The dependence of delivery capacity of log trucking industry research by means of simulation modelling

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Abstract. Dependence of delivery capacity of log trucking industry research by means of simulation modelling results are described in this article. In this research article the significance of logging industry development are grounded. Delivery capacity of log trucking and development of quality of forest infrastructure are marked as key problems in improvement of the forest industry effectiveness. The main research method is simulation modeling, by means of which theoretic models that help to evaluate the delivery capacity are devised. The factors which affect on capacity were also analyzed. The results were approbated by the example of logging operations in Krasnoyarskiy region.

1. Introduction

Forest industry includes a various set of actions, which exercise complementary industrial functions. One of the most important and still often “problematic” is forest industry. Many problems here are determined by geographical inconsistency and remoteness of logging areas from consumers of this production [1]. Climatic conditions still make a great impact on process of timber logging and log transporting [2, 3]. The last can highly differ in lines of one region and even area. It is extremely important for logging enterprises to plan the activities and to take into consideration a big variety of influencing facts in order to achieve the key objective - profit maximization.

One of the most important factors of effectiveness of logging industry is efficiency improving of timber logging. It evident that two the most important aspects here are quality and health of infrastructure and incidentally road and delivery capacity of log trucking industry. Considering the logging period itself it’s worth noting that to improve efficiency of logging enterprises differentiate timber compartments by degree of complexity of organization of timber hauling from their areas. In particular, large enterprises carry out initial delivery of timber products from “troublesome timber compartments” to intermediate warehouses. The last ones are placed much closer to such compartments then traditional lower compartments. Due to the shorter distance there appears an opportunity to deliver much bigger amount of loads then it is possible to deliver with complete timber hauling to the lower warehouse. Such hauling in the vast majority of cases, it is discharged in winter. The hauling of the rest volumes of timber to the lower warehouse is discharged in spring and summer.
It significantly increases variety of discharging timber organization and effects to achieve efficiency of logging and the whole process of timber cutting.

The factor of necessity of effective transport resources usage agrees with the practices of logging enterprises where this practice in its quality and quantity are formed with taking into account the planned targets of logging (transporting) and distance of movement of wood raw materials. At the same time the timber harvesting itself is carried out in forest-dispersed cutters. The last ones have a different distance from intermediate and lower warehouses. Thus, there appear some difficulties with timber hauling, which are determined by ineffective time of logging truck on loading and unloading stations, which appear as a result of uneven traffic on the transport network, and consequently simultaneous stay at the points.

2. Methods and Materials
Timber hauling is one of the most important stages of logging process. In addition to the significant impact on final cost (self cost) of production it affects the quality of wood resources and delivery terms directly or indirectly. Modern technologies provide an opportunity to do a simulating process of different aspects of logging. The main purpose in this case are: reducing delivery terms; selection of the most effective techniques; minimizing delivery costs; choosing the “easiest” way of delivery; etc.

In the end, the simulation purpose is to determine the optimal delivery routes and the technological process of timber hauling. Both technological and economic-organizational processes are being researched. Various mathematical modeling tools are used to solve these problems. Presently, many scientists research the application possibility of simulation modeling in solving problems of improvement of the logging effectiveness. The usage of this instrument is mentioned in publications of such authors as Sukhanov U V [4], Sokolov A P [5], Onuchin E M [6], Posmetiev V I [7], Vasiliev O I [8], etc. However, the direction of the researches is characterized by breadth of problems raised and depth of their analysis.

The analysis of publications mentioned before and publications of other authors lets us get following results about simulation modeling: it is an effective instrument of analyzing and forecasting development of different objects and systems; it can be used together with other methods and instruments; it is often used to get exact, detailed models of concrete processes; there are some approaches in using it to analyze large systems; one of the most promising area of its usage is timber hauling process.

The research purpose of corporate author is development of the program of modeling of cut timber movement from cutting area to terminals. Thus, the result model must found on modern developments in logging science.

The main method used in research for accomplishment of simulation modeling is agent-based modeling process method. It allows analyzing actions of decentralized dynamic interacting agents with concrete set of characteristics and rules of interaction and assess the significance of its impact on the functioning of production systems moving from micro-level to macro-level estimates. Thus, by setting the actions of modeling agents at the individual level, it is possible to justify global changes in the activities of the entire enterprise [9].

Along with the agent approach of creating elements of model describing systems of mass service it is used a well-known discrete event-driven approach in modeling of production processes representing each event as an object delaying the simulated process for the exact time, taking into account the probability theory.

The purpose set in the work, which was in compiling the mathematical dependencies of the productivity of log trucking industry on various natural, and production conditions was determined using the regularities of the functioning of this technique, revealed in the course of simulation modeling. In this case, the most important research method was the method of agent-based modeling of processes [10]. Its use made it possible to analyze the interactions of agents that act in a decentralized manner, but rely on a common set of rules and principles of behavior. Also, this instrument made it possible to simulate production processes in the forest area, as well as assess the
significance of their impact on the efficiency of the entire logging process. In the AnyLogic simulation environment, a model of the technological process of logging from the forest area was created (figure 1) [11, 12]. The picture below shows the scheme of cutting areas, variants of the location of an intermediate warehouse and the development of cutting areas.

![Diagram](image)

**Figure 1.** The scheme of the movement of timber trucks in the simulation experiment mode.

It is not possible to present the whole complex of the results of simulation modeling within the framework of this work. However, one of the examples of the results of the research can be attributed to various aspects of modeling the technological process, for example, loading and unloading operations when timber hauling from the forest area [13]. In particular, the state diagram characterizing the stages of loading and unloading operations and timber hauling from the forest area is shown in figure 2.

In any case, in order to increase the efficiency of hauling, it is necessary to calculate variants of hauling from the cutting area as to the lower timber industrial warehouse with the time expenditure on the movement of the timber truck equal to $t_{nc}$, and hauling to the intermediate warehouse with the time expenditure $t_{pc}$. It is also necessary to substantiate the optimal amount of logging equipment, based on the possible timing of the development of cutting areas, which obviously requires an increase in the units of the transport used. As a result of research and processing of practical data of the equipment operation, the model of the regression equation was obtained, which allows calculating the average hourly productivity of logging equipment:

$$
P = \max \left\{ \begin{array}{l}
1; \min(p_p; \left\{ \begin{array}{l}
9.54 - 2.308 \cdot t_{pc} \cdot (1 - d_L) - 0.386 \cdot k_L + 0.2775 \cdot q_L + \\
+0.00835 \cdot k_L - 0.1491 \cdot d_L + 0.00524 \cdot q_L \\
+0.0202 \cdot t_{nc} \cdot d_L - 0.063 \cdot t_{pc} \cdot (1 - d_L) \\
+0.061 \cdot k_L - 0.944 \cdot d_L + 0.017 \cdot q_L \\
+0.368 \cdot k_L - 2.91 \cdot d_L + 0.0318 \cdot q_L \\
+0.1218 \cdot d_L - 0.0215 \cdot q_L \\
+0.00086 \cdot p_p^2 - 0.0416 \cdot k_L^2 - 3.1579 \cdot d_L^2 - 0.0043 \cdot q_L^2
\end{array}\right\})
\right\}
\right). \ (1)
$$
In this model the factor features are: $p_p$ — unstacker capacity, $m^3$; $t_{nc}$ — time of movement from the place of timber loading to the lower timber warehouse and back, hour; $t_{pc}$ — time of movement from the place of timber loading to the lower timber warehouse and back, hour; $k_L$ — number of logging tracks at the plant, pcs; $d_L$ — part of timber trucks going directly to the lower warehouse; $q_L$ — cargo capacity of logging tracks, $m^3$.

Figure 2. State diagram of the implementation of the technological process of loading operations when timber hauling from the forest area.

The calculation in the Statistica software package figured out the magnitude of the multiple determination coefficient $R^2$ of the obtained regression model equal to 0.979. Other studies of the resulting model have also confirmed the validity and significance of the result.

On the basis of the results obtained, graphical displays of the impact of the researched factors on the productivity of logging equipment were obtained (figure 3)
Figure 3. Diagrams of changes in the productivity of a set of logging trucks in various production conditions of a wood enterprise.

3. Conclusion
As a result of the research, a simulation model has been developed, which makes it possible to plan the activities of logging enterprises in many-forested areas when hauling from cutting areas and intermediate warehouses of enterprises. The application of the results achieved, consisting of a combination of previously known modeling instruments, will ensure the management of the material and technical resources of logging enterprises in the many-forested regions of the Russian Federation and increase the efficiency of their functioning by substantiating the rational number and organization of work used at the enterprises of logging transport and loading and unloading equipment.

The regularities of work of a logging enterprise obtained in the course of simulation modeling during the timber hauling made it possible to carry out a complex analysis of the results and develop a regression model for calculating the average hourly productivity of a set of logging trucks, depending on the set of natural production conditions for the development of cutting areas. The resulting dependence is distinguished by the possibility of analyzing productivity, taking into account the possible downtime of logging tracks in the queue for loading and the possibility of dividing the movement of logging tracks of the enterprise into two streams, simultaneously following from the cutting area both to the intermediate and to the lower timber industrial warehouses of large logging areas. The regression dependence makes it possible to determine the lookup values of the hourly productivity and makes it possible to rationalize the part of the use of the territory of intermediate warehouses when justifying the direction of timber hauling from cutting areas.
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