Perfection of decision-making methods in multilevel hierarchical transport systems

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Abstract. The article discusses the multi-level transport linking systems of timber enterprises, which are a hierarchical structure. It consists of the regional transport system management, which distributes limited resources and several transport subsystems (types of transport) producing the same type of transport products - interchangeable transportation.

1. Introduction
The regional transport system (RTS) is a two-level hierarchical structure consisting of the RTS management, distributing limited resources \[ \sum_{i=1}^{3} X_i = W \] and three transport subsystems (types of transport) producing the same type of transport products \( P_1, P_2, P_3 \) - interchangeable transportation. Each type of transport is characterized by a certain structure, technology of operation and the means at its disposal [1]. Territorial models for fixed structures of the district economy solve the problem of locating production objects taking into account the transport factor and the characteristics of the territory.

With the help of such models it is proposed to carry out variant calculations, and to take the intersectoral balance or linear programming models as the basis for the model.

Here it is necessary to emphasize that in order to obtain concrete values of the parameters of the corresponding economic and mathematical models, the achievements of economic geography were widely used (in explicit or implicit form). The use of balance methods and linear programming methods for territorial models of developed regions does not raise any fundamental objections. In such areas, the territorial cells in which production development is possible are known in advance (as it happens, for example, in the locations of old enterprises, and in new places, enterprises are usually not built). In addition, the settlement system is known, and the structure of transport communications does not change; in the worst case for it we only recalculated throughput [2].

Underdeveloped or new territories are assigned enormous tasks. First, there is definition of places of construction and the dynamics of the development of the capacities of new enterprises. Second, there is definition of the dynamics of development and reconstruction of existing enterprises of various industries. Third, there is calculation of the capacity structure and the dynamics of the development of the transport communications system. Finally, there is formation of a settlement system. For such
territories, balance methods can be used to balance the volume of consumption and output within the area and to determine the volume of import of products into and out of the area [8]. The methods of linear programming can be used for an approximate assessment of the costs of resources and material and technical means necessary for the development of the area. However, these methods failed to give satisfactory results when developing schemes for the integrated development of territories that determine the options for the development and location of the productive forces of the region. This is explained by the fact that the main tasks, the solution of which is the process of territory development, are poorly described by linear models, since the development process itself has a pronounced non-linear and discrete character [3].

The analytical dependence between these parameters can be built on the basis of the apparatus of production functions, and the formal connection between them is:

$$ P_i = P_i(\bar{P}_i, X_i, V_i) $$  \( i = 1, 2, \ldots, 3 \)  \( \bar{P}_i \) - traffic volume of the i-th mode of transport; 
\( X_i \) - the amount of resources led into the i-th mode of transport; 
\( V_i \) - vector of own controls of the i-th transport subsystem; 
\( P_i \) - vector of parameters of the i-th mode of transport, which characterizes its structure and the number of input resources; 
\( A_i = \{ \bar{Y}_i = (y_{i1}, \ldots, y_{ik}) \sum_{k=1}^{K} y_{ik} \leq X_i, y_{ik} \geq 0, k = 1, \ldots, K \} \rightarrow \min $$

2. Materials and methods

The purpose of the i-th transport subsystem is to maximize its share in the total traffic. Then its objective function \( F_i \) is written as:

$$ F_i(\bar{B}, \bar{X}, \bar{Y}_1, Y_i, Y_i) = \frac{P_i(\bar{B}, X_i, \bar{Y})}{\sum_{i=1}^{3} P_i(\bar{B}, X_i, Y_i)} \rightarrow \min $$

where \( \bar{B} = (\bar{B}_1, \bar{B}_2, \bar{B}_3) \), \( \bar{X} = (X_1, X_2, X_3) \).

The objective function of the organizational structure of management of a unified regional transport system (URTS), reflecting the effectiveness of the entire transport system as a whole, will be written as:

$$ F_i(\bar{B}, \bar{X}, \bar{Y}_1, \bar{Y}_2, \bar{Y}_3) = \frac{3 \sum_{i=1}^{3} P_i(\bar{B}_i, Y_i)}{3 \sum_{i=1}^{3} X_i} $$

At the same time, the means of the transport system are limited:

$$ \sum_{i=1}^{3} X_i \leq W, X_i \geq 0 $$

And the total traffic should not be less than a planned target N:

$$ \sum_{i=1}^{3} P_i(\bar{B}, X_i, \bar{Y}_i) \geq N. $$

The set of vectors characterizing the distribution of funds between modes of transport has the form and is an acceptable set of development strategies belonging to the organizational structure of the management of the unified regional transport system (URTS):
$$S = \left\{ \overline{X} = (X_1, X_2, X_3), \sum_{i=1}^{3} X_i \leq W, X_i \geq 0 \right\}. \quad (7)$$

3. Results and discussion

The main problems encountered during the development of methods for solving these problems were the following:

- multi-extremity;
- the interdependence of various factors that is non-linear;
- multi-criteria;
- dynamics;
- uncertainty of the initial information;
- non-formalizability of a complete description of the mastering process;
- the need for dynamic design (or rolling planning).

The formulation of the problem is considered from the standpoint of game theory. There are four participants in the game with different interests: the organizational structure of the management of the RTS and the three transport subsystems [4, 9]. Each of the participants has its own control vector, which belongs to a given set: $X \in S, \overline{F_i} \in A_i, i = \overline{13}$.

Target functions of participants depend on the management of all participants: $F(\overline{B}, \overline{X}, \overline{F_1}, \overline{F_2}, \overline{F_3})$, $F_i(\overline{B}, \overline{X}, \overline{F_1}, \overline{F_2}, \overline{F_3}), i = \overline{13}$.

One of the participants of the game, the RTS management, occupies a separate position, that is, it does not have the right to join any coalitions with any of the other participants. A case of complete awareness is considered, in which the hierarchical structure and all the objective functions of the system are known to the participants. The resulting formulation of the problem is modeled by the game of four individuals with different interests. The game is considered in terms of transport subsystems. This means that it is necessary to determine this distribution $F_i(\overline{B}, \overline{X}, \overline{F_1}, \overline{F_2}, \overline{F_3})$, which will be optimal from the point of view of maximizing the volume of traffic performed by the $i$-th subsystem [5].

Let us introduce the following hypothesis of awareness and the order of moves: the first move consists in the simultaneous selection by the transport subsystems of their strategies, $F_i(\overline{B}, \overline{X}, \overline{F_1}, \overline{F_2}, \overline{F_3}), i = \overline{13}$ which are communicated to the organizational structure of the URTS management $\overline{X} = \overline{X}^\ast$. Built RTS strategy in the form of a function vector:

$$X^\ast = X^\ast(\overline{B}, \overline{F_1}, \overline{F_2}, \overline{F_3}) \quad (8)$$
determined from the condition:

$$\max F(\overline{B}, \overline{X}, \overline{F_1}, \overline{F_2}, \overline{F_3}) = F(\overline{B}, \overline{X}^\ast, \overline{F_1}, \overline{F_2}, \overline{F_3}) \quad (9)$$

Thus, it turns out to be a three-person game with a constant amount, in which each $i$-th participant ($i = \overline{13}$) is characterized by a winning function and has strategies of their allowable set $C_i$, depending on the strategy of all players:

$$F_i \in C_i(\overline{B}, \overline{F_1}, \overline{F_2}, \overline{F_3}) \quad (10)$$

In addition, each player can influence the set of strategies of other players. If the rules stipulate that transport sub-systems make a choice of strategies independently of each other, without any coordination of their actions, then the optimal strategy of the $i$-th subsystem will be determined from the decision of a non-coalition game of three persons with a fixed amount, in which the goal $i$ player is:

$$\max F_i(\overline{B}_i, \overline{Y_1}, \overline{Y_2}, \overline{Y_3}) \quad (11)$$
The decision of the game will correspond to situations of equilibrium in the sense of Nash (situation \( Y_1^*, Y_2^*, Y_3^* \)); we considered equilibrium in this sense, if it is not beneficial for any player to deviate from the strategy prescribed in this situation, provided that all other players do not deviate from their equilibrium strategies. If the formation of coalitions between transport subsystems is allowed, then the decision of the game is in the sense of Neumann - Morgenstein on the basis of an analysis that reveals the conditions of the coalitions [6].

For the description of the above interrelation of the parameters defining the activity of a particular type of transport, the method of production functions (PF) is used. For illustration, the most simple and widespread PF in economic research is given, which links the production of final products with production factors in the form of a product of degrees [7, 10]. The following resources are considered as factors of the i-th transport subsystem: the fixed production assets of the subsystem in monetary terms (\( \Phi_i \)); labor resources in man-hours (\( L_i \)); energy resources in terms of value (\( R_i \)). The output of the final transport products is characterized by the volume of traffic in the tonne-kilometers (\( P_i \)), which is calculated by the formula:

\[
P_i = \delta_i \phi_i^{\alpha_i} l_i^{\beta_i} R_i^{\gamma_i},
\]

where \( \delta_i, \alpha_i, \beta_i, \gamma_i \) - parameters characterizing the structure of the subsystem determined on the basis of statistical data using regression analysis methods.

In the first approximation we considered:

\[
\Phi_i = \Phi_{i0} + f_i L_i = \frac{l_i}{\omega_i}, \quad R_i = r_i,
\]

where \( \Phi_{i0} \) - initial production assets of the i-th subsystem in terms of value; \( f_i \) - capital investments in the i-th subsystem; \( l_i \) - salary fund; \( \omega_i \) - hourly wage ratio; \( r_i \) - working capital of the i-th subsystem.

Assume that the allocations received by the i-th subsystem are distributed over the following items of expenditure: capital investments; salary fund; working capital; depreciation, equal to \( \mu_i \Phi_{ic} \), where \( \mu_i \) - the rate of depreciation. Then the balance of the i-th subsystem will be determined by the ratio:

\[
X_i = f_i + l_i + r_i + \mu_i \Phi_{ic}.
\]

Using the above dependencies, the analytical formula for the relationship of parameters will be:

\[
P_i = \delta_i (\Phi_{i0} + f_i)^{\alpha_i} \left( \frac{l_i}{\omega_i} \right)^{\beta_i} (X_i - f_i - l_i - \mu_i \Phi_{ic})^{\gamma_i}.
\]

The considered static task of distributing funds can be formulated taking into account the time factor, that is, as a dynamic task on a time interval \( t = 0, T \). Then the expression for \( P_i \) will be:

\[
P_i(t) = \delta_i (\Phi_{i0} + f(t))^{\alpha_i} \left( \frac{l_i(t)}{\omega_i(t)} \right)^{\beta_i} (X_i(t) - f_i(t) - l_i(t) - \mu_i(t) \Phi_{ic})^{\gamma_i} e^{\nu i t},
\]

where \( e^{\nu i t} \) - exponential function of time, which characterizes the influence of NTP on the volume of traffic performed by the i-th subsystem; \( \nu i \) - is based on regression analysis of statistical data; \( \omega_i(t), \mu_i(t) \) - specified time functions on the interval \( t = 0, T \).

Transport system management is now reduced to setting resource \( X_i(t) \) allocation programs in the form of a vector - a functional:

\[
\vec{Y}_i(t) = (f_i(t), l_i(t)).
\]

From the admissible set it follows:
$$C_{it} = \left\{ \begin{array}{l} \frac{Y_i(t)}{F_i(t)} = \left( f_i(t), I_i(t) \right), f_i(t) \geq 0, I_i(t) \geq 0, \\ X_i(t) - f_i(t) - \mu_i(t) \mathbb{P}_{i0} \geq 0, t = t, T \end{array} \right\}. \quad (18)$$

4. Conclusions

The tasks arising from the development of territorial programs of integrated economic development of territories are complex and diverse. The main difficulties of their solutions are derived from cross-sectoral and inter-regional nature and complexity of regional problems.

In a single draft, the territorial program should be linked activities of several industries. In addition, the project should be dealt with issues related to the development of infrastructure, transport, with rational use of natural, material and labor resources, environmental protection.

For these tasks, regional programming methods are used, by which we mean the development of theory and quantitative methods for solving problems arising in the drafting of territorial programs, i.e. projects of programs (schemes) of integrated development of separate (fixed) sites of the territory. In determining the objective function of the organizational structure of URTS, only direct costs in the transport system that are equal are taken into account $\sum_{i=1}^{3} X_i$.

The proposed models are based on production functions, the objective function of the organizational structure of management, the vector criterion for optimizing the formulation of the problem from the standpoint of game theory. The methods of production functions have many opportunities. The considered approach is a hierarchical structure consisting of the governing body of the regional transport system, distributing limited material resources and several transport subsystems (types of transport) producing the same type of transport products - interchangeable transportation.

Thus, the transport operation programming for delivery of raw materials is a problem of multi-level operational planning and management (OPM) with a daily correction that is specific requirements for calculation speed, and therefore, for the simplicity of the proposed article approaches. Development of these approaches in a single inter-sectoral and territorial aspect should be linked to the development of infrastructure, transport, material and labor resources.

The previously used statistical methods used in forecasting do not give results that are satisfactory in accuracy if the trend of the indicator under consideration and the mechanism of its value formation remain in the analyzed period. The methods of linear programming and balancing also do not take into account the nonlinear and discrete factors characteristic of the problems of planning transport systems. Determining the scale of development for the future modes of transport, it is necessary to take into account the close connection of this development with other sectors of the national economy and the fact that the economic effect of each type of transport is also different.

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