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Key words: *logging, management decisions, wood removal, technological chain*

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NETWORK PLANNING OF THE TECHNOLOGICAL CHAIN FOR TIMBER LAND DEVELOPMENT

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Making managerial decisions when choosing a variant of the technological chain for logging is complicated by the variety of natural and climatic conditions. The climatic features of the periods affect the productivity of technological machines and the cost of implementation. This research suggests using network planning to determine the technological chain of timber land development. The purpose of the research is construction of multi-purpose network models for planning the technological chain of logging operations in various production conditions of forestry enterprises operation. These models are aimed at making it possible to conduct calculations to increase the efficiency of labour, materials, funds, equipment distribution with the maximum reduction in the cost of logged products. As a result of the analysis of possible options for technological chains, several network models for the implementation of logging technological processes have been built.

Key words: logging, management decisions, wood removal, technological chain

INTRODUCTION

This is expedient to divide technological process of logging implementation for most enterprises in well forested areas into several periods [1]. The number and duration of periods are associated with the presence or absence of waterways, the amount of rainfall, soil conditions of the area and a variety of other reasons. The technological operations carried out in each period may vary depending on the type of technological process adopted at the enterprise, the presence or absence of reloading-and-sorting yards and banking grounds. The noted facts make it expedient to create multi-purpose network models of the technological chain for the implementation of logging operations in large forestry enterprises.

Such problems were addressed by many researchers using various mathematical tools [2, 3]. The authors of this research used graphic-analytical methods with calendar year division into periods in previous works [4, 5] to improve technological chains. Methods of felling areas development and technological chains formation in dynamic climatic conditions are also described in the publications of K. P. Rukomojnikov [6].

However, the suggested methods did not take into account the fact that work at each operation cannot start until a sufficient operational stock of timber is created for this technological site. Thus, the model allows substantiating the sequence of technological process operations, not paying attention to the relationship between operations at their initial stages.

The scientists of Petrozavodsk State University together with their colleagues from Finland suggest using different decision-making systems [7] GIS technologies and simulation modelling [8, 9] to solve such problems. P. V. Budnik in his works [10, 11] suggests using functional-technological and probabilistic-statistical analysis to improve technological chains. Network planning is also used in solving decision-making problems when choosing technological chains [12, 13, 14]. However, the suggested tools in most cases do not make it possible to take into account the variety of natural and production conditions of the enterprise and the seasonality of the logging process as well as analyse the likelihood of accurate adherence to work completion dates in order to justify the need to adjust the organization of work and the technological process of the enterprise.

The implementation of the models suggested in the theoretical researches of this article is carried out taking into account the logging work volumes suggested at the early stages of planning in each period and is a consequent structural link in the chain of use of the mathematical apparatus for the technological process optimization.

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METHODOLOGY

As a result of the analysis of possible technological chains variants, several network models for the implementation of logging technological processes have been built. They are presented in Figure 1, 2, 3. The tops of network models, indicated as circles divided into sectors, represent technological process operations. Names of operations and their serial numbers are indicated in the lower sectors of the circles. Operation is indicated by an arrow following the top, indicating the operation of the logging technological process chain. The duration of the technological operation is indicated above the arrow. The earliest calculated dates of the technological operation execution are determined in the left sectors. The latest calculated dates of the technological operations implementation, which do not change the planned date for completion of the entire project for timber land development in the analysed time interval under the model, are indicated in the right sectors of circles. The late and early deadlines are equal for the initial and final event.

Since it is enough to partially perform the previous operation to start the majority of operations of logging technological process, the previous technological operation shall be divided into several same technological operations, the numbers of which are marked with one or two strokes above the corresponding operation number and symbolic indicators of its duration and time of the start of implementation.

The special features of the built network models include fixed start and completion dates for each of their estimated periods, which it is advisable to divide the whole yearly technological process of the enterprise into due to the obvious differences in the performance of the implementation of transport operations of each period. On the suggested network models, these operations are highlighted in bold circles and represent the starting and ending tops of the graphs, as well as the tops showing the start and completion of timber talking out by road and waterways in periods. When calculating the early and late terms for the implementation of these operations, it should be borne in mind that they characterize the boundary values of the periods and must correspond to the earlier established dates for the start and completion of works in their relation. Thus, for example, operations on timber taking out by waterways cannot start before the beginning of the timber rafting period.

RESEARCH OBJECTIVE

The objective of this research is to build multi-purpose network models of the technological chain planning for logging operations in various industrial environments of forestry enterprises operation, making it possible to perform calculations to increase the efficiency of labour, materials, funds, equipment distribution with a maximum reduction in the cost price of logged products.

The research was carried out in the production conditions of logging enterprises of the Krasnoyarsk territory of Russia. Large volumes of wood harvesting and long distances of wood transportation characterize enterprises.

All activities are presented in the models using the following symbols: tfpi, trci – the duration of felling at timber land followed by transportation to reloading-and-sorting yard and banking ground respectively within the i-period, days; tfi'– the duration of felling at timber land, ensuring the start of work on timber taking within the i-period, days; twrii, twrci – the duration of timber taking out from timber

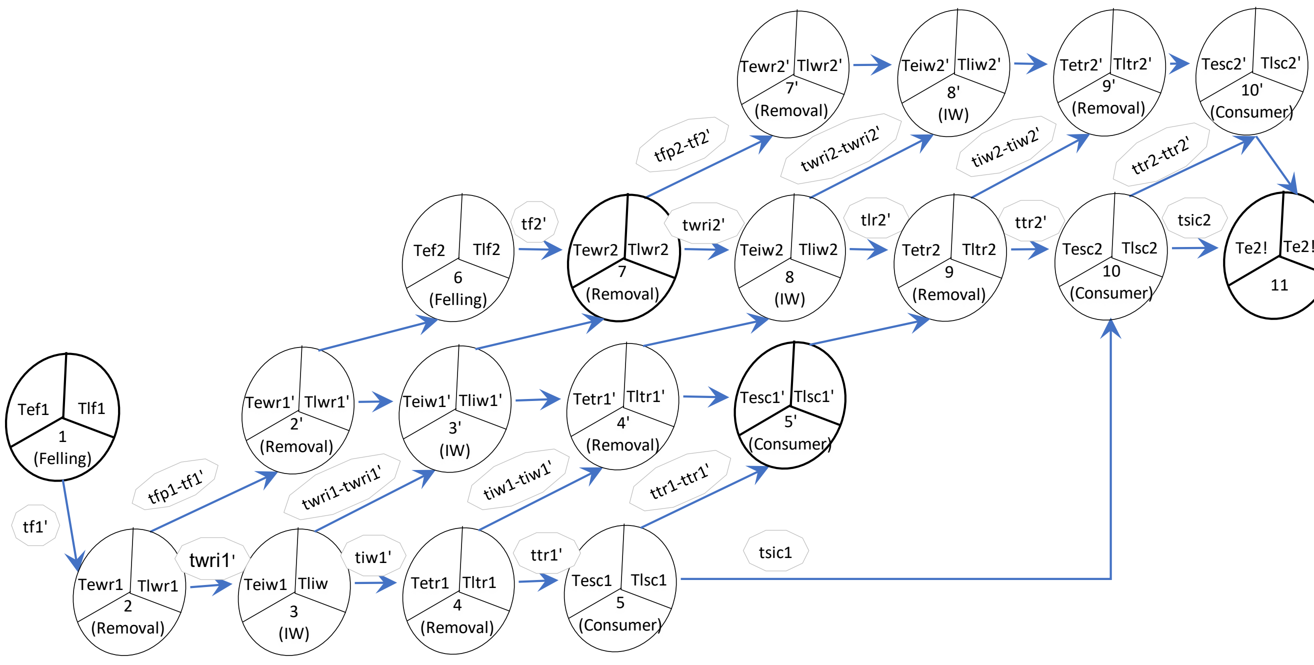

Figure 1: Network model of the technological chain for the implementation of two periods with the presence of an reloading-and-sorting yard without waterways

land to reloading-and-sorting yard and banking ground respectively within the i-period, days; twrii', twrci'– the duration of timber taking out from timber land within the i-period, ensuring the beginning of work in the reloading-and-sorting yard and banking ground respectively, days; tiwi, tcwi – the duration of the timber processing in the reloading-and-sorting yard and banking ground respectively within the i-period, days; tiwi', tcwi' – the duration of the timber processing in the reloading-and-sorting yard and banking ground respectively within the i-period, ensuring the start of work on timber taking out (rafting), days; twrmi', twri' – the duration of timber taking out from the reloading-and-sorting yard and rafting from the banking ground respectively within the i-period, ensuring the beginning of work on the products sale, days; ttri, twri – the duration of timber taking out from the reloading-and-sorting yard and rafting from the banking ground respectively within the i-period, days; tsici, tscci – the duration of timber sale to the consumer from reloading-and-sorting yard and banking ground respectively within the i-period, days, (RSY) - reloading-and-sorting yard.

The early and late dates for the start of the execution of certain operations of the logging process chain are represented in the model by the following symbols: Tefi – early and late time of the start of timber felling of the i-period, days; Tewri – early and late time of the start of timber taking out of the i-period, days; Teiwi – early and late time of the start of work at the reloading-and-sorting yard within the i-period, days; Tetri – early and late time of the start of timber transportation from the reloading-and-sorting yard within the i-period, days; Tesci – early and late time of the start of timber sale to the consumer within the i-period, days; Tecwi – early and late time of the start of work at the banking ground within the i-period, days; Teri – early and late time of the start of work on timber rafting within the i-period, days, (RSY) – reloading-and-sorting yard, (BG) – banking ground.

Modified Bellman-Kalaba algorithm may be used to find the late and early dates of the onset of events, as well as the maximum paths in a digraph.

When setting a task in a fuzzy natural production environment, which fully corresponds to the technological process of logging operations of large forestry enterprises in well-forested areas, it is possible to display the initial

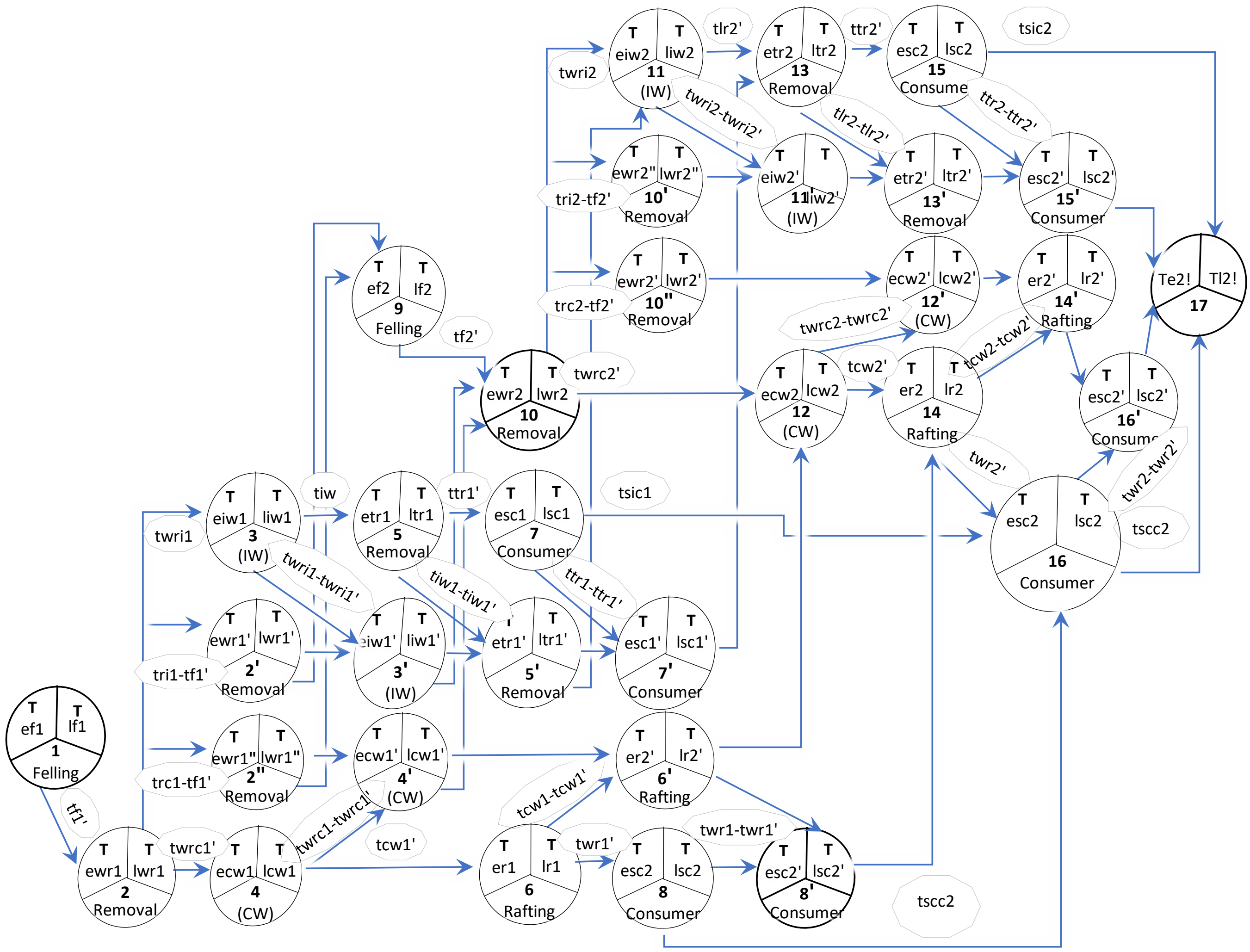

Figure 2: Network model of the technological chain for the implementation of two periods with the presence of a reloading-and-sorting yard (RSY) and a banking ground (BG) with timber rafting in the second period

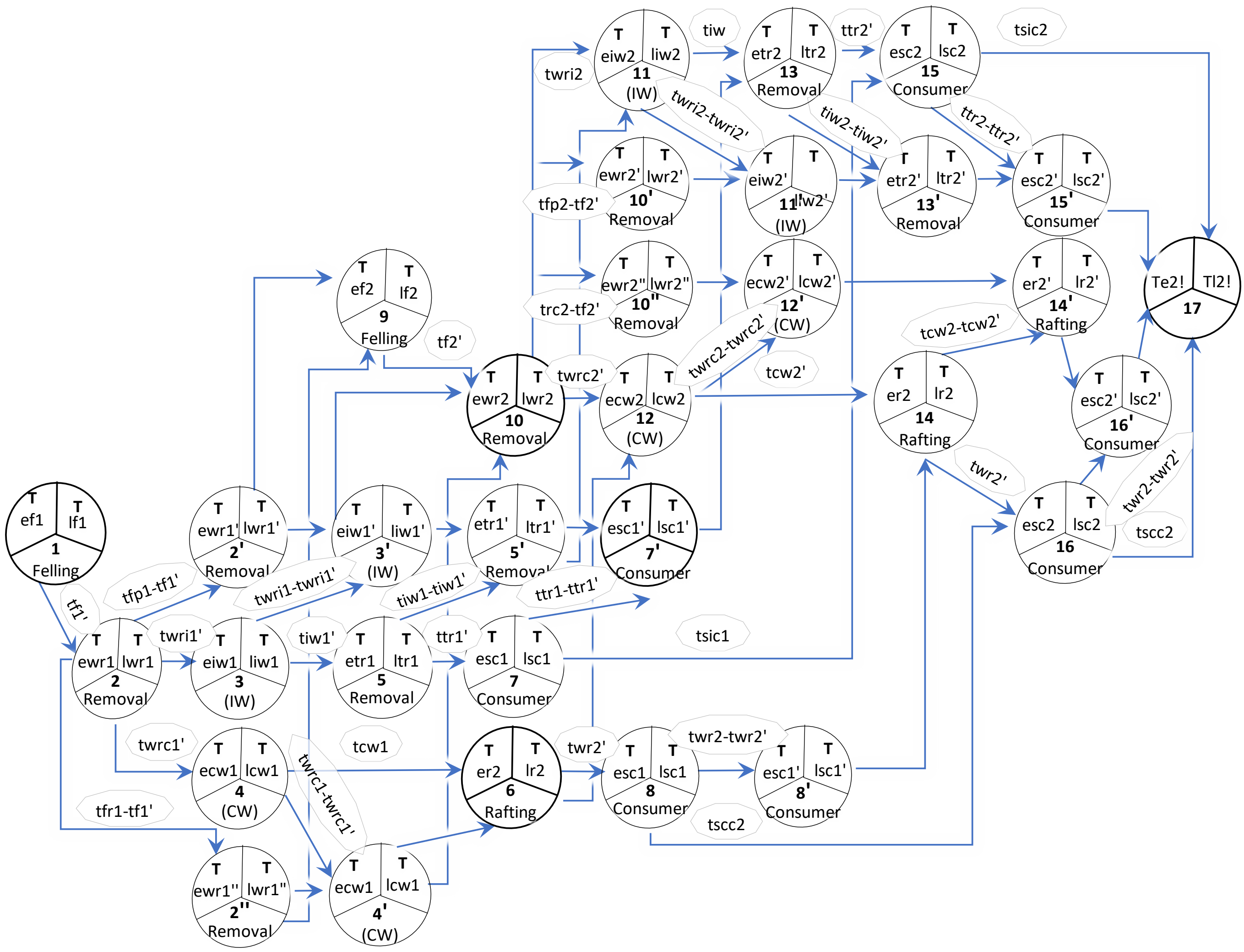

Figure 3: Network model of the technological chain for the implementation of two periods with the presence of a reloading-and-sorting yard (RSY) and a banking ground (BG)

data typical for the technological process implementation in the form of random durations of events with their variances and mathematical expectations. To ensure uninterrupted operation of the enterprise, the organization of work, which satisfies the suggested network models with a certain degree of probability, taking into account the influence of a number of random natural production factors on the technological process, is required.

RESULTS AND DISCUSSION

To demonstrate the variant of application of one of the models, let us carry out the calculation using the suggested network model of the technological chain for the implementation of two periods of timber land development with the presence of a reloading-and-sorting yard and a banking ground. It is required to justify a rational plan for the timber land development. Two periods of timber taking out are analysed: winter (124 days), winter-spring (31 day). In the first period, it is planned to lodge 13 thousand m^3 transporting 5 thousand m^3 of timber to the reloading-and-sorting yard with their subsequent transportation by land to the consumer, and transporting and storing 8 thousand m^3 of timber in the banking ground in order to ensure timber rafting in the next period. In the second period, it is planned to transport 1 thousand m^3 of timber by land and 1 thousand m^3 – by water. The calculation data are summarized in Table 1.

Based on the initial data and suggested variant of the network model of the technological chain for the implementation of two periods with the presence of a reloading-and-sorting yard (RSY) and a banking ground (BG) with timber rafting in the second stage, let us build a network model (Figure 4). The calculated indicators of the duration of work indicated in the initial data table are random variables characterized by their distribution law and characteristics of average values and variances. Variances of random variables are not indicated in the initial data table, but are previously known. The notations on the arcs of the network model, constructed to solve the example of the suggested problem, demonstrate the mathematical expectation of the operation duration ($\bar{\mu}$) and their variances (σ_2) separated by a semicolon.

The constructed model demonstrates that, based on the mathematical expectation of the suggested performance

Table 1: Initial data to exemplify solution of the problem

Indicators	Period			
	winter		winter -spring	
	transportation to			
	RSY	BG	RSY	BG
Initial data				
Average shift productivity of the logging team, m³/shift	100			
Number of teams engaged in logging operations, pcs.	1	2	1	1
Average shift productivity of machines for timber transportation to warehouses, m³/shift	25	40	20	25
Number of vehicles for timber taking out to the warehouse, pcs	2	2	2	2
Average shift productivity during handling and processing operations in warehouses, m³/shift	100	120	100	120
Average shift productivity during timber transportation and rafting from the warehouse to the consumer, m³/shift	44	0	30	350
Number of vehicles for transportation to the consumer, pcs.	1		2	
Average shift productivity during handling operations at the consumer's warehouse, m³/shift	100	0	100	300
Calculated indicators				
Days required for felling, days	50	40	10	10
Days required for taking out, days	100	100	25	20
Days required for handling and processing operations at warehouses, days	50	66.7	10	8.3
Days required for transportation and rafting to the consumer, days	113.6		16.7	25.7
Days required for handling at consumer's warehouses, days	50		3.3	30

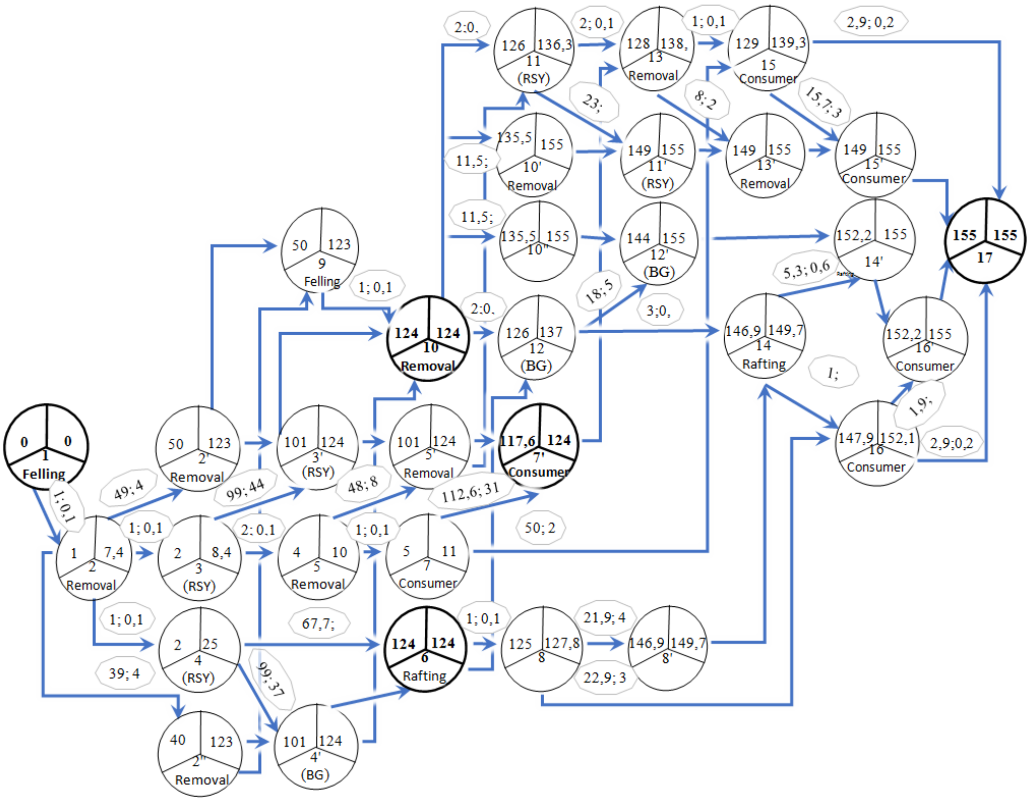

Figure 4: Results of the calculation of the network model and justification of the schedule of the enterprise operation in two analysed periods

values indicated in the initial data for the problem, the variant of organizing the work and the vehicles and mechanisms selected there for may ensure the implementation of the project, since this does not violate the deadlines noted at the top of the graph: 6, 7', 10, 17.

In addition to the visual calculation of indicators of the theoretical feasibility of the project based on the average values of the duration of operations (mathematical expectations), the analysis of the graph enables to evaluate

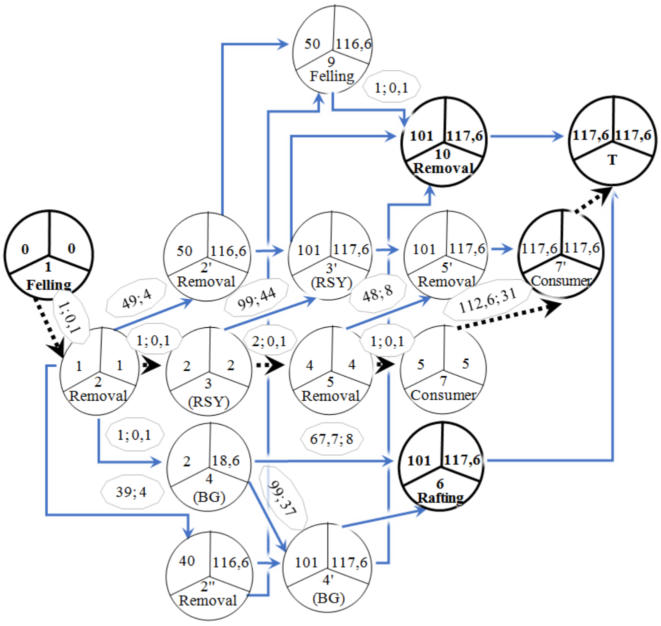

Figure 5: Example of calculating the critical path of the first period

the reliability of the suggested variant of operation, implemented on the network schedule.

To do this, we define critical paths in the implementation of each period. We get that when implementing the first period, the critical path of this graph is a path characterized by vertices: 1, 2, 3, 5, 7, 7', T (Figure 5), and when implementing the second period, the most time-consuming path is: S, 6, 8, 8', 14, 14', 16, 17 (Figure 6).

The values marked on the vertices completing the graphs are indicated in days and mean that the lengths of the critical paths of the first and second periods $\bar{t}_{cr}$ on average are $\bar{t}_{cr1}$=117.6 and t_{cr2}=28.2, which means that the obtained values do not exceed the duration of the periods indicated in the initial data. However, in each project of timber land development implemented in conditions of uncertainty, deviations of the lengths of critical paths from their found average value are possible. The magnitude of these deviations is most likely to happen at high values of the total variances of the durations of technological operations of the critical path.

We determine the probability of the implementation of the first period in the allotted time for this (T).

Considering the average length of critical paths using random values of with the normal law of their distribution, we obtain

$$P\left(\bar{t}_{cr} \le T\right) = 0.5 + 0.5 \cdot f\left(\frac{T - \bar{t}_{cr}}{o_{cr}}\right)$$

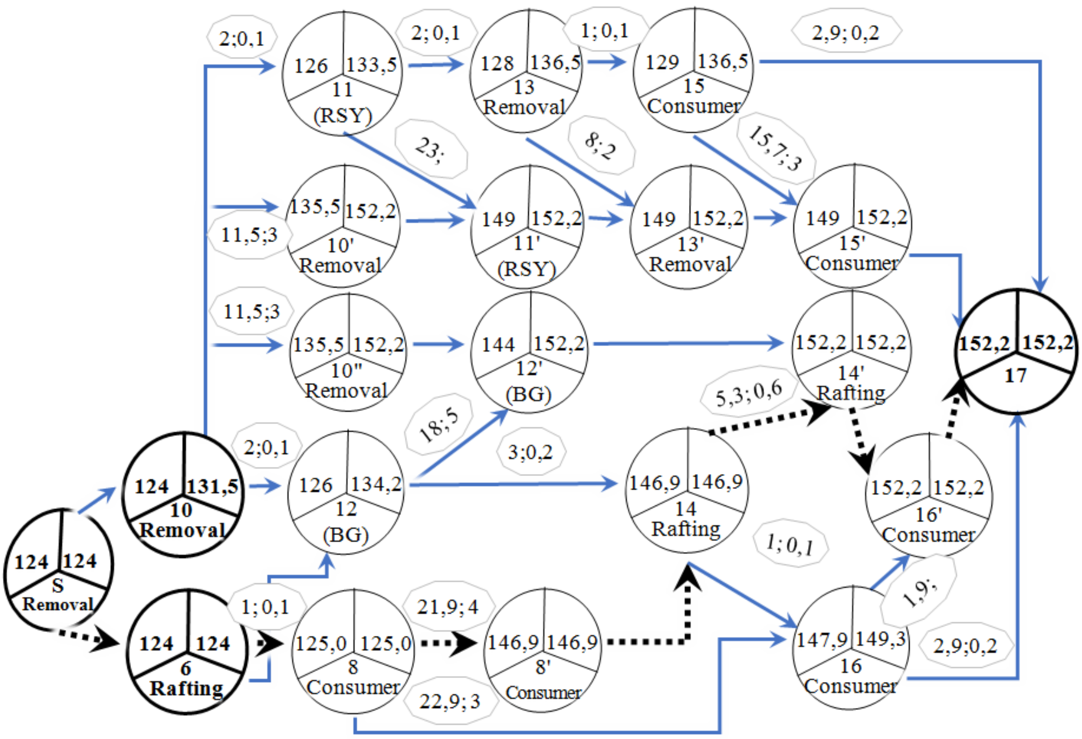

Figure 6: Example of calculating the critical path of the second period

where $f\left(\frac{T-\bar{t}_{cr}}{o_{cr}}\right)$ is the tabular value of the Laplace probability integral; σ_{cr} root mean square deviation of the critical path length.

For the first period:

$$o_{cr1}=\sqrt{\sum o^2_{ij(cr1)}}=5.60$$

For the second period:

$$o_{cr2}=\sqrt{\sum o^2_{ij(cr2)}}=2.17$$

Then, the desired probability of implementation of the technological process operation on time for the first and second periods respectively will be equal to:

$$P\left(\bar{t}_{cr1}\leq 124\right)=0.5+0.5\cdot f\left(1.136\right)=0.69$$

$$P\left(\bar{t}_{cr2}\leq 31\right)=0.5+0.5\cdot f\left(1.296\right)=0.70$$

Obviously, in order to increase the likelihood of delivering the logged volume of wood to the consumer, it is necessary to take measures to reduce the time spent for critical path operations of the first and second periods of the enterprise operation. In particular, in the first period priority attention shall be focused on the activation of the process of timber taking out from the reloading-and-sorting yard to the consumer's warehouse; and in the second period – on timber rafting from the banking ground to the consumer's warehouse. Another variant of the decision, adopted on the basis of the network model may be a change in the contractual relationship with the consumer to reduce the planned volume of timber supply from the reloading-and-sorting yard in the first period and increase them in the next period.

CONCLUSION

Thus, the calculations enable to determine the probability of completing the set of technological operations of the enterprise exactly within the deadline. The number of logging teams, timber removal machines, handling and processing equipment in reloading-and-sorting yards, banking grounds, consumer's warehouses etc. has been substantiated. It is possible to achieve reduction of the need for material resources of the enterprise by shifting non-critical operations of the technological process within their full reserve of time, identified on the basis of calculations in the presented models.

Application of one or a set of several interconnected network models enables to choose a rational system for the functioning of the forestry enterprise for any number of periods, distribute production capacities, determine the start and end terms, justify the time intervals required for individual operations, the maximum allowable delays without introducing additional time restrictions for the implementation of model elements. Application of the data obtained makes it possible to perform calculations with the construction of the calendar schedule for the project of timber land development. Subsequently, the built schedules of operation may be easily converted to the time scale applied to substantiate the efficiency of use of material resources of a forestry enterprise.

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