters and forwarders. The fleet utilization rate increases, the index of loaded distance increases slightly, and the total volume of transported roundwood per 1 km increases by 39%. The productivity of the CTL system (harvester and forwarder) increases by 13%. Also in this case it is clear that optimization of the operations has input in the economic output.

Conclusion. Extraction of short-wood and fuel wood from harvesting processes is becoming common practice in Russia, but they have limited knowledge of the potential in logistics. The developed DSS is a tool to assist the logging companies to make comprehensive decisions on organizational options for woody biomass harvesting and logistics most beneficial for them. Application of the program allows efficiency to be increased when introducing CTL technology in Russia, wood harvesting and transport costs to be decreased, and utilization of the CTL machinery fleet to be improved. Testing of the program and comparison of alternative delivery plans show that the efficiency of short-wood transport and fuel wood can be increased substantially. The DSS could also be used for other applications and provides an excellent opportunity to convey knowledge gained in research to the companies by practical and understandable means.

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СПЕКТРЫ ПОГЛОЩЕНИЯ ЩЕЛОЧНО-ГАЛОИДНЫХ КРИСТАЛЛОВ ПОСЛЕ РАДИОЛИЗА СИСТЕМЫ «КРИСТАЛЛ – ВОЗДУХ»

Исследованы гетерогенные реакции в системе «щелочно-галоидный микрокристалл – атмосферный воздух» при воздействии с ионизирующими излучениями. Изучены оптические свойства кристаллов после обработки. Рассмотрены особенности формирования пленок нитратов на границе раздела фаз кристалл/воздух. Обсуждена возможность радиационно-химических реакций в атмосферном аэрозоле.

Ключевые слова: аэрозольные частицы, щелочно-галоидные кристаллы, радиоактивность атмосферы, гетерогенные реакции, рентгеновское излучение.

Введение. Кристаллы щелочно-галоидных соединений с составом MX (M – щелочной металл, X – галоген) широко использовались в научных исследованиях для изучения действия ионизирующих излучений на твердые тела. Были получены экспериментальные данные о том, что ионизирующие излучения стимулируют гетерогенные реакции в системе «кристалл MX – атмосферный воздух», а радиолиз данной системы приводит к образованию нитратного покрытия поверхности кристаллов [1 – 3]. Начиная с 1958 года стали появляться работы, в которых методом электронной микроскопии исследовались изменения поверхности кристаллов MX, сопровождающиеся образованием радиационных кристаллитов (РК). Образование РК наблюдалось при воздействии ультрафиолетового и рент-