Improvement of logging operations technological chains in the conditions of seasonal dynamics

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Abstract. There are many options for organizing the logging process by timber enterprises. In most cases they are chosen by management based on personal experience. Cost-effective development of the forest sector is associated with the use of the most rational technological chains of logging operations, adapted to the specific natural and industrial conditions of forest territories. This research is a continuation of the author's team work on the complex task of improving the efficiency of logging operations, taking into account the analysis of various moving and processing operations of the technological process. In previous publications the authors presented a graphoanalytical and mathematical models to solve the task. This article presents a solution based on them to improve the technological chains of logging operations, taking into account the seasonal nature of logging for the conditions of the Krasnoyarsk territory. Special attention is paid to the comparative analysis of costs for performing transport and loading and unloading operations in the conditions of seasonal dynamics. A rational chain of logging operations has been determined, which allows to reduce costs compared with other options for organizing the technological process and, as a result, to increase profits from the sale of products.

1. Introduction

Cost-effective development of the forest sector is associated with the selection and justification of the most rational technological chains of logging operations, adapted to specific natural and industrial conditions of forest territories. Currently, logging enterprises choose the "result — cost" criterion as the main one for economic efficiency of production. At the same time, minimization of the costs of performing logging operations is considered, which is reflected on the profit as the basis of efficiency [1]. The paper [2] notes that the main costs in logging production are transportation costs, which exceed 50% of total costs. The author draws attention to the fact that for the organization and management of wood transportation, it is necessary to apply an integrated logistics approach, analyze the consumer market, the forest fund, as well as transport infrastructure both at the regional level and at the level of timber enterprises.

The territories of the country's forest fund are characterized by various and rather complex natural and industrial conditions, which affects both the process of wood harvesting and its transportation. Natural and climatic factors affect the cost of construction and maintenance of forest roads, as well as the specific cost of removal harvested wood [3].

Shegelman I R and Lukashevich V M [4] note that one of these factors is the logging seasonality and provide a methodology for its assessment. The seasonal nature of logging is a characteristic feature of our country, which is a consequence of unfavorable forest soils for logging. In Russia, logging does not depend on weather conditions only on 7% of forest territories. The most unfavorable
soils for forest exploitation account for 57% of the total forest area [5]. Another reason for the seasonal nature of logging is the lack of logging roads, especially year-round roads. This leads to the need for logging enterprises to create an inter-seasonal timber stock in the cutting areas, which results in losses caused by a decrease in its quality. Transshipment timber warehouses are created at the borders between the removal by different in value modes of transport, intermediate warehouses-at the borders between temporary and year-round logging roads to increase the capacity of seasonal roads. For transshipment from road transport to water or rail transport, lower coastal or rail-based forest warehouses are organized. These warehouses can also be used for wood processing delivered in the form of trees or whips. The structure of the technological chain, the system of machines and equipment depends on their availability and location [6].

When organizing the wood transportation from the cutting area to the consumer, engineering problems arise that involve a variety of options for their solution: determining the sequence of wood removal from the cutting area; identification of the need to use warehouses; the choice of the mode of transport, the technological chain of transport, storage and processing operations, the time period for performing certain operations, choice of the consumer.

The researches [6, 7] provide mathematical models that justify the flows of harvesting, transportation, and processing of wood. Application of graphic-analytical models that display the relationships between operations allows to represent the technological chain of different logging operations in the form of a logical sequence [8]. However, the above studies do not allow us to use them for modeling the technological chain taking into account seasonal dynamics.

The methods for finding the shortest paths in a graph described in Dijkstra’s [9], Floyd’s [10], Bellman’s [11], Moore’s [12] and other researches can be used to find rational flows in transport systems [13], as well as to represent technological operations of the logging process in dynamics as a dynamic network. However, they assume passing through the arcs of each time period only one flow option and do not take into account the specifics of the logging industry, which consists of the simultaneous development of several cutting areas. In addition, the considered algorithms do not allow taking into account costs that are not dependent on the volume of timber transportation (construction costs, road restoration, etc.). In addition, the considered algorithms do not allow taking into account costs that do not depend on the volume of timber transportation (construction costs, road restoration, etc.).

The simultaneous consideration of several cutting areas leads to the fact that the resources of machines and equipment involved in the performance of works on one of the logging sites will be reduced while performing the same operations on another site in the analyzed time interval. The noted researches allow us to analyze only the graphs with independent from each other throughput capacities of parallel arcs of analyzed time ranges. In this regard, they cannot always be used to find an effective logging technological chain in the conditions of seasonal dynamics.

Therefore, one of the options for solving this problem is the use of a graphic-analytical model, taking into account the seasonal nature of logging production.

2. Experimental Part

The task of improving the technological chain of logging operations was solved by us for one of the logging enterprises of the Krasnoyarsk region.

In accordance with studies [3], it is advisable to divide the natural and climatic conditions of the logging area into 5 periods: winter (124 days), winter-spring (31 days), spring (72 days), summer (62 days), autumn (71 days). In each period, the productivity of machines when performing operations is different. Logging is carried out on two forest areas, from which wood can be transported to the consumer either directly or through the lower coastal warehouse. Roads are temporary or year-round use. The schematic diagram of the logging site is shown in figure 1.

Timber can be harvested in the form of whips or sortiments with a volume of up to 20000 m$^3$ in the first area and up to 50000 m$^3$ in the second area. Loading of wood in the cutting areas and unloading at the lower warehouse is performed by boom loaders. Removal is carried out by ten logging trucks with a transport volume of 21 m$^3$. All machines for logging, loading and unloading and transport operations are rented. It is possible to transport the wood by rafting along the river from the lower coastal warehouse, rafts can be formed for this purpose. Timber storage between periods is carried out
in stacks in the lower warehouse, for this purpose, a land area is rented and personnel is hired for security. The consumer can accept wood in any period in the amount of 70000 m$^3$.

To solve the problem, the cost of performing technological operations, the productivity of machines and equipment for their implementation, as well as labor costs for performing operations are determined.

![Figure 1. Schematic diagram of the logging site.](image)

The data obtained showed that in different periods of the year, the performance of machines on a particular operation is different. This is due to various natural and climatic conditions that affect their work. As a result, labor costs (the amount that determines the number of days for the preparation (transportation) of a unit of production, day/m$^3$) will also depend on the time period (figures 2, 3).

Based on the data shown in figure 2, it can be concluded that the labor costs for loading and unloading of sortiments are the same in all periods, and for whips, this indicator increases significantly in the III and V periods, due to the specific soil and ground conditions of the considered site.

If we analyze the results shown in figure 3, it can be noted that in the third period, wood removal is not performed due to the lack of temporary logging roads and the inability to export on year-round roads, due to soil and ground and climatic conditions of the spring period. For the same reason, wood is not exported via temporary roads in the V period. A comparison of labor costs by periods allows us to conclude that this indicator increases significantly in the II period, which is also explained by the complex natural and production conditions of the territory.

The costs incurred during the production process can be divided into variables C and constant Z. Fixed costs are taken into account only if the wood is stored between periods, therefore, when solving the problem, they are fixed when moving the flow from one period to the next. These include...
expenses related to depreciation charges, planned costs for maintenance and repair of used equipment, its lease, wages for time-based payment of workers (watchman in the lower warehouse), rent of territory, etc.

The dynamics of changes in wood transportation costs depending on the period are shown in figure 4.

**Figure 2.** Labor costs for performing loading and unloading operations.

**Figure 3.** Labor costs for wood removal.

**Figure 4.** The costs of wood transportation.
Analysis of the data shown in figure 4 leads to the conclusion that the lowest costs are typical for transporting wood in rafts, the cost of removal is minimal in the first period, and in the fourth period, the highest costs are for removal along temporary logging roads.

When calculating variable costs for transportation to the consumer, it is necessary to take into account the income received by the enterprise from the sale of products. The sale price of wood is taken equal to 3600 rubles.

The task is to find the technological chain of operations for primary processing and transportation of harvested wood from two forest areas to the consumer, characterized by a minimum cost (as a result, the maximum profit from the sale of products) and providing maximum integrated production when performing of all types of work.

2.1. Methods and materials

In papers [14, 15], graphical models of the sequence of logging process operations are considered, and a mathematical model and method for solving this problem are proposed based on the graphic-analytical model.

Taking into account the variety of existing options for the technological process of wood transportation from the cutting area to the consumer(s) with the performance of all loading and unloading and bundling work, it can be represented as a "time-stretched" dynamic graph. The mathematical dependencies considered in [15, 16] allow us to find the maximum flow of the minimum cost in it and thus determine the technological chain of the logging process operations, the need to use forest warehouses, loading and unloading raids, the modes of transport used for wood removal (water, land), the consumer and the type of final commodity products in dynamic natural and production conditions.

In the Krasnoyarsk region, due to natural and climatic conditions, timber transportation from the cutting area to the consumer in most cases is carried out in the winter (I) and summer (IV) periods. Therefore, to simplify the problem, the graph is made only for these periods, taking into account the time parameters of the remaining periods. The solution is relied on determining the minimum cost flow in the considered transport network based on the Busacker-Gowen’s algorithm, which has been adjusted. When flow passes through one of the arcs of the graph, the throughput of adjacent arcs decreases, so they were recalculated after each iteration of the algorithm. This takes into account the reduced productivity of machines and equipment involved in different technological areas.

3. Results and Discussion

As a result of solving the problem, rational routes and volumes of timber removal were determined. The timber harvested in sortiments on the first forest area in the volume of 20000 m$^3$ will be exported to the consumer by road in the I period. From the second forest area, the volume of harvested sortiments equal to 31400 m$^3$ will be exported to the consumer by road in the I period, the remaining volume of 18600 m$^3$ will be transported by road to the lower warehouse and then by water in the IV period.

To assess the effectiveness of the obtained technological chain, an analysis of alternative and most commonly used variants of technological chains of transport and relocation works in the territory of the Krasnoyarsk region under similar conditions was carried out:

1) Transportation in whips in the summer period to the lower warehouse with further rafting of the maximum possible volume of wood, the remaining volume is exported by road to the consumer during the harvesting period (winter). In this case, a volume of wood equal to 18600 m$^3$ is transported from the second forest area to the lower warehouse in the summer period and then by water transport to the consumer. The remaining wood volume of the second forest area (31400 m$^3$) is exported by road to the lower warehouse in the winter period. The entire volume (20000 m$^3$) from the first forest area is transported in the winter period.

2) Transportation to the consumer by road of the maximum possible volume of sortiments in the winter, the rest of the volume is exported by road in the summer. In this case, the entire volume (50000 m$^3$) from the second area will be delivered to the consumer in winter, part of the volume (3770 m$^3$) from the first area will also be transported in winter, and the remaining volume (16230 m$^3$) of the first forest area in summer.
3) transportation to the consumer by road of the maximum possible volume of sortiments in the winter, the rest of the volume is exported in the summer to the lower warehouse with further rafting. In this case, the entire volume (50000 m³) from the second area will be delivered to the consumer in winter, part of the volume (3770 m³) from the first area will also be transported in winter, and the rest of the volume (16230 m³) of the first forest area will be transported by rafting in summer.

Figure 5 shows the cost of performing operations of the rational and given alternative technological chains.

As can be seen from the graphic, the cost of implementing a rational technological chain is minimal. As a result, this option of organizing the logging process maximum profit will be obtained from the sale of products to the consumer. In this case, the cost of transporting wood is also minimal, which is the largest part of the total cost of performing the entire chain of operations.

Thus, as a result of solving the problem:
- a rational sequence of forest areas development has been established;
- the rational volume of timber that can be exported to the lower coastal warehouse for further transportation by water transport at the minimal cost of performing works has been determined;
- the possibility of reducing the total cost of implementing the work plan for transport and relocation operations by 3% compared to other possible options for technological chains has been noted. The economic effect can reach 46 rubles/m³ relative to alternative options.

The results obtained can be used for solving similar problems in other conditions, for example, when transporting other types of cargo.
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