Improvement of the methodology for the design of technological transport of timber industry enterprises

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Abstract. The article deals with the formation and optimization of the technological transport system of a timber enterprise. Problems were identified in the formation of cargo flows of forest material. These include poor development of methods for designing transport systems in the timber industry and disunited transport links in the operation of the enterprise. Computer simulation allows the operator to change the parameters of the designed system to optimize it. A multi-level algorithm for designing the transport system of the LPC is also proposed, including: determining the initial parameters for the design; calculating the number of vehicles; developing a simulation model of the production process in the LPC; calculating the technical characteristics of the transport system; developing an algorithm for managing the transport system; selection of the transport system option. An analytical calculation of the use of different quantities of trucks when loading vehicles is made in order to find an economically profitable number of them. As a result, calculations were made to compare the performance of the transport system with different quantities of loading equipment. When we received them, we saw that changing the number of loaders affects the capacity of the entire transport system.

1. Introduction
When transporting timber from the places of harvesting and processing, the main role is played by the forest transport system. The efficiency and stability of the forest transport system largely determines the cost of production. Transportation costs can reach up to 60 % of the cost. Reducing transport costs can be achieved by optimizing the functioning of the transport system of forest enterprises [1, 2].

The current state of logging production is characterized by a variety of technological schemes for transporting forest products. In this case, various types of transport (road, rail, water), road networks (specialized or General use), storage capacity structures, and machine systems are used. The creation of an optimal system of technological transport will ensure the technical, technological and transport accessibility of forest resources, which is an urgent task in the forest complex [1-3].

The creation of such systems is associated with the solution of discrete problems, placement, synthesis of schedules, etc. To solve these problems, various methods are used: graph-analytical, dynamic programming, decomposition of problems by decomposing into subsets, iterative methods, and metaheuristic algorithms [1, 2, 6-10].

In this case, discrete optimization problems with a heterogeneous structure are used. Among them, problems from the mathematical point of view are often NP-difficult [6, 8, 9]. Many methods for solving problems of this plan have significant computational difficulties in finding the local optimum [6, 9, 10]. Local search methods and, in particular, numerical iterative methods can be used to solve discrete problems of placing production capacities of technological transport [4-7]. Many of the
known methods are poorly applied in practice due to significant uncertainty in describing the systems of technological transport of timber enterprises [1-3, 5].

The appearance of timber-processing complexes (LPC) and the problems associated with their practical development have made the task of project calculation of their efficiency indicators very relevant. The effective use of technological transport depends to a large extent on the structure of the LPC and the methods of building the transport system determined at the design stage.

Due to the poor development of methods for designing transport systems, the latter are either chosen by a strong-willed decision, or they determine the parameters of the transport system, calculating them by the average values of the duration of technological operations. These calculations are based on significant assumptions that lead to significant errors, as a result of which, either there are downtime of technological transport during the operation of the LPC, or there are excessive capabilities of the transport system. In both cases, the effectiveness of the LPC is reduced.

The variety of configurations of processing equipment and part of the transport system, the stochastic nature of the receipt for shipment and the probabilistic nature of the time-consuming activity of the whole range of timber products for cars, lack of information and irreducibility to a set of separate design and analytical tasks lead to a complex multivariate task of designing the transport system and allow to take PBL to the class of complex systems.

2. Material and methods
The current state of the theory and practice of designing complex systems requires the use of a systematic approach methodology, i.e., when designing a transport system of LPC, simultaneous and interrelated consideration of technological processes of storage, accounting and loading of timber, the functioning of the transport system, the operation of auxiliary equipment and automation tools is necessary.

The basic design techniques for timber industry transport systems are based on mathematical placement problems typical for areas of strategic planning. Many methods of this class are focused on finding local optima, and the problem of the computational complexity of finding local optima arises. In theory, the number of steps in the algorithm for computing the optimum can grow exponentially, which makes these methods poorly applied in practice.

The aim of the work is to improve the methodology for designing a transport system for timber industry enterprises based on the widely used apparatus of the queuing theory to reduce labor intensity and computational complexity.

The problems of uncertainty of stochastic processes of complex technological transport systems arising at the initial stage of designing can be done using the methods of the queuing theory. At the same time, the queuing system is a set of tools for information and analytical processing of orders, technological transport, means of picking cargo consignments in accordance with the incoming flow of requirements (requests). The service line in this case is a set of lifting and transport vehicles for picking and loading timber.

The multilevel algorithm for designing the transport system LPC includes: determining the initial parameters for the design; calculating the number of vehicles; developing a simulation model of the production process in the LPC; calculating the technical characteristics of the transport system (vehicle speed, load capacity, number, warehouse capacity); developing an algorithm for managing the transport system; technical and economic assessment and selection of the transport system option.

Requests for transport services come from a sufficiently large number of technological operations that exist independently of each other, the time intervals between requests are uniformly distributed random variables. That is, there is a stationary ordinary flow without aftereffect. Therefore, the total flow of customers can be considered Poisson with intensity λ_∑.

The average service time of a single requirement by a transport system (t_тр) is a quantitative characteristic of the transport system and an estimate of its capacity. The average time between the receipt of requests to the transport system is defined as t_i = 1/λ_∑; then the number of vehicles can be
determined from the comparison of $t_{tp}$ and $t_4$ [4, 6, 8].

**Figure 1.** Simulation model of the transport process in the forestry complex Pr - program; N is the nomenclature of raw materials; n is the volume of batches of raw materials; n* - batch loading order; $N_t$ is the number of vehicles; ST - the composition of technological equipment; M - routes of movement of raw materials; V is the loading speed $T/C$; AY - control algorithm; $N_e$ is the number of loading facilities; T - application processing time; S - layout of technological equipment; $K_1(t)$ and $K_3(t)$ - load factors of the transport system and technological equipment; Q is the performance of the forestry complex; $E_{sk}$ - required vehicle load capacity; $K_{tp}$ - coefficient of productive work of the transport system.

A simulation model with considerable flexibility is essentially a computational procedure. Based on the initial data, the modeling algorithm can, with information about the initial state of the production process and its parameters (Figure 1), get information about the state of the process at any time and about its characteristics for a certain period of time. The operator controls the model in the program as it would like to do in a real system.

Creating a machine simulation requires a preliminary formal description of the technical part of a complex system in a single formalization language. The task of building a simulation model of a LPC is the task of adequately describing its production process [1-3].

The process of decomposition of the LPC model is considered as a process of minimizing its complexity. LPC is considered as a system with relatively separate objects (loading and unloading equipment, vehicles, control and functioning LPK provided by external links $\eta_i$, by which transport processes LPK connect with external systems (receipt of bids for the shipment and management information, issuing of raw materials and operational information), structural relationships ($r_{j,k}$), connecting the technological processes of transportation LPK, and internal connections ($r_{j,i}$), processes that provide a connection between the "input" into the system and "exit" from it [6].

The decomposition process is also applied to selected transport operations, which in terms of time costs are characterized by the following phases of operation: acceptance of requests, "loading" (processing, transportation, control, etc.), temporary storage after "loading", transfer of raw materials ($j + k$) to the consumer. In this approach to the formalization of transport operations of LPC, they differ from each other only in numerical characteristics and structural features.
3. Results
An analysis of the effectiveness of the functioning of forest transport machines interacting with each other on cutting areas has shown that it can be represented as a queuing system with simple flows.

Analyzing the indicators of the different organization of work of wood loaders (individual and group) serving road trains at loading points, we found that in the first case, one \((n = 1)\) serves 4 wood trains \((m = 4)\), which make 4 flights per shift, while the intensity the flow of forest trains \(\mu = 4/8 = 0.5 \text{ auth / h}\). An average loader can service one wood truck in 24 minutes, i.e., the loading intensity is \(\mu = 2.5 \text{ auth / h}\). In the second case, three loaders \((n = 8)\) work together at the same loading point and serve three times as many wood transport trains \((m = 12)\) (the same number of road trains fall on each truck) the intensity of arrival of the road trains and the loading intensity are the same as in the first case, \(\lambda = 0.5, \mu = 2.5\). Flows of wood trains will be considered Poisson flows with an indicative distribution of loading time \([7, 8]\).

The probability of a system condition with one or more loaders:

\[
P_1 = \frac{m!}{K!(m-K)!} \left(\frac{\lambda}{\mu}\right)^K P_0; \quad (1 \leq K \leq n)
\]

(1)

where \(P_1\) is the probability that one loader serves one road train; \(P_k\) - the probability that the truck serves one road train, and \((K - 1)\) road trains are waiting for loading.

\[
P_K = \frac{m!}{n^{K-n}(m-K)!} \left(\frac{\lambda}{\mu}\right)^K P_0; \quad (n \leq K \leq m)
\]

(2)

where \(P_1, P_2, P_3\) - the probability that the loaders serve the first, second, third wood road trains and there is no queue; \(P_K\) - the likelihood that three road trains are under loading and \((K - 3)\) stand in line. Given that the sum of all system states is 1 i.e. \(\Sigma P_k = 1\), an expression is obtained for determining \(P\) (the probability of the free state of all loaders).

\[
\sum_{k=1}^{m} \frac{P_k}{P_0} \cdot \frac{1}{P_0} \sum_{k=1}^{m} P_k = \frac{1}{P_0} \sum_{k=1}^{m} P_k \cdot \frac{1}{P_0} = 1 \quad P_0 = \frac{1}{\sum_{k=1}^{m} P_k}.
\]

(3)

For a single loader operation, \(P = 1 / 2.514 = 0.39834\).
For group \(P = 1 / 9.90940 = 0.10091\).

The probabilities of the remaining states are determined by the formula:
Then the probabilities \((k - n)\) are determined \(P_k\) and \(kP_k\) and its summation was carried out. According to the results of calculations, it is possible to determine the performance of loaders and road trains. These indicators are summarized in Table 1.

Analyzing the results of the calculations summarized in Table 1, we can conclude that during group work, the same three loaders will more efficiently service road trains, the downtime of which in waiting for loading will be reduced by 6 In addition, the loading factor of loaders for individual work will be slightly reduced \([6]\).

### Table 1. Calculation of performance indicators of loaders and trains.

| Mathematical expectations | Single loader work | Loader teamwork |
|---------------------------|-------------------|----------------|
| 1. The probabilities of free state of the loader. | \(P_0^{(1)} = 0.39834\) | \(P_0^{(3)} = \frac{3P_1 + 2P_2 + P_3}{3} = 0.35116\) |
| 2. Loader utilization rate over time \(P\). | 0.6 | 0.65 |
| 3. The number of road trains idle at the loading point, under loading and in line. | 0.99700 | 2.24575 |
| 4. The idle rate of the road train at the loading point. | 0.2 | 0.14 |
| 5. The number of road trains in line. | 0.38004 | 0.40188 |
| 6. Queue idle rate. | 0.09 | 0.03 |
| 7. The idle rate of the road train under loading. | 0.11 | 0.11 |

The stochasticity of the individual parameters of the production process in the wood processing complex (the complexity of loading the entire range of parts by automobiles, delivery routes) is ensured in the model by the introduction of a pseudorandom number generator that implements various distribution laws. The designer may include in the model program additionally developed procedures, taking into account the specifics of the real wood industry, since the algorithm is built on an open principle.

While moving from one design level to another, the degree of detail and accuracy of the LPK model increases from heuristic at the first level to a fairly accurate model that reflects the stochastic nature of the processes that occur in the deterministic structure of the LPK at the final stages of design. Based on the estimates formed during the modeling process, the designer makes a decision to change the organization of the functioning of the transport systems, individual parameters of the wood industry complex and selects the best option for the latter.

The results obtained allow us to conclude that there is a significant reduction in the complexity of computing operations compared to the methods described in the works \([1-8]\).

However, taking into account the goals of deliveries, a long distance, or a significant range of goods being moved, the reliability of the transport system is somewhat reduced due to an increase in the probability of deviations in the schedule compared to the work \([2, 7, 10]\). This reduction does not lead to significant losses due to the specifics of the transported goods (the possibility of long-term storage without special conditions). However, further research can be aimed at finding methods for solving problems related to optimizing the operation of technological transport in interaction with related types, primarily multi-modal transport at the regional level, taking into account the existing transport network.
4. Conclusion
The value of designing transport systems for LPK allows you to decide on the degree of technological equipment and forestry transport, to eliminate bottlenecks and at the stage of design or modernization to determine which economic indicators can be achieved when operating LPK for design of the transport system.

It is determined that after calculating the productivity, only those vehicles remain in the variants, with the help of which it is possible to carry out transport work for a certain time. In this case, the number of options may include complexes consisting of one transport unit of higher productivity or several units of lower productivity, if their simultaneous use is permissible (the corresponding condition should be among the qualitative signs of work).

After comparing all the functions, we conclude that group work of loaders is more profitable. To test the obtained empirical expressions, we found that the true values of the expressions are within confidence intervals of up to 10% (i.e., with confidence probabilities of 0.96).

The proposed methodology for the design of technological transport of timber industry enterprises, characterized by the ability to obtain, in a limited number of iterations, its optimal structure in terms of loading technological handling equipment while reducing the waiting time for the queue of applications.

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