E3S Web of Conferences 390, 03026 (2023) https://doi.org/10.1051/e3sconf/202339003026
AGRITECH-VIII 2023

Parameters of optimization of transfer operations of the harvesting process

Aleksandr Pankratovich[1*], *Pavel* Protas[1], *Yuliya* Misuno[1], *Natalia* Chernetskaya[2], *Venera* Yumagulova[3], and *Airat* Safin[3]

[1]Belarusian State Technological University, Minsk, Republic of Belarus
[2]Rubtsovsk Industrial Institute (branch) Polzunov Altai State Technical University, Traktornaya 2/6, Rubtsovsk, Altai Region, 658207, Russia
[3]Kazan Federal University, 18, Kremlin Street, Kazan, Russia

Abstract. The development of the forestry complex, its technical equipment, the increase in the volume of harvested wood in the Republic of Belarus, as well as increased competition in the timber market have become prerequisites for the need to study issues in the field of optimizing transport processes and ensuring the rhythm of logging production. Moving operations in the cutting area, including the collection and loading of timber, their sorting and skidding, the formation of stacks in an intermediate warehouse, are the most labor-intensive in logging production. In turn, the effectiveness of these operations largely depends on the optimal placement of technological elements in the cutting area and their geometric parameters. Among the ways to improve the efficiency of the development of the forest fund, one can single out the solution of the problem of optimizing the relocation operations of logging production, for which it is necessary to determine the appropriate parameters and restrictions.

1 Introduction

Modern processes of logging production are developing, including in the direction of increasing the volume of wood harvesting by machine. This makes it possible to increase labor productivity, provide safe and efficient conditions for workers, reduce the time for developing logging sites, increase the rhythm of production, etc. This trend is observed not only in Western European countries, but also in the Republic of Belarus and the Russian Federation. Thus, on the basis of the "harvester-forwarder" machine system in the Republic of Belarus, in 2022, more than 52% of the total volume of harvesting for all types of cuttings was harvested [1], and this figure is gradually increasing. At the same time, the introduction of such expensive machine systems (with the cost of the "harvester-forwarder" complex for final cuttings 0.6–1.1 million US dollars) requires their efficient loading and operation, taking into account many influencing factors.

It should be noted that in the absence of proper organization of work, the efficiency of harvesting is significantly reduced even with a rationally selected system of machines. This

* Corresponding author: halva97@mail.ru

https://doi.org/10.1051/e3sconf/202339003026

is especially noticeable when the forwarder performs moving operations in the cutting area, which include the collection and loading of timber, their sorting and skidding, and the formation of stacks at an intermediate timber warehouse. Depending on the quality of work organization, operator experience, operating conditions and other factors, the forwarder work cycle and its operations will be differently effective. Previous studies [2] have shown that the average time ratio of moving operations performed by a forwarder in a cutting area can be represented as the following diagram (Figure 1). These values were obtained at an average hauling distance of timber of 300–350 m, a cutting area of 1.5–1.8 ha, when working during daylight hours on soils with a satisfactory bearing capacity.

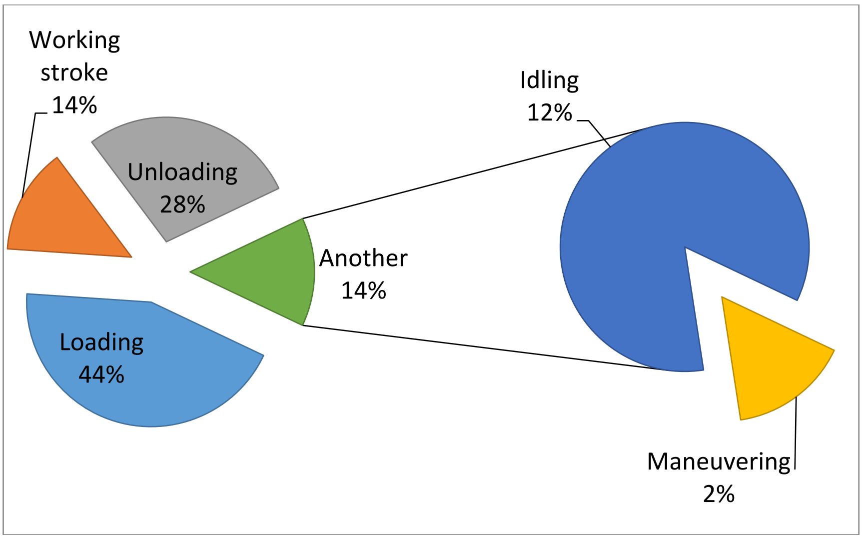

Fig. 1. Average ratios of forwarder cycle time costs.

Another significant factor influencing the ratio of the forwarder cycle time and, consequently, its efficiency is the bearing capacity of the soil and the performance of skid trails.

Therefore, an important element in improving the efficiency of logging activities is the high-quality organization of work, which should be based on the performance of optimized operations, including transfer operations, carried out both in the cutting area and in the intermediate warehouse, taking into account many factors. In order to optimize moving operations in the cutting area, when performing calculations, first of all, it is necessary to determine the parameters for evaluating the efficiency of the object being optimized. Such parameters should be linked in a single system with a ranking according to the degree of influence on the efficiency of the logging process.

2 Results and discussion

The aim of the study is to analyze the parameters of optimization of the moving operations of logging performed by a forwarder, with their systematization. In accordance with the purpose of the task, the research includes:

- analysis of requirements for the selection of parameters for optimizing moving operations;
- selection of the main optimization parameters, taking into account their influence on the efficiency of the logging process;

- assessment of methods for determining the selected parameters.

The choice of parameters used in solving the problems of optimizing the transfer operations of logging should be based on the compliance of the object being optimized with some social, economic, environmental and technical requirements [3]:

- social requirements are reduced to ensuring labor safety, improving sanitary and hygienic conditions to facilitate the work of workers. Compliance with these requirements is based on compliance with various sanitary and hygienic standards and safety regulations;
- economic requirements are reduced to ensuring the economic feasibility of the optimized object, i.e., the introduction of a new optimized object into production should increase labor productivity at minimal material and labor costs, and the optimization of an existing object should allow it to perform a given amount of work or output with minimum possible costs of material and labor resources;
- environmental requirements are reduced to the need to ensure the norms of the impact of machines and technologies on forest ecosystems in accordance with TNLA and the requirements of forest certification;
- technical requirements for the object being optimized, as well as for the organization of work, are based on the use of modern achievements in science and technology. The object must fully comply with its purpose, and its technical parameters must ensure the high-quality performance of the required work and their volumes. When considered as an optimized object of logging equipment, its technical level of structures is evidenced by such parameters as material consumption, operational reliability, degree of unification, and others, and constructive perfection is evidenced by machine performance, working cycle duration, specific fuel consumption, level of work automation, labor safety.

Optimization of objects for such a large number of parameters is not possible, therefore, it should be based on solving the optimization problem by choosing the most efficient method:

- choosing a single generalized parameter;
- carrying out consistent optimization for the most important indicators;
- carrying out optimization by several parameters (multi-criteria optimization).

Solving urgent problems of optimizing logging operations with the help of one parameter is not enough [4–7] due to the complexity of production processes and the mutual influence of social, economic, environmental and technical factors on them.

Accordingly, the optimization of objects and processes of logging production, as well as their optimal management, is possible only if a system of parameters is used, as well as through sequential optimization with the creation of various restrictions on the value of indicators that are not used as parameters, or when conducting multi-criteria optimization.

When carrying out timber industry activities, a large amount of moving operations are performed that affect the efficiency of logging production. At the same time, the statistical evaluation of these operations requires taking into account temporary (duration of cycles, downtime), technical and economic (productivity, unit cost, etc.) and operational criteria (taxation, soil, etc.).

Increasing the efficiency of moving operations in the cutting area requires compliance with many requirements and restrictions, both in the organization of the technology of equipment operation and in the placement of technological elements in the cutting area [8–15]. In addition, a significant limitation in improving the efficiency of moving operations performed by a forwarder is difficult operating conditions, such as low soil bearing capacity, rugged terrain, etc. [16, 17].

The development of logging sites is carried out according to several typical layouts of hauling trails [18]: parallel, diagonal, radial. At the same time, the operation of the forwarder

 https://doi.org/10.1051/e3sconf/202339003026

is most effective with a parallel layout of skidding trails. On cutting areas of a simple rectangular shape, such placement of portages does not cause difficulties. In practice, cutting areas are allocated with an irregular (complex) shape due to various factors, mainly taxation and operational. In such cases, some problems arise with the choice of placement of technological elements in the cutting area and the necessary calculations become more complicated. Therefore, the calculation of determining the optimal location of portages, access roads, as well as loading points (intermediate timber warehouses) must be based on reducing the cost of developing a cutting area, as well as minimizing the load work for hauling wood in accordance with the schemes for developing cutting areas (Fig. 2) [7].

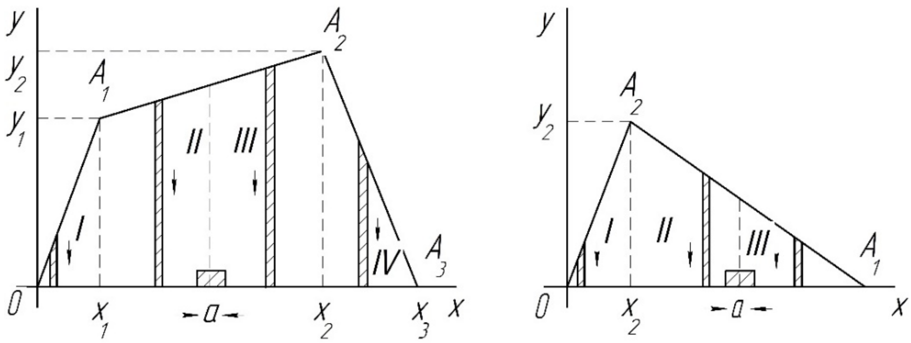

Fig. 2. Schemes for the development of cutting areas of complex shape.

The calculation should take into account the geometry of the cutting area (its shape and dimensions) and the volume of cargo work performed on individual sites I - IV. The assumption is a uniform distribution of plantings over the area of the cutting area. The location of the loading point should ensure a minimum amount of cargo work.

Correlations for determining the location of the loading point in the cutting area, taking into account its geometry, are given below.

1. When the shape of the cutting area corresponds to a trapezoid, the location of the loading point a will be calculated according to the following formula [7]:

$$a = \frac{x_1 + x_2 + x_3}{4}, \tag{1}$$

where x_1, x_2, x_3 are the coordinates of the vertices A_1, A_2, A_3, respectively.

2. In the case of a triangular cutting area

$$a = \begin{cases} x_1 - \sqrt{\dfrac{x_1(x_1 - x_2)}{2}}, \; if \; x_2 > \dfrac{x_1}{2}, \\ x_2, \; if \; x_2 = \dfrac{x_1}{2}, \\ 1 - \sqrt{\dfrac{x_1 x_2}{2}}, \; if \; x_2 < \dfrac{x_1}{2}. \end{cases} \tag{2}$$

3. In the case of a rectangular cutting area

$$a = \frac{x_2}{2}; \tag{3}$$

The location of the loading point, as well as the atypical shape of the cutting area, have a significant impact on the skidding distance (S_{av}, m) - one of the most important factors influencing the volume of moving operations and the efficiency of logging production. With a decrease in the skidding distance, the time required for carrying out moving operations in the cutting area will be significantly reduced. This parameter for cutting areas of complex geometry is determined by the formula [19]:

$$S_{av} = \frac{2\sum dR}{abq_o}, \tag{4}$$

where dR is elementary cargo work; q_0 is the average stock of wood per 1 m^2, m^3.

With a simple cutting area, the calculation of the average skidding distance is simplified and with a sufficient degree of accuracy this indicator can be determined by the formula [19]

$$S_{av} = \left(k_1 a + k_2 b\right) k_0, \tag{5}$$

where k_1 and k_2 are coefficients depending on the layout of skid trails in the forest area; a – plot width, m; b – plot length, m; k_0 is the elongation coefficient of skidding trails, depending on the terrain (for tractor skidding k_0 = 1.1–1.4; for skidding with rope installations k_0 = 1.05–1.15).

It should also be taken into account when determining the skidding distance, the loss of operability of skidding trails due to waterlogging of the soil. In this case, the operator rolls in a new portage, which leads to an increase in hauling distance and impact on forest ecosystems.

The operability of the skid trail can be determined through a connection with the indicator of the admissible pressure of the mover on the soil:

$$\frac{2 \cdot E \cdot h_{al} \cdot q_s}{2 \cdot E \cdot h_{al} + \pi \cdot q_s \cdot a \cdot b \cdot J \cdot Q_1} = q_s \cdot g \cdot k_{se} \cdot k_{st} \tag{6}$$

where E is the modulus of soil deformation Pa; h_{al} – allowable track depth, m; q_s is the bearing capacity of the soil, Pa; a is the coefficient of attenuation of stresses in the soil; b – stamp width, m; J – coefficient taking into account the ratio of the length and width of the stamp; Q_1 is a parameter that takes into account the thickness of the soft soil layer; g is the free fall acceleration of the body, m/s^2; k_{st} – coefficient of strengthening of the skid trail with logging residues; k_{se} – coefficient of seasonality of works.

An important parameter of the efficiency of logging equipment and the operations it performs is productivity (the amount of products received or moved per unit of time). The calculation of productivity for different types of logging equipment is very different, but in general it can be determined by the following formula [20]:

$$P = \frac{T\varphi_1 V}{t_c}, \tag{7}$$

where T is the duration of the machine, s; φ_1 – coefficient of use of working time; V is the volume or mass of a unit of production (if productivity is determined by the number of units of production, V = 1); t_c – the time required to process or move a unit of production, s.

The cycle time of the forwarder will include the time spent on: idling; collection and loading of timber; moving between technological parking lots; work stroke; unloading of timber with their stacking; movement along the stack when unloading timber materials.

As economic parameters during optimization, the maximum profit, or the maximum income growth, or the total reduced costs for the creation, maintenance and operation of the object can be used. In addition, you can use the system indicator, which includes the specific investment K and the specific cost C of work or products. In such a situation, the determination of the best option for performing transfer operations is determined by comparing the cost of work C and the capital investments required for their implementation K. In this case, several options are possible [3]:

1. The options are equivalent: $C_1 = C_2; K_1 = K_2$.

2. The second option is more efficient: $C_1 > C_2; K_1 > K_2$.

3. When for the final decision it is additionally necessary to determine the payback of capital investments: $C_1 > C_2; K_1 < K_2$.

In the case when there are more than two such options, it is necessary to additionally calculate the costs of C_p, rubles, for carrying out work or obtaining products according to the following formula:

$$C_p = C + E_n K, \tag{8}$$

where E_n is the sectoral normative coefficient of efficiency of capital investments.

3 Conclusion

An analysis of the optimization parameters for the transfer operations performed by the forwarder led to the following conclusions:

- the choice of optimization parameters should take into account social, economic, environmental and technical requirements in the aggregate;
- solving the problems of optimizing transfer operations in the process of timber industry production requires an integrated approach. In such cases, one optimization parameter is not enough and it is more efficient to apply sequential or multi-objective optimization;
- The following parameters can be used as parameters for solving the problem of optimizing moving operations in the logging area: layouts of portages, access roads and loading points; hauling distance; machine performance; specific capital investments and cost of work;
- carrying out the optimization calculations mentioned above requires a large amount of up-to-date data not only about the object being optimized, but also about the enterprise as a whole. These data can be obtained in different ways from various legal acts [21–23] regulating the conduct of forestry activities, local technical and economic documentation of specific enterprises, as well as by conducting experimental studies directly on the optimized area of the forest fund.

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