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Ecological and economic efficiency assessment of forest-transport systems based on the principles of sustainable territorial development

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Abstract. In order to solve the urgent problem of the development of forest transport systems efficiently, it is necessary to develop strategic principles for their planning, taking into account the current realities of a market economy and the transition of the world community and Russia to the principles of sustainable development. Formation of transport systems in general and the new road network on the territory of forest lands in particular requires significant financial and material resources and therefore it is important to justify the cost effectiveness of their creation and development, taking into account the principles of sustainable development of the territories and the overall environmental and socio-economic effect of the implementation of state project. The paper substantiates the need to take into account environmental, social and economic factors when planning transport systems on the territory of forestland. The principles for assessing ecological and socio-economic efficiency are proposed. Quantitative efficiency criterion is developed taking into account the principles of consistency. The developed objective function of the optimization problem reflects the profitability of the timber transport system (including costs for all stages of its life cycle) for the entire planned period of interaction with the forest ecosystem, i.e. recoupment of the design, construction and operation of the forestry fund of the country's regions by achieving the maximum productivity of the forest ecosystem from their coexistence over the entire planning period.

1. Introduction

The transport system on the territory of the forestry fund of the country's regions (FFCR) in general should be considered as a complex transfer system developing in dynamics of the track, rolling stock, loading, reloading, unloading machines and mechanisms linking the totality of forest-forming forest blocks and sections with the transit route of forest products to consumers.

The structure of the FFCR is defined in 2 aspects - static (stable relations) and dynamic (way of functioning and interaction of the elements), since there are technological, technical, economic, organizational and managerial connections between the elements that directly determine the structure of the FFCR [1].

A specific feature of the transport infrastructure development of the forest territories is the use of territorial and sectoral approaches, which take into account both the interests of carriers - users of forest roads, and the needs of progressive socio-economic development of forest areas.

The territorial approach includes the following elements that influence the socio-economic development of forest areas: specialized transport and logistics centres, roadside repair and service organizations, public roads of forest areas.

The sectoral approach includes a system of special forest roads that affect the functioning of the regional logging complex [2, 3].

Taking into consideration the statements given above, it can be argued that the development of an adequate mathematical model of FFCR planning is an urgent scientific task.

2. Objects and methods of research

According to the national forest use, forest roads were built only for the development of forests with ripening and ripe stands, not taking into account the optimality in the context of the forest fund of the region as a whole. With the transition to a market economy, the construction of forest roads has virtually ceased.

At present, at the federal level, it has been decided to finance the construction of forest roads from budgets of various levels, since the state, in the person of its subjects, according to the current Forest Code of the Russian Federation, is the owner of the forest fund lands. In order to solve this extremely resource-intensive task efficiently, it is necessary to develop strategic planning principles for FFCR, taking into account the current realities of a market economy and the transition of the world community and Russia to the principles of sustainable development, first declared at the international level by the UN Conference on Sustainable Development z000000076 (Rio-92 [4]) and to the extent promoted by the international community (Johannesburg 2002 [5, 6]; UN Economic Commission for Europe, 2012 [7]; Fücks, 2014 [8] Duwe, 2015 [9]; GI Broman and K.-H. Robert, 2017 [10] and others.).

The task of planning a new FFCR in general, and its road network in particular, must be scientifically justified and planned, since the designated project requires considerable financial and material resources. The cost-effectiveness of the creation and development of the forest road network (FRN), taking into account the overall environmental, social and economic effect of the implementation of the state project, should be justified by taking into account the environmental orientation of modern forest management. Based on the realities, the forest industry cannot in a short time increase the level of development of the existing FFCR and develop it to the optimal parameters due to the huge capital intensity of the task. In these conditions of forest management, there is an urgent need to form a unified scientific and technical strategy for its development, in which it is necessary to consider not the development of a forest transport infrastructure as a whole based on the principles of sustainable development of territories [1].

FFCR is capital-intensive and one of the most significant components of a modern forest ecosystem; it is not possible to obtain any real economic income from the use of forest resources and the realization of the ecological potential of forest areas without it, not to mention achieving their maximum ecological-socio-ecological productivity. The formation of synergistic relations between the FFCR and the forest ecosystem represents the adoption of an integrated environmental and socio-economic criterion as a base when planning it. The indicator of the best design solution in this case is to achieve maximum productivity of the FFCR and the forest ecosystem from their joint operation over the entire planning period [1].

Naturally, the rational inclusion of individual roads into the overall FFCR system is a difficult but urgent task for society. For example, the German scientist P. Dietz believed that the optimal ratio of capital invested in equipment, roads and forestry was 1: 15: 100 [11].

When planning a FFCR project, it is necessary to take into account that the existing forest transport infrastructure was planned:

- by elements of different design organizations;
- without adaptation to changes in the production conditions associated with changes in the external environment;
- without taking into account the development prospects.

FFCR as a system exists in a production environment that is subject to change - the parameters of the forest fund change in accordance with the biological patterns of growth of forest stands, a part of the forest territory is transferred from one category to another, the forest and environmental legislation, the requirements for the technologies used are changed, etc. That is why it is cost-effective if at each moment in time it meets the requirements of the external environment. The process of such an adaptation is an adaptation. Therefore, it is now topical to consider FFCR not only as a formed system in the form of a materialized unity of interconnected technical objects, but also as a complex open system characterized by functioning, development and adaptation in conjunction with the external environment. In addition, the task of planning FFCR is not only constructive and functional, but also a compromise nature due to the fact that its cost, environmental friendliness and technical efficiency are contradictory, and these compromises are interconnected and define new contradictions.

Taking into account the above, FFCR can be considered as a complex transfer, dynamically developing system of paths, vehicles, loading, reloading, unloading machines connecting the set of cargo-forming forest quarters with the transit route of forest products to consumers. There are technological, technical, economic, organizational and managerial connections between the FFCR elements, which together define its structure in 2 aspects - static (stable relations) and dynamic (way of functioning and interaction of elements)

The development of a mathematical algorithm for solving the stated optimization problem requires an unambiguous description of all dependencies included in the FFCR mathematical model, the objective function and the constraint system [1].

3. Results and discussions

Planning FFCR is a multi-criteria task, since, as noted above, the cost of its construction and operation, environmental, social and technical efficiency are contradictory. Based on the above, contradictory criteria, it is necessary to consider the planned FFCR and the territory of the forestry fund proposed for development, as a single system that is in synergistic relationships with each other. Since the main criterion for the operation of any system is its effectiveness (ratio of result to cost), we are invited to evaluate the performance of the planned FFCR with regard to the project's environmental and economic indicators.

Qualitatively, this can be expressed as the achievement of the maximum of all potential revenues from the use of various forest resources and the ecological potential of the territory on the basis of the planned FFCR.

Quantitatively, the objective function of the environmental and economic assessment of the efficiency of the FFCR, taking into account the analysis of the sources studied [2-3, 12], may in the first approximation be the ratio of net discounted income derived from the development of the forestry fund to the total costs, which include the construction and operation of FFCR. It shows the amount of net profit per ruble of total expenses for the planned period:

$$A_{ef} = \frac{NVP}{S} \rightarrow \max \qquad (1)$$

where NPV – net present value, obtained as a result of the development of the forestry fund through the implementation of FFCR, rubles; S – planned total costs, rubles.

In order to solve the economic problem of determining the time of harvesting a forest resource that manages prices, costs, interest rates and productivity of a resource, it is necessary to set the resource

growth function $Q(T)$, then the amount of the resource suitable for market implementation is determined as $Q(t)$ from the selected age t.

The definition of NPV obtained as a result of the development of the forestry fund territory through the implementation of the FFCR is given by the function of maximizing the present value of net income:

$$\text{NPV} = \frac{\sum_{t=0}^{T}\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{K} P_{ij}\cdot Q_{ijk}(t)}{(1+e)^T} \rightarrow \max, \tag{2}$$

$$(i=1,\dots m), \ (j=1,\dots n), \ (k=1,\dots K), \ (t=0,\dots T)$$

where P_{ij} – net profit from the sale of $1 m^3$ (or other units of forest resources) by types of forest resources from the *i-th* forest area (hectare, section, m^2), for the *j-th* warehouse (railway station, to the consumer), rubles;

$Q_{ijk}(t)$ – total volume by types of forest resources from the *i-th* forest area (hectare, section, m^2), for the *j-th* warehouse, subject to storage and transportation by *k-th* type of transport at t moment of time, m^3 (or other units of forest resources);

e – discount coefficient;

T – period of the forestry fund development, years;

t – time from the moment of evaluation to the moment of resource procurement, years.

The planned total costs (maximum allowable costs associated with logging, reforestation, construction and operation of the FFCR for the period of the forestry fund development) are determined by the expression (3):

$$S = \sum_{t=0}^{T} \frac{(R_c + R_p + P'_{ij}\cdot \Delta t(t))}{(1+e)^T}\cdot(1+\frac{1}{(1+e)^T}) \rightarrow \min \tag{3}$$

where R_c– reduced costs for the creation and operation of FFCR, rubles;

R_p – regulatory costs for the reproduction, protection and protection of forests, guaranteeing their restoration in clearings, growing up to the age of maturity, protection and protection, rubles.

P'_{ij} – the deadening of the forestry asset (not sales) from not developing the forest fund due to the lack of FRN, per $1 m^3$ (hectare, allotment, m^2) at time t, rubles;

Δt - period of the forestry fund non-development.

P'_{ij} is considered as costs, including the potential income lost due to the postponement of income from forest use plus the cost of removing income from future production cycles for a period of time Δt.

When implementing the mathematical model proposed by us for the ecological-economic assessment of the efficiency of FFCR, the following limitations should be considered:

1. FFCR payback project planning can be defined as:

$$\sum_{t=0}^{T} \frac{(R_c + R_p + P'_{ij}\cdot \Delta t(t))}{(1+e)^T}\cdot(1+\frac{1}{(1+e)^T}) \leq P_{\max} \tag{4}$$

where $P_{\max}$ – enterprise financial possibilities.

2. Distance between *i-th* forest section and *j-th* warehouse (according to [2] the effective shoulder of the removal of the forest resource from the *i-th* forest plot to the *j-th* raw stockpile should not exceed 120 km), determining the transport accessibility of forest sites is as follows:

$$L_{ij} \leq 120 \tag{5}$$

where L_{ij}– distance between the *i-th* forest site and the *j-th* raw material storage, km.

3. Natural non-negativity of freight traffic is as follows:

$$Q_{ijk}(t) \geq 0, \ (i=1,\ldots m), \ (j=1,\ldots n), \ (k=1,\ldots K), \ (t=0,\ldots T) \tag{6}$$

4. The requirement of continuous, inexhaustible forest use is:

$$\sum_{t=0}^{T}\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{K}\sum_{l=1}^{L}\left\{\left[Q_{ijk}(t+1)_l \cdot C_{ij}(t+1)_l - R_c(t+1)_l - R_p(t+1)_l - P'_{ij}\cdot \Delta t(t+1)_l\right]\right.$$
$$\left.-\left[Q_{ijk}(t)_l \cdot C_{ij}(t)_l - R_c(t)_l - R_p(t)_l - P'_{ij}\cdot \Delta t(t)_l\right]\right\} \geq 0, \ l=1,\ldots,L \tag{7}$$

where $C_{ij}(t)$ – sales price of 1 m^3 (or other units) of the amount of forest resources from the *i-th*, to the *j-th* warehouse (road section, to the consumer), rubles.

4. Conclusion

The developed system mathematical model of the ecological and economic assessment of the efficiency of the FFCR reflects the profitability of its operation (including the costs for all stages of its life cycle) for the entire planned period of interaction with the forest ecosystem, recoupment of design, construction and operation of FFCR due to the development of the forestry fund.

The scientific novelty of the methodology for developing a systematic mathematical planning model for FFCR will consist of:

- consideration of the planned FFCR and the territory of the forestry fund proposed for development, as a unified system that is in synergetic relations with each other;
- formulation of the qualitative criterion of the FFCR efficiency as the achievement of the maximum of all potential revenues from the use of various types of forest resources and the ecological potential of the territory on the basis of the planned FFCR;
- development of a quantitative environmental-economic criterion for FFCR effectiveness, taking into account: the costs associated with reforestation, forest protection from fires and pests, lost opportunity for obtaining potential income due to the postponement of revenues from forest use, plus the costs of removing revenues from future production cycles.

The practical significance of the work is to develop a planning methodology for FFCR, taking into account the modern principles of sustainable development of territories, allowing to scientifically substantiate the size of investment in the forest industry.

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