The Dynamic Model of Macroregion Transport Activity Development Based on a Generalized Optimization Criterion

K S Tchumlyakov\textsuperscript{1[0000-0002-4248-3691]}, D V Tchumlyakova\textsuperscript{2[0000-0002-2765-9572]} and Yu L Ignatyuk\textsuperscript{1[0000-0001-7379-7661]}

\textsuperscript{1}Tyumen Industrial University, Volodarskogo Street, 38, 625000 Tyumen, Russia

E-mail: ks.tchumlyakov@yandex.ru

Abstract. The article is devoted to the research of the development of transport activities of the Ural Federal District. This macroregion of Russia acquires the opportunity to use the specifics of the modern period of development on the Eurasian continent in the context of international economic integration and the involvement of countries in the processes of international unification of economies. The possibility of using a generalized indicator as a measure of dynamic development concerning the transport system of a macroregion is being investigated. The dynamics of changes in the generalized criterion for optimizing the transport activities of the macroregion is calculated. The dynamic model of the development of the transport activity of the macroregion based on the generalized optimization criterion determines the result of the activity of the regional transportation system in the process of its implementation. The values of the optimization criterion deviate from the optimum significantly over the period under research. The suboptimal development of the transport system of the macroregion is observed.

1. Introduction

The task of ensuring sustainable economic growth and improving the living conditions of the population is paramount in the context of international economic integration and the involvement of countries in the processes of international unification of economies. The implementation of such an integration task is possible only if transport links develop, ensuring reliable international and domestic (interregional, suburban, and urban) communications.

The strengthening of integration ties in the Eurasian direction has been observed recently, which promotes new economic cooperation between Russia and intensively developing Asian countries. Under such circumstances, the Ural Federal District, which is one of the largest macroregions-exporters of hydrocarbons, as well as due to its middle geographical position, gets the opportunity to use the specifics of the modern period of development of transport activities and infrastructure on the Eurasian continent [1; 14].

The Ural Federal District is one of the most dynamically developing territories in Russia, which is largely due to its favorable economic and geographical position and the historically established specialization of the economy of its individual territories. The Ural Federal District includes Kurgan, Sverdlovsk, Chelyabinsk, Tyumen regions, as well as the Khanty-Mansiysk Autonomous Okrug – Ugra and the Yamal-Nenets Autonomous Okrug. The unique geographical position of the Ural Federal District gives it special significance in the foreign economic relations of Russia. The leading industrial
enterprises of the macroregion are export-oriented, therefore the Ural Federal District occupies one of the most significant places in the country’s foreign trade [7; 20].

The level of development of transport activities is characterized by a large number of technical and economic indicators. Therefore, relying on probabilistic and statistical methods, it is possible to determine the assessment indicator by establishing the level of development of the transport activity of the macroregion is a complex system.

2. Formulation of the problem and brief literature review
Transport scientists and economists, such as V. Baginova [10], T. Esikova [3], L. Fedorov [10], S. Goncharenko [3], T. Kargapoltsvea [15], B. Lapidus [8], O. Larin [9], L. Mirotin [10], M. Petrov [15], T. Prokofieva [3], V. Samuylov [15], Yu. Shcherbanin [16], O. Smirnova [13; 17], and others are engaged in research on the development of transport and the transport industry, as well as the problems of the practical application of methods for analyzing the effectiveness of activities based on mathematical methods.

The use of a generalized optimization criterion is possible when assessing the prospects for the development of complex systems [18]. This criterion will determine the optimal solution. About the transport industry, this criterion will allow assessing the current state of the level of development and forecasting changes in the long term.

The presence of many technical and economic indicators complicates the quantitative assessment of the overall level of development, because the significance of the influence of each of the indicators, which are interrelated and interchangeable, is not known in advance. In such conditions, the primary task of research is the probabilistic and statistical processing of accumulated information and experimental data, as well as their classification. The introduction of a generalized criterion as a measure of dynamic development will make it possible to streamline the information base and carry out a reliable classification of technical and economic indicators according to certain criteria, as well as assess transport activity in the period under research, as well as strategically plan and predict its further development.

The construction of generalized indicators (integral indicators) in conditions of constant growth in the volume of scientific and technical knowledge is quite relevant. This scientific direction solves the problem of processing and classifying large amounts of information. Assessment of the level of development of complex systems using a generalized indicator, which represents the direction of dynamic development, according to technical and economic indicators, is possible without significant loss of information [19]. In other words, replacing the original technical and economic indicators with one generalized indicator, if there is a simple and logical connection between them, will lead to the minimization of the loss of initial information.

However, the requirements of visibility and accuracy to the generalized indicator impose some restrictions on the analyzed information base. Such restrictions may be the following: the information base should comprehensively characterize the investigated complex system; the expert nature of the content of the information base and its further adjustment as the system develops (becomes more complex).

Cluster analysis, discriminant analysis, statistical indices, taxonomy are in demand as one of the possible ways to simplify the compression of the initial information in the transport industry to the construction of generalized indicators of economic development, since they allow maintaining the accuracy of information presentation necessary for practice [5; 11].

Taxonometric procedures for calculating the development level indicator are used to determine the relative indicator (di) to compare objects characterized by a large number of features [11]. Taxonomy (from the Greek “taxis” – an arrangement in order; “nomos” – law) is a theory of classification and systematization of complex areas of reality and knowledge that have a hierarchical structure [4]. Taxonomy requires the establishment of taxonomic ranks, that is, the implementation of the correct grading procedure, which provides for the sequential inclusion of a class in a class. In other words, it is assumed that objects, phenomena, or categories are classified according to some attribute or
principle and explores the issues of the volume and mutual relation of subordinate groups or categories [4]. Taxonomy methods have virtually no drawbacks and combine the advantages of cluster analysis methods and statistical index methods. The method proposed by Z. Hellwig allows one to give a generalized assessment of the level of development of an economic phenomenon or process [5].

Next, we will analyze the possibility of using the taxonomy method to build a model for the development of a complex dynamic system such as transport activities.

3. Methodology for constructing a model for the development of a complex dynamic system

At the first stage of creating a model for the development of transport activities in a macroregion, it is necessary to determine the elements of the observation matrix (1), which are the values of the features expressed in units of measurement specific for each feature.

So, we have a set of objects (for example, objects and subjects of the transport complex, rolling stock, transport enterprises, pipelines, roads and communication routes, etc.) \( I = \{1, 2, ..., m\} \), each of which is characterized by \( n \) features (technical and economic indicators of their work). The effectiveness of each object is determined by comparing their quantitative indicators to a certain standard.

The standard is an exemplary measure, a sample for comparison, an object with the best and optimal values in terms of indicators in the sample under research [12]. The matrix of initial information is presented in the form:

\[
X = \begin{bmatrix}
    x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1n} \\
    x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{in} \\
        \vdots & \vdots & \ddots & \vdots & \cdots & \vdots \\
    x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{nn}
\end{bmatrix},
\]

where \((x_{ij})\) is the value of the \( j \)-th parameter of the \( i \)-th object.

An object characterized by quantitative indicators is represented as a point for a vector in a multidimensional feature space. The values of the attributes describing an object indicate its coordinates in multidimensional space. The task will be reduced to determining the distance in the \( n \)-dimensional Euclidean space \((\mathbb{E}^n)\) between the points-objects and the point-standard, and, therefore, to constructing on its basis a taxonomic indicator of the level of development of the transport complex.

The distance between the points-objects and the point-standard is determined by the formula:

\[
c_{i0} = \left[\sum_{s=1}^{n}(z_{is} - z_{0s})^2\right]^{1/2},
\]

where \((z_{01}, z_{02}, ..., z_{0n})\) are the standardized values of the coordinates of the reference point; \((z_{11}, z_{22}, ..., z_{mn})\) are the standardized values of coordinates of points of objects, \( i = 1, 2, ..., m \).

Next, a matrix of standardized values is formed. The average value of an element is determined, and then all elements of one indicator are divided by this average element. Based on the calculation results, a matrix of standardized values is created.

The next step is to construct the coordinates of the reference object of research. All the variables of the matrix of initial information must be differentiated according to the nature of the influence of each of them on the level of development: signs that have a positive, stimulating effect on the level of development of the object are defined in one group. They are called stimulants. Signs that have an inhibitory effect are assigned to another group. They are called destimulants. The coordinates of the point of the standard \( P_0 \) are \( z_{01}, z_{02}, ..., z_{0n} \), where \( z_{0s} = \max z_{rs} \), if \( S \in I; z_{0s} = \min z_{rs} \), if \( S \notin I (S = 1, 2, ..., n) \), where \( I \) is the set of stimulants, \( z_{0s} \) is the standardized value of the attribute \( S \) for the unit \( r \).

The average estimates of the distance function over the entire set of objects (average value of the distance \( c_{i0s} \), standard deviation) are determined by the formulas:

\[
c_0 = \frac{1}{m} \sum_{i=1}^{m} c_{i0},
\]

\[
S_0 = \left[\frac{1}{m} \sum_{i=1}^{m}(c_{i0} - c_0)^2\right]^{1/2},
\]

\[
c_0 = c_0 + k \cdot S_0,
\]

where \((k)\) is some positive number depending on the distribution law.
The taxonomic indicator of the level of development is calculated according to the formula proposed by Z. Hellwig [5]:

\[ di = 1 - \frac{c_i}{c_0}, \]

where \((c_0)\) is the distance between the points-objects and the point-standard; \((c_i)\) is the standardized distance.

The taxonomic indicator is the resultant of all the features characterizing the units of the studied population [11]. Using this model of the indicator, it is possible to assess the level of the value of the features that characterize the phenomenon under research achieved in a certain period or moment in time.

This model implies an economic and mathematical model in which all dependencies are referred to one point in time [6]. Such models can describe both static systems and dynamic ones based on the characteristics of their state at a given moment in time.

The economic interpretation of the indicator is thus, the closer the indicator value to 1, the higher the development of the given object. Using this indicator, it is possible to linearly order the elements of a given population by placing the value \((d_i)\) in ascending order. Rank the sequence of indicators \((d_1 < d_2 < \ldots < d_m)\) to the left will have the worst results for the set of indicators taken into account.

The disadvantage of using a static criterion to research the technical and economic development of the regional transport system is the change in the normalizing value \((c_0)\), as well as the coordinates of the development standard when analyzing the changes that occur over a certain period of time.

The dynamic criterion reflects the process of changing the state of the regional transport system and its functioning. It shows the differences between the states of the system, the sequence of state changes, and the development of events over time.

The use of a dynamic taxonomic indicator model is possible in a similar way. Let us represent the parameters of the economic activity of the transport system (or object) as the coordinates of the vector \(\vec{X}_t \in \mathbb{E}^n\), where \((t)\) is the considered moment in time, \(t \in [T_0, T]\); \((n)\) is the number of parameters; \((\mathbb{E}^n)\) is an \(n\)-dimensional Euclidean space.

The interpretation of the development of an object, in this case, is the movement of a multidimensional point \((z_i)\) in the space of signs \((\mathbb{E}^n)\) relative to the selected point-standard. The development standard is a vector \((\vec{P}_0)\) with coordinates \(z_{01}, z_{02}, \ldots, z_{0n}\), where \(z_{0s} = \max z_{ts}, t \in [T_0, T]\), if \(S \in 1; [T_0, T]\) – discrete time interval of development (in years); \(1\) – many stimulants; \(z_{0s} = \min z_{ts}\) if \(S \notin 1; [T_0, T]\).

The distance between the vectors \((z_i)\) and \((\vec{P}_0)\) in the Euclidean space \((\mathbb{E}^n)\) is defined as follows:

\[ c_{t0} = \left[ \sum_{s=1}^{n} (z_{ts} - z_{0s})^2 \right]^{1\over 2}, \]

where \((c_{t0})\) characterizes the closeness of the development level of the object to the reference one at a time \((t)\). Next, we calculate the time-averaged estimates of the distance function \(c_{t0}\) introduced above:

average distance value:

\[ \bar{c}_0 = \frac{1}{T-T_0} \cdot \sum_{t=T_0}^{T} c_{t0}; \]

standard deviation:

\[ s_0 = \left[ \frac{1}{T-T_0} \cdot \sum_{t=T_0}^{T} (c_{t0} - \bar{c}_0)^2 \right]^{1\over 2}. \]

As an objective indicator of the level of economic development, we introduce a dynamic taxonomic indicator:

\[ d_i = 1 - \frac{c_{t0}}{c_0}, \]

The interpretation of the dynamic taxonomic indicator of the level of development is as follows: the closer the indicator value \((d_i)\) is to 1, the higher the level of development at the moment \((t)\) is the system.
The indicator is presented in the form \( d_t = c_{t0} / c_0 \) in the case when a comparative analysis of the rates of development of an object is carried out, which is an intensively developing system with a monotonically increasing rate of growth of scientific and technological progress. In this case, the value of the vector \((z_{t0})\) characterizing the initial level of development is taken as the vector \((\overline{P_0})\). The interpretation of the indicator of the level of development is similar. With predictive estimates, the reference vector \((\overline{P_0})\) can be specified using expert estimates.

4. Creation of a dynamic model for the development of transport activities in a macroregion based on a generalized optimization criterion

To determine the dynamics of the development of transport activities in the Ural Federal District using the generalized optimization criterion, we use the main statistical indicators of transport organizations according to the Federal State Statistics Service of Russia (ROSSTAT) for 2014-2018 [2]. The parameters characterizing the transport activity of the macroregion are presented in table 1.

**Table 1.** The main indicators of the development of transport activities in the Ural Federal District.

| Indicators                                      | 2014     | 2015     | 2016     | 2017     | 2018     |
|------------------------------------------------|----------|----------|----------|----------|----------|
| Freight transported by rail, million tons      | 185,2    | 180,2    | 178,5    | 179,7    | 177,5    |
| Passengers carried by rail, million people     | 30,855   | 30,019   | 30,053   | 29,449   | 29,17    |
| Transportation of goods by road, million tons  | 471,9    | 433,8    | 367      | 350,4    | 290,2    |
| Freight turnover of road transport, million ton-kilometer | 26743   | 22650   | 21592   | 20870   | 22340   |
| Length of paved motor roads, including the length of streets, thousand km | 89,907   | 91,618   | 92,819   | 93,891   | 97,181   |

The observation matrix is built based on the selected parameters, the matrix of standardized values is formed.

The matrix of standardized \((Z)\) values is:

\[
Z = \begin{bmatrix}
1.03 & 1.00 & 0.99 & 1.00 & 0.98 \\
1.03 & 1.00 & 1.00 & 0.98 & 0.98 \\
1.23 & 1.13 & 0.96 & 0.92 & 0.76 \\
1.17 & 0.99 & 0.95 & 0.91 & 0.98 \\
0.97 & 0.98 & 1.00 & 1.01 & 1.04
\end{bmatrix}
\]  

(12)

All the given indicators are stimulants, therefore the coordinates of the reference point will be \(P_0 = (1.03; 1.03; 1.23; 1.17; 1.04)\).

The dynamics of changes in the generalized criterion for optimizing the transport activity of the macroregion is shown in Fig. 1.
According to fig. 1, it should be noted that during the period under research, the value of the optimization criterion deviates from the optimal value close to 1. Such suboptimal development of the transport system of the macroregion is due to multiple reasons and the general economic situation in the country, for example, the high cost of transport services, high depreciation of fixed assets, the lack of a unified management system for the transport complex, aging of the vehicle fleet, irrational tariff policy and, as a rule, unprofitable activities, etc.

The inclusion of additional indicators will make it possible to more fully assess the situation and take into account all the factors influencing the development of transport activities in the macroregion. The main condition for obtaining reliable results is the availability of capacious empirical material.

5. Conclusion
The dynamic model of the development of the transport activity of the macroregion based on the generalized optimization criterion determines the result of the activity of the regional transportation system in the process of its implementation. Correlation of objects described by a large number of features using the methods of mathematical statistics makes it possible to systematize multidimensional statistical data and build an optimization criterion. This makes it possible to assess the dynamics of the development of the transport sector of the macroregion's economy, promptly manage, predict, and optimally plan economic development measures.

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