Testing of machines selecting mathematical model for a forest plantation operating

O Markov¹, R Voronov² and M Sysoev²

¹ Department of Transport and Production Machines and Equipment, Petrozavodsk state University, 33 Lenin Avenue, Petrozavodsk 185910, Republic of Karelia, Russia Federation
² Department of Applied Mathematics and Cybernetics, Petrozavodsk State University, 33 Lenin Avenue, Petrozavodsk 185910, Republic of Karelia, Russia Federation

*Corresponding email: markov@petrsu.ru

Abstract. Forest plantations have been successfully established and operated in many countries since the middle of the last century. At the same time, in the Russian Federation (RF), where forest plantations are not widespread, timber processing enterprises are beginning to feel a raw material hunger due to the gradual exhaustion of available operational Mature forests. As a result, the average distance of harvested wood removal from natural forests is constantly growing, and the cost of logging roads increases every year. One of the problems that hinder the creation of forest plantations is the lack of a scientifically based system of machines in the Russian Federation that can perform the entire cycle of work: starting with planting (sowing) woody plants and ending with the collection of wood crops and preparing the territory for a new succession. This article describes a refined mathematical model of the modular principle of machines selection that intended for the full cycle of forest plantation operation. During testing, the optimal value was found that meets all the specified requirements. During testing was found out that finding the optimal solution by the chosen method requires a large amount of time.

1. Introduction
The demand for wood raw materials in the world doubles every 25 years. In the world, products grown using plantation forestry account for up to half of the harvested and processed wood [1-7].

In the Russian Federation (RF), as a result of long-term, extensive forest management, despite large forest reserves and not full use of the estimated cutting area, timber processing enterprises are beginning to feel raw material hunger. The raw material starvation of timber processing enterprises and the increase in the cost of wood raw materials are due to the gradual exhaustion of available operational Mature forests. As a result, the average distance of removal of wood harvested in natural forests is constantly growing, and the cost of creating and operating logging roads is increasing every year.

In the Russian Federation, forest plantations are currently in their infancy. However, there is a large amount of agricultural land that has been withdrawn from economic use at various times and is overgrown with shrubs and low-value tree species [8]. These lands often have a developed road network and are closer to wood consumers. The arrangement of forest plantations on unused agricultural lands will allow not only to use overgrown land, but also to significantly reduce the
removal distance, which is constantly increasing due to the depletion of the available raw material base.

One of the problems that currently hinder the creation of forest plantations is the absence in the RF of a scientifically based system for selecting machines for plantation forestry that can perform the entire cycle of work, starting with the planting of woody plants and ending with the collection of wood crops and preparing the territory for a new succession.

2. Methods and Materials

The optimal choice of machines whose results would correspond to economic efficiency needs methodological support. Therefore, it is necessary to create a decision-making system that allows you to select machinery for the operation of a forest tree species plantation, such a way that allow you to get the maximum profit at the end of the growing cycle. It is necessary to take into account the cost of operation of machines and equipment, their technical readiness, depreciation, and duration of operation.

Depending on the type of soil, contamination and target rock, the composition of technological operations is assigned for each stage [9]. For each stage, a set of possible machinery and equipment is set for its execution [10].

Some technological operations are seasonal, such as planting [11]. Equipment for these operations is idle most of the time during year. Other operations, depending on weather conditions, may continue for most of the year [12]. Accordingly, there may be several options for selecting and using machines and equipment. Thus, the process operation — aggregate relations are of the many-to-many type. That is, one operation can be performed by different units, and one machine with installed equipment can be used to perform different operations [13]. For example, various types of attachments can be installed on a tractor: plows, rooters, machines for cutting stumps, sprayers, manipulators, mulchers, rotovators, etc. [14]. To solve these problems, it is advisable to apply mathematical modeling and optimization methods [15], which are also used to justify technologies and select parameters of machine operation at timber enterprises [16, 17].

2.1. Mathematical model description

Introduce the notations:
- \( n \) — number of stages in the technological cycle of forest plantation operation;
- \( N \) — multiple process operation numbers;
- \( N_t \) — multiple numbers of technological operations of a stage, \( N_t \subset N \), \( t = 1, \ldots, n \);
- \( M \) — multiple numbers of all possible aggregates used;
- \( Q \) — multiple numbers of machines and equipment used (hereinafter referred to as equipment);
- \( R_{MN} \) — a relationship that defines the relationships between process operations and the aggregates that perform it, \( R_{MN} \subset M \times N \);
- \( A \) — relationship matrix \( R_{MN} \), consisting of elements \( a_{ij} \), \( i \in M \), \( j \in N \), где \( a_{ij} = 1 \), if the process operation \( j \) can be performed by the aggregate \( i \), and \( a_{ij} = 0 \), if cannot be performed;
- \( R_{QM} \) — the relationship that defines the relationships between equipment and aggregates, \( R_{QM} \subset Q \times M \);
- \( B \) — relationship matrix \( R_{QM} \), consisting of elements \( b_{qi} \), \( q \in Q \), \( i \in M \), где \( b_{qi} = 1 \), if the aggregate \( i \) including equipment \( q \), and \( b_{qi} = 0 \), if not including.

Exogenous variables (input parameters of the model):
- \( S \) — the area of land (hectare);
- \( w_{ij} \) — productivity of the aggregate \( i \in M \) when performing a technological operation (hec/hr);
- \( T_t \) — limit time allowed for a stage, \( t = 1, \ldots, n \);
- \( C_q \) — cost per unit of equipment \( q \in Q \) (rub.).

Endogenous variables (unknown models):
Let's imagine an optimization problem statement. The objective function is the minimum cost for the purchase and maintenance of aggregates, machinery, and equipment:

$$\sum_{q \in Q} C_q x_q \rightarrow \min.$$  \hspace{1cm} (1)

At each stage the units used perform the entire amount of work:

$$S = \sum_{i \in M} W_{ij} \tau_j z_{ij}, \ j \in N.$$  \hspace{1cm} (2)

The time for stage \( t \) is limited by maximum:

$$\sum_{i \in N,} \tau_j \leq T_t, \ t = 1, ..., n.$$  \hspace{1cm} (3)

Exactly one type of unit must be used for each process operation:

$$\sum_{i \in M} y_{ij} = 1, \ j \in N.$$  \hspace{1cm} (4)

All technological operations must be performed only by the unit intended for their execution:

$$0 \leq y_{ij} \leq a_{ij}, \ i \in M, j \in N.$$  \hspace{1cm} (5)

The number of aggregates used is an integer:

$$y_{ij} \text{ integer, } i \in M, j \in N.$$  \hspace{1cm} (6)

Units are completed only if they are used:

$$0 \leq z_{ij} \leq D y_{ij}, \ i \in M, j \in N.$$  \hspace{1cm} (7)

where, \( D \) – a fairly large constant (a number that is known to be greater than any possible value of the variable \( z_{ij} \)).

The number of units equipment depends on the number of units used:

$$x_q \geq b_q z_{ij}, \ q \in Q, i \in M, j \in N.$$  \hspace{1cm} (8)

In the presented mathematical model, it is assumed that the type of plantation, the target breed for a forest plantation has already been set and, accordingly, the amount of wood grown on the site and the amount of logging on the plantation are known. After solving the optimization problem, it is necessary to compare the cost of grown wood and the cost of operating a forest plantation.
increases significantly. Selecting the initial values of variables so that they meet the conditions of the task significantly complicates testing.

Also, the mathematical model does not take into account the cost of labor. The work will continue to improve the mathematical model and search for effective algorithms for its solution.

References

[1] Koman S, Molnar S and Sabov V V 2010 Study of poplar wood properties, its role and use in the forests of Russia in the XXI century Materials of the third international scientific and practical Internet conference. (SPb: FTA) pp 11–16.

[2] Bemm A and Knust C 2010 AGROWOOD: Kurzumtriebsplantagen in Deutschland und europäische perspektiven (Weißensee verlag, Berlin) ISBN 978-3-89998-159-9.

[3] Borovics A 2007 Energetiki célú nyárfatermesztés. Erdészeti lapok CXLI 4 pp 110–113.

[4] Czupy I, Vágvölgyi A and Horváth B (2012) The biomass production and its technical background in Hungary. In: t pentek, t prosinsky, m sporcic Proceedings of 45th international symposium on forestry mechanization "Forest engineering: concern, knowledge and accountability in today’s environment" (Zagreb: University of Zagreb) pp 1–9. ISBN: 978-953-292-025-3

[5] Fiala M and Bacenetti J 2012 Economic, energetic and environmental impact in short rotation coppice harvesting operations. Biomass and bioenergy 42 pp 107–113.

[6] Hansen E A 1999 Poplar woody biomass yields: a look to the future. Biomass and bioenergy 1 pp 1–7.

[7] Horváth Z S, Marosvölgyi B, Idler C, Pecenka R and Lenz H. 2012 Storage problems of poplar chips from short rotation plantations with special emphasis on fungal development. Acta silv. Lign Hung 8 pp 123–132.

[8] Agroecological status and prospects of use of lands of Russia withdrawn from active agricultural rotation / edited by G. A. Romanenko. (Moscow: Rosinformagrotech) 2008.

[9] Grigoreva O I and Nguyen F Z (2017) Forest plantations for raw material supply of wood-processing enterprises Materials of the third All-Russian scientific and practical conference with international participation Improving the efficiency of the forest complex pp 59–61.

[10] Nguyen F Z and Grigoreva O I 2016 Forest plantations in the timber industry of the Republic of Vietnam Improving the efficiency of use and reproduction of natural resources: Materials of scientific and practical conference pp 48–51.

[11] Grigorev V I 2018 Forest plantations in the Asia-Pacific region Science and innovation: vectors of development: Materials of the International scientific and practical conference of young scientists. Collection of scientific articles pp 75–78.

[12] Gasparyan G D and Davtyan A B 2019 Transport-technological machines for development of energy-efficient forest plantations Transport and transport-technological systems: Materials of the International scientific and technical conference pp 56–60.

[13] Grigorev I V, Grigoreva O I and Werner N N 2017 systems of machines for creation and operation of forest plantations Actual directions of scientific re-search of the XXI century: theory and practice 5 5 (31) pp 438–443.

[14] Nikiforova O I and Nguyen F Z 2017 Prospects for the development of machine systems for plantation forestry in the Republic of Vietnam // Natural resources and ecology of the far Eastern region: materials of the II international scientific and practical forum pp 225–230.

[15] Voronov R V, Markov O B, Grigorev I V and Davtyan A B 2019 Mathematical model of the modular principle of selecting a system of machines for the creation and operation of forest plantations Evestiya higher educational institutions. Forest magazine 5 (371) pp 125–134.

[16] Voronova A M, Voronov R V and Piskunov M A 2012 Modeling of the hauling scheme by means of covering the hypernet with a weighted root tree Scientific notes of the Petrozavodsk State University 2 (123) pp 114–117.

[17] Voronov R V, Kostitsyn D P, Shabaev A I, Voronova A M and Shechetoleva L V 2013
Mathematical model of the problem of planning multi-transfer production in the timber industry *Scientific notes of the Petrozavodsk state University* 4 (133) pp 101–104.