Information and simulation model for complex regional transport

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Abstract

The main difficulties related to the economic study of traffic problems are caused by the large number of interrelated factors, hierarchical and competing goals of economic subjects, social and environmental problems of the territory, the degree of administrative independence of its individual parts, as well as the importance of regional economy within the country. The application of rigorous mathematical tools to assess trends in the development of transport infrastructure in these conditions is very limited and is usually reduced to the justification of a few scenarios. The paper offers specific methodological approaches, analytical apparatus with a number of the analyzed conditions and factors, a logical basis for the formation of scenarios in the design of transport systems, including the railway infrastructure of the region. The novelty of the approach used is a combination of accounting features of the territory from the perspective of mineral resources development, and quantification of long-term needs in the freight made on the balance calculations basis.
Keywords: aggregated cargo flows, efficiency, region, balance, cargo correspondence, model, territorial complex, forecast.

1 Introduction

The range of problems connected with research into regional transport systems grasps growth drivers of the transportation sector on a national level, prospects of development of interregional relations and economies of regions, analysis of the general situation in regional transport infrastructure and its main performance factors, the structure of existing management mechanisms, justification of prospects of development of certain kinds of transport and assessment of priorities of the regional transport policy.

Another important area of improving transport system performance is connected with the development of its industrial and service departments. The issues here are well known: technological development, modernization and renewal of rolling stock, development of maintenance and repair facilities, technical and service provisions for cargo transportation, restructuring solutions etc. Institutional and organizational differences, departmental and territorial disconnection between the modes of transportation and transport operators and, consequently, a lack of real opportunities to choose the most efficient scheme of cargo transportation reduce the efficiency of regions' economies. There is no doubt that the time is just right to search for ways to achieve a rational proportion between the modes of transport as well as an interconnected dynamics in their development and use.

2 Research methodology

We suggest conducting the investigation into the problems of regional transport systems on the basis of a generalized information and logical model which makes it possible to structure the processes of analysis of both general issues of improving performance of transport systems' and of specific issues connected with the implementation of territorial programs and projects. This approach takes into account the main requirements for consistency and integrity in applied studies. For specific calculations, the authors used a general model aimed at analyzing the problems of rail transport development that contains three main segments: reference and forecasts (Fig. 1), and relevant specific target blocks – for example, a block on development of rolling stock repair facilities, maintenance provisions of cargo transportation, or a block on the development of a rail network in emerging regions [1]. Some stages of the analysis covered by the model may include different methods for getting quantitative assessments. It is impossible to provide a formal mathematical description of stages of research and applied procedures of selecting scenarios (except for balancing and other quantitative calculations). According to the structure of the model focusing on the variability of conclusions, the first stage uses procedures of logical, economical and systemic analysis.

A brief description of corresponding blocks of the suggested model as applied to the conditions of the Urals Federal District (UFD) can be summarized as follows.

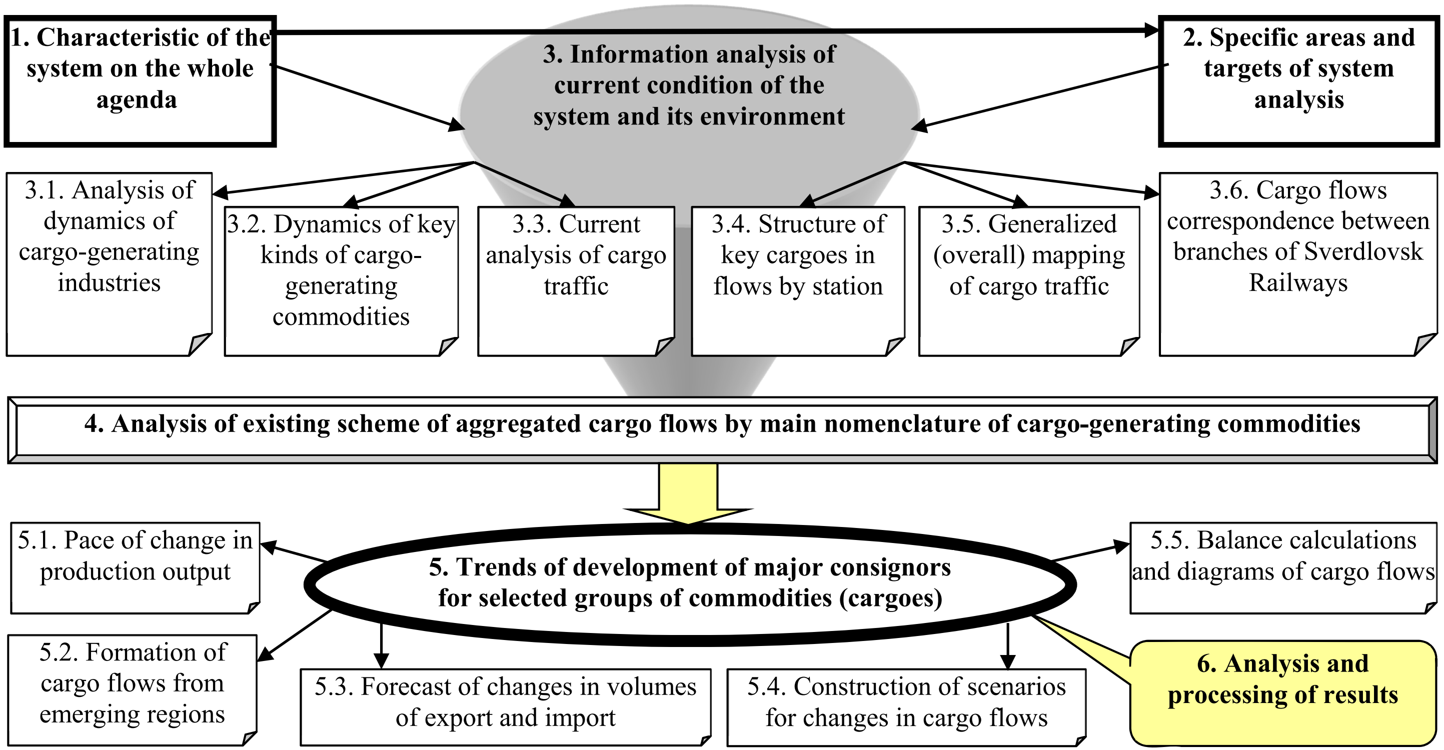

Figure 1: Information and forecast fragment of the simulation model of the territory transport subsystem development – rail network.

Assessment of the place and role of the transport system of the UFD in the unified transport system of Russia (block 1 of the model). Conclusion – geopolitical and geo-economic location of the UFD and its infrastructure directly influences the factors of functioning and development of transport: configuration of railway and road networks, directions and volumes of main cargo flows, ratio of transit and local operations, structure of carried cargo, prospects of development in the short- and, especially, mid- and long-term periods. The factors are: the economic potential and geographical position in the middle of Eurasia at the border between European and Asian subcontinents, almost one third of all proven fossil fuel reserves, one sixth of iron ores, 4.5% nonferrous metal ores, almost 10% of wood, a massive industrial complex. The economic position of transport is defined by a set of factors:

- importance and prospects (tendencies) of development of the economy of the area where services are provided (i.e., the size and structure of transportation services market);
- position and role of the UFD in the national economic space and the world economy, the position and role in the integrated network of transport communications, geographical and mode structure of traffic;
- common trends in the government's industrial, regional and technological policies;
- global economic tendencies: interworking of interests on global markets and subsequent processes (integration and competition of economies, globalization of the world economy).

The purpose of specific investigations in the given segment of the model (block 2) is to provide economic justification of mid-term prospects for changes in main cargo flows that define the development of regional transport systems as an important constituent of the regional economy while taking into account their role in forming the integrated economic space of Russia, processes of integration of the country into the world economic system.

The primary focus here is on forecasting possible changes in cargo flows serviced by railroads, considering the basic nomenclature of carried cargoes. The main factors of upcoming changes are seen as immediately proceeding from development trends in major industrial complexes and the largest cargo-generating businesses in the Urals, West Siberia as well as from the prospects of allocation of productive powers, economic development of emerging, and primarily, northern areas, international business activity. The research yields the following data and their substantiation:

- basic and forecast station-by-station balances on arrival and dispatch of cargoes in view of their main nomenclature;
- forecast interactive schemes of aggregated cargo flows with reference to territory;
- summary data on cargo flows in territorial branches of the railroad and the largest industrial and transportation junctions;
- forecast schemes of cargo correspondence between branches.

Due to the complexity of the system and its interconnections a range of relatively independent stages in the implementation of block 3 was set out. The analysis of dynamics of cargo-generating industries made it possible to collect vast analytical material including, together with retrospective industrial indexes, the characteristics of cargo flows [2]:

1) current condition of cargo flows classified in line with the nomenclature, its structure by arrival and dispatch; import and export of industrial and technical cargoes;
2) the nomenclature of the most important cargo-generating commodities, their share in arrival and dispatch station-to-station;
3) generalized (summary) display of aggregated cargo flows by stations and branches;
4) balance calculation and active diagrams of cargo flows for the reference period of time.

Calculation were automated in order to simulate forecast indices. The structure of cargo flows was defined for all kinds of aggregated goods – thermal and coking coal (in the context of major enterprises), iron ore, cast iron, steel, rolled metal, pipes, cement, construction cargoes, non-ferrous ores (aluminum and copper industry), titanium-magnesium, chromite and other ores, petroleum cargoes, potassium fertilizers, timber cargoes, other cargoes for railways. Moreover, receiving stations arrival and main corporate customers were determined and assessment was performed for evolving dynamics of coal cargo flows.

The architecture of *block 5 of the model reflecting stages of formation of forecast cargo flows* is given in a simplified form. All elements of this block are interconnected and it appears practical to highlight relatively independent blocks of the forecast, with interconnections between being irregular. Analytical results for each block are incorporated into a total result – scenarios of prospective changes in cargo flows – on the basis of logic and economic analysis and formal calculation procedures. Some of the blocks, namely, block 5.2 of the model (assessment of opportunities for formation of prospect cargo flows from emerging regions), are characterized by high uncertainty of future factors, since investment in new production facilities might generate new cargo flows. This enhances the qualitative characteristics of the forecast and proves it wrong to attempt to bring it down to formalized calculations only.

Annual measures of cargo flows for a retrospective period were defined on the basis of corporate statistics which becomes available when specific projects are implemented. To decrease the amount of analytical work, balance calculations were made for tonnes of cargo, and the received factors for specific branches (regions of operation) of the railway and districts in appropriate blocks were complimented with markers “number of carriages”, “type of carriage”, “cargo traffic”. The target blocks of the model were also different in terms of the nomenclature of aggregated cargo. Despite their significant volume, balance calculations have a simple logic and are easily automated, saving a considerable amount of work required for construction of formation of cargo flows scenarios. The used ratios are typical for transportation problems and some of them are given below in a simplified form:

$\boldsymbol{i=1...k}$ – aggregated nomenclature of cargoes; $\boldsymbol{j=1 ...n}$ – stations;

$\boldsymbol{Otp^j}$ – volume of cargo dispatched from a station $\boldsymbol{j}$ (in all directions);
$\boldsymbol{Pr^j}$ – volume of cargo arriving at a station $\boldsymbol{j}$ (from all directions);
cargo flows between two adjacent stations: $\boldsymbol{V^{j,j+1}}$ – volume of cargo traffic between stations $\boldsymbol{j}$ and $\boldsymbol{j+1}$;

$$V^{j,j+1} = \sum_{i=1}^{k} \overrightarrow{V}_i^{j,j+1} + \sum_{i=1}^{k} \overleftarrow{V}_i^{j,j+1} \tag{1}$$

where $\overrightarrow{\boldsymbol{V}}^{\boldsymbol{j,j+1}}, \overleftarrow{\boldsymbol{V}}^{\boldsymbol{j,j+1}}$ – volume of cargo traffic $\boldsymbol{i}$ between stations $\boldsymbol{j}$ and $\boldsymbol{j+1}$ in outbound and return journeys correspondingly (volume of cargo dispatch is equal to volume arriving at the address station). For cargo flows scenarios, limits on carrying capacity of single-track and double-track lines were taken into account as well as the throughput of stations: $\boldsymbol{S_j} = \sum_{i=1}^{k} \boldsymbol{S_i^j} \leq \boldsymbol{F^j}$, where $\boldsymbol{F^j}$ – carrying capacity of station $\boldsymbol{j}$, $\boldsymbol{S^j}$ – volume of cargo coming through station $\boldsymbol{j}$, equal to the sum of arrivals from all directions and loading of certain aggregated cargoes: $\boldsymbol{S_i^j} = \boldsymbol{Pr_i^j} + \boldsymbol{Pgr_i^j}$. Thus, the balance of cargo flows at the station is described by the ratio:
arrival and loading: $\boldsymbol{Pr^j} = \sum_{i=1}^{k} \boldsymbol{Pr_i^j}, \boldsymbol{Pgr^j} = \sum_i^k \boldsymbol{Pgr_i^j}$;
dispatch and unloading: $\boldsymbol{Otp^j} = \sum_{i=1}^{k} \boldsymbol{Otp_i^j}$, $\boldsymbol{Vig^j} = \boldsymbol{Pr^j} + \boldsymbol{Pgr^j} - \boldsymbol{Otp^j}$.

Given the already known factors of import $\boldsymbol{Vv^j}$ to and export $\boldsymbol{Vz^j}$ from other railroads for every station $\boldsymbol{j}$, a balance for every kind of cargo and the whole complex will be determined as:

$$Otp_i^j + Vv_i^j = Pr_i^j + Vz_i^j \tag{2}$$

$$\sum_{i=1}^{k} Otp_i^j + \sum_{i=1}^{k} Vv_i^j = \sum_{i=1}^{k} Pr_i^j + \sum_{i=1}^{k} Vz_i^j \tag{3}$$

Similarly, the balance of cargo flows by branch (region of operation) of the railroad and by each kind of cargo and all cargoes is determined ($\boldsymbol{ml}$ – number of stations in a branch) as:

$$\sum_{j=1}^{ml} Otp_i^j + \sum_{j=1}^{ml} Vv_i^j = \sum_{j=1}^{ml} Pr_i^j + \sum_{j=1}^{ml} Vz_i^j \tag{4}$$

$$\sum_{j=1}^{ml}\sum_{i=1}^{k} Otp_i^j + \sum_{j=1}^{ml}\sum_{i=1}^{k} Vv_i^j = \sum_{j=1}^{ml}\sum_{i=1}^{k} Pr_i^j + \sum_{j=1}^{ml}\sum_{i=1}^{k} Vz_i^j \tag{5}$$

Correspondence with other branches is specified in cargo flows. The cargo flows for the railway system as a whole is structured in the same way– import and export of every kind of cargo, all cargoes, and its components – by specific stations, considering correspondence with other railways. For example, the cargo flow by cargo types and the total cargo flow are described by ratios (4) and (5), replacing the number of stations ***ml*** with ***n.***

Scenarios of changes in cargo traffic are built in block 5.4 of the model. The entire process was divided into several stages (steps). That made it possible to look at individual scenarios that are related to general development conditions for the territories' economies and their interconnections with other regions, as well as scenarios that reflect changes in production and technological links between industries and major cargo-generating companies. In accordance with the research goals, the analysis was limited to identifying key trends in cargo traffic and assessing the general rate of change under the selected scenarios.

The approach makes it possible to factor in both local infrastructure development problems and problems of the national transportation network, which shows very well in a targeted project of rail extension in the north of the Urals. The most complicated task is to forecast freight demand due a large number and variety of cargo-generating companies. Statistical and analytical models were used for the task in combination with data from accepted forecasts of the socio-economic development of areas in the catchment area of the railway network being considered. When building the scenarios on the basis of retrospective information, base case (inertial) scenarios trends in cargo traffic were identified that were adjusted for future periods, taking into account big investment projects and local socio-economic development programs. Information that was used in calculations encompassed major customers of junction stations, interaction with other means of transport, demand for passenger transportation and changes in transit cargo traffic.

From the formal point of view, the described model is a representation of a distributed simulation process. For regulation application the model is supplemented with procedures that improve its functionality. For this, each block of the model is decomposed into smaller ones through functional decomposition in order to attain the required level of detail for analysis goals, methods and means in use, input information and information links with other blocks. Using the active graphic display of information flows in the model allows for clarifying its structure, the logic of connections between individual phases of the study and, eventually, ensuring the adequacy of the model to existing and future parameters of interrelation between the transportation system and economic entities in a region.

3 Practical application of the considered approaches

The information and simulation system has proved very effective for construction and expert analysis of development scenarios for the transportation network. The authors have been able to use the results of information base monitoring when developing:

1) a set of integrated investment projects of rail transport development in the operation areas of a number of regional railway companies;

2) restructuring and operation options for company-owned rail lines, the strategy and tactic of increasing their competitive ability with regard to intersectoral competition;
3) modern organizational and economic technologies for effective management, including effective transport marketing mechanisms [3, 4].

The studies were viewed as an integral part of an information system for economic monitoring and forecasting of development indicators of the transportation industry.

An example of the model application is an investment project for the development of the northern areas of Russia, namely, of the Yamal-Nenets Autonomous Area. The project is essentially aimed at conquering promising transportation services markets in order to speed up the development of northern oil and gas deposits and to further the economic development of the region as a whole

- by creating favourable conditions for an accelerated development of northern deposits by creating transportation infrastructure as well reducing the shipping costs of resources consumed by the region;
- by expanding passenger transportation until local demand is fully satisfied;
- by improving the performance of local railway companies.

The feasibility study of the project included the analysis of prospects for oil and gas extraction in the catchment areas of rail links under construction, an overall general social and economic assessment of the Yamal-Nenets Autonomous Area, its deposits, growth trends in the oil and gas industry. Alternative modes of hydrocarbon shipping were considered and appropriate options for aggregate car shipping were worked out. Scenario hypotheses included forecast data on the production of oil, gas and gas condensate, the delivery of construction materials and detailed information about the key customers of railway stations.

The project implementation plan was approved by the relevant higher authorities, which attests to the viability of the described methodology for assessing development areas in the local transportation and, specifically railway complex.

4 Conclusion

The conducted research shows that when the "principle of comprehensive factors" is used for analysis of development issues in the transportation system, the multitude of the factors, connections and possible contradictions between them, their hierarchy and relative uncertainty predetermine the advantages of using an integrated approach to assessing the areas of development of the regional transportation infrastructure through the combination of the formal statistical and balancing methods with economic logic, expert reviews and scenario constriction tools.

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