Quantitative Assessment of the Impact of Innovations on the Economic Efficiency of the Transport Industry in the Region

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Abstract: The issues of assessing the economic efficiency of the functioning of the transport industry in the region are considered on the basis of a system-analytical approach, including the use of optimization mathematical models of socio-economic systems and application software packages oriented to their analysis. A meaningful statement of the problem, a description of the quantitative characteristics used and the limitations of the functioning of the transport industry of the region are given. The expediency of using the proposed tools is emphasized, provided that the principle of their model, algorithmic and information technology balance is fulfilled, which makes it possible to develop systems to support the adoption of investment, production and financial decisions in the functioning of the regional transport industry. The algorithm of accounting for innovations in its development projects is described. A model computational experiment was carried out to quantify the impact of a specific innovative technology for the acquisition of a fleet of buses in the region on economic efficiency indicators and the life cycle of a project for the development of the transport industry in the region. The key strategic tasks aimed at managers of the mesoeconomical level, manufacturers, investors, financiers and other project participants are identified, the solution of which makes it possible to justify the adoption of optimal management actions for the effective development of the transport industry in the region.

1 INTRODUCTION

The problem of quantifying the impact of innovations in various spheres of the economy remains permanently relevant, primarily due to the complexity of adequately solving the problems of planning and forecasting the development of large, in particular, regional socio-economic systems. The socio-economic development of the regions is determined by the effective use of the totality of their diverse competitive advantages, including in the field of innovations in the transport infrastructure of the territories. The complexity of solving the problem of assessing the impact of these innovations is determined by the complexity of the issues of modeling the complex development of these territories in order to select from the model a set of key factors that affect this assessment and have reasonable, quantifiable values. Obviously, they need to include innovative factors that should be taken into account when modeling procedures for assessing the impact of innovations, or at least they should be given appropriate interpretations. In the transport industry, various aggregated aspects of its development can be attributed to innovation: new production and management technologies, digitalization, robotization, the use of artificial intelligence, and others. In this paper, a universal technology for evaluating innovations in development projects in the transport industry is proposed.

When quantifying the efficiency and performance indicators of the transport sector of the region's economy, the issue of not only the availability of mathematical models of the activities of economic agents in the region, but also the availability of appropriate methods and algorithms for their analysis, allowing the development of automated information systems and systems to support investment,

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production and financial decisions on the management of strategic parameters of socio-economic systems and in particular, the economic sectors of the region. Among the significant number of publications on the topics of concepts, modeling and the impact of innovations introduced in the transport industry of the region, evaluating the effectiveness of their functioning, testing models, algorithms and software packages within the framework of market economic mechanisms, we note works (Makarov, 2015; Medvedev, 2020; Bassiac, 2021; Masoumeh, 2020; Galushko, 2020; Agureev, 2017; Shesterov, 2016; Zamanian, 2020) describing general system-analytical aspects of the study of large socio-economic systems (Makarov, 2015; Medvedev, 2020; Bassiac, 2021; Masoumeh, 2020), similar aspects in the transport industry of regions at the country level (Galushko, 2020), territories (Agureev, 2017; Shesterov, 2016), issues of marketing and logistics of supplies (Zamanian, 2020) of products. Most of the approaches used are based on the widespread concept of sustainable development of socio-economic systems, one of the significant disadvantages of which is the orientation to production functions of a certain class (convex up elementary mathematical functions, usually irrational Cobb-Douglas type functions, logarithmic, logistic functions and their combinations), which, in our opinion, does not always correspond to real business processes in the modern economy. This work is based on models of socio-economic systems free from these shortcomings, methods and algorithms for their analysis described in the monograph (Medvedev, 2020).

2 MATERIALS AND METHODS

The software and analytical tools used to describe the functioning of innovations in the production sectors of the region are based on a systematic approach, which consists in using a set of optimization mathematical models for analyzing the problem of optimal distribution of flows arising during the functioning of economic agents (Medvedev, 2020).These agents in the regional transport industry include the manufacturer of the transport service, the consumer of the service (the population, enterprises of the region) and the management center with their main economic roles (production, consumption of products and tax collection, respectively). It should be noted that the use of optimization mathematical models makes it possible to find optimal volumes and proportions of investments, production and financing of the activities of industry organizations. In addition, the solution obtained by the model will allow us to identify the maximum of a certain economic quality indicator – added to the investments made in projects for the development of the transport industry – and, thereby, the economic potential of this socio-economic system. In turn, the knowledge of the economic potential of the system justifies the adoption of management decisions that motivate economic agents to effective (according to one or more criteria) activities, uses market mechanisms for innovation.

The use of a systematic approach is also necessary to create a comprehensive, balanced toolkit for assessing the socio-economic efficiency of the system, which includes, in addition to mathematical models and algorithms for their analysis, also the possibility of developing end-user-oriented systems – managers of various territorial levels, investors, entrepreneurs, financiers, economists, analysts - systems to support the adoption of investment, production and financial solutions by specialists – theorists and practitioners of the subject area of research.

Let's consider the following meaningful statement of the task of describing the activities and assessing the economic efficiency of the transport industry in the region. Let a set of organizations related to the production and sale of n types of transport services (for example, railway, air, river, motor transport, and others) function on some economic territory (it is assumed to function). For the production of each type of transport service by manufacturing enterprises, in accordance with the principle of clean industries, it is assumed to use (procurement, modernization, etc.) n sets of production assets (SPA), which are understood as a set of such tangible and intangible assets, without which it is impossible to manufacture and sell the corresponding products (transport services). The production of each type of transport service is characterized by its own conditions (labor and material intensity, as expert-defined shares of total production costs), as well as its management and market environment (management system, a set of training organizations, financing conditions, inflation, planning horizon, etc.). Further, for convenience, the project of production of the k-th type of transport service in the industry will also be called the k-th project of the industry.

It is assumed that during the functioning of the transport industry in the region, from the relevant transport enterprises, the budget of the region receives tax flows collected by the governing bodies of the territory, and maximizing the amount of such flows is considered a criterion for the managerial efficiency of the transport industry in this territory. As a criterion of socio-economic efficiency of the transport industry, the maximization of the value of the total discounted profit flows of transport enterprises and the wage fund of industry professionals received at a given planning horizon is considered. Let's define the efficiency of the functioning of the transport industry in the region as a solution to a three-criterion task - maximizing both managerial and socio-economic efficiency of the transport industry while achieving optimal (Pareto) investment volumes in each of the n projects of the industry, taking into account production and technological (production capacity, technological innovations), market (volume of demand for products, its prices), and financial (solvency of enterprises, maximum volumes of investments, loans and subsidies) restrictions on the functioning of the transport industry in the region.

In Table 1, in accordance with the mathematical model (Kirenberg, 2021), the quantitative characteristics of the activity of the transport industry of the territory are reflected, which are necessary for making an automated software package for solving static and dynamic multi-criteria linear optimal control problems described in (Medvedev, 2020, Chapter 2).

Table 1: Quantitative characteristics of the transport industry.

Group of characteristics	Characteristics identificator	Measuring unit	Conceptual meaning of the characteristic
Characteristics of the SPA of the *k*-th direction of development of the transport industry	n	pieces	the number of directions of the transport industry of the SPA region and the corresponding types of products produced by cluster enterprises
	c_k	monetary units (m.u.)/SPA	the cost of SPA of the *k*-th type
	T_k	economic cycles (e.c.)	service life of SPA of the *k*-th type
	V_k	units of production (u.p.) / SPA	SPA performance of the *k*-th type
	$\delta_k = P_k V_k / s_k$	%	return on funds (profitability) SPA of the *k*-th type
Characteristics of the *k*-th products of the transport industry and features of its production	P_k	m.u./u.p.	the market price of a unit of production of the *k*-th type
	q_k	m.u.	demand for *k*-type products
	β_k	%	the share of total costs Z_k used to pay for labor in the production of *k*-th products (labor intensity of production)
	p_k	%	the share of total costs Z_k used for the purchase of raw materials, materials and other current costs consumed during one economic cycle in the production of *k*-th products (material intensity of production)
Characteristics of the external environment, financial conditions of the transport industry enterprises	T_0	*e.c.*	the term of the loan to finance current activities
	r_0	%	loan rate for financing current activities
	Crmax	m.u.	the maximum amount of the loan taken to finance current activities
	Dotmax	m.u.	the maximum amount of subsidies to the manufacturer
	Imax	m.u.	maximum investment amount
	$\alpha_1,\ldots,\alpha_5$	%	rates of tax and non-tax expenses
Risks of functioning of transport industry enterprises	r_{inf}	%	inflation risk (accounted for through the inflation rate)
	r_{inv}	%	the risk of the investor's claims (taken into account through the loan rate and/or other forms of borrowing)
	$r = r_{inf} + r_{inv}$	%	general risk, taking into account the risks of inflation and the requirements of the borrower of funds
Restrictions on the functioning of the transport industry	PRODUCTION		
	The volume of production is not higher than the production capacity		
	The volume of production is not higher than the demand for products		
	INVESTMENT AND FINANCIAL		
	$DS \geq 0$ – the condition of solvency of industry enterprises on the planning horizon T		
	$I \leq Imax$ – the condition of limited investments by the maximum amount on the planning horizon T		
	$Cr \leq Crmax$ – the condition of limited loans by the maximum amount on the planning horizon T		
	$Dot \leq Dotmax$ – the condition of limited subsidies by the maximum amount on the planning horizon T		

It should be noted that most of the indicators given in Table 1 that characterize the SPA and the products of transport industry enterprises, the specifics of its production and sale, production restrictions and the surrounding market environment can be obtained by analyzing market information from various sources (official economic statistics websites, open analytics publications, open enterprise reporting, etc.) or set by experts. Examples of the description of the conceptual meaning of the desired variables, algorithms built on them and the laws of the formation of income and expenditure flows, limitations of functioning, formulated and constructed relatively more general, compared with the transport industry, socio-economic systems, can be found in (Medvedev, 2020), and the use of the approach on the example of the food industry of the region – in (Fedulova, 2016).

The stated substantive formulation of the problem allows us to obtain a quantitative assessment of the economic and innovative potential of the transport industry, as well as to interpret various features of the functioning of the industry – marketing, transactional, innovative, infrastructural, environmental, financial. For example, accounting for marketing, transaction, and environmental costs is possible in the model by considering the corresponding cost flows proportional to the volume of production of transport services or in the discount rate. The innovative nature of the products produced can be taken into account by considering the following chain of reasoning. Let's call the set T $(c_k, T_k, V_k, P_k, q_k, \beta_k, p_k)$ a traditional (old) technology for the production of products of the *k*-th type (or an analog of innovative products corresponding to it in functionality, or an analog of old products produced at innovative SPA, using innovative marketing schemes, etc.), and a set of $T^*(c_k^*, t_k^*, V_k^*, P_k^*, q_k^*, \beta_k^*, p_k^*)$, where $c_k^* = \gamma_k c_k$, $T_k^* = \tau_k T_k$, $V_k^* = \nu_k V_k$, $P_k^* = \pi_k P_k$, $q_k^* = \sigma_k q_k$, $\beta_k^* = \varphi_k \beta_k$, $p_k^* = p_k p_k$ is an innovative (new) technology for the production of the *k*-th type of products. Here the coefficients γ_k, τ_k, ν_k, π_k, σ_k, φ_k, p_k are exogenously (in particular, expertly) set values reflecting estimates of changes in the numerical values of the characteristics of SPA, products, features of production and sale of products during the transition to a "new" technology, which we will call technological coefficients. Comparison of projects for the development of the transport industry with characteristics corresponding to the technologies T and T^* can help to identify the impact of production, technological, marketing innovations on the indicators of the development of the transport industry by varying the coefficients γ_k, τ_k, ν_k, π_k, σ_k, φ_k, ρ_k and considering their various combinations. For example, the inclusion in an innovative project of technological innovations related to the use of computers, robots and other elements of artificial intelligence used in the new fleet of vehicles to provide better services obviously affects the improvement of consumer properties of the service and, accordingly, the expansion of market share and an increase in demand for the service. At the same time, changes in such aggregated characteristics of the road transport industry as the cost of SPA, the cost estimate of demand, labor intensity, material intensity and others are quantified. The creation or re-profiling of infrastructure organizations such as specialized educational institutions (technical schools) affects the training of qualified personnel for the transport industry, etc. At the same time, these changes, the costs and benefits associated with them, can be taken into account and evaluated (both expertly and with the help of marketing analysis) through varying the values of the coefficients γ_k, τ_k, ν_k, π_k, σ_k, φ_k, ρ_k. Quantitative characteristics of investment financing of transport organizations are traditionally reflected in the discount rate r_{inv}, financing methods (lending, subsidizing, etc.) – through the rates r_k and r_0, and are also determined by the availability of own funds of transport industry enterprises.

3 RESULTS AND DISCUSSION

The above approach to quantifying the impact of innovations on the economic efficiency of the transport industry in the region allows us to obtain numerous numerical characteristics of its development projects – optimal values of investment volumes, production of services and financing, comparison of various development scenarios by varying technological coefficients. At the same time, the life cycles of development, economic potential (maximum value added to investments), optimal moments of reinvestment in production facilities and other key indicators of the efficiency of the transport industry are identified without conducting real socio-economic experiments.

To substantiate the above theses, let's consider a model example describing the project of the functioning of the transport industry in the region with the following numerical values of industry indicators: n=1; c_1=10 Rbn; T_1=10 years; V_1=160 million passengers per year; P_1=200 rubles; q_1=36 RBn; β_1=0.15; p_1=0.6; T_0=10 years; r_0=0.15; α_1=0.2; α_2=0.02; α_3=0.2; α_4=0.3; α_5=0; Cr_{max}=0; *Dot*

$_{max}$=5 Rbn; I_{max}=10 Rbn; r_{inf}=0.1; r_{inv}=0.2. The numerical values given can characterize the following features of the functioning of the transport industry in the region: in comparison with the existing system of providing passenger transportation services. It is planned to purchase passenger vehicles (buses) from the manufacturer in the amount of 10 Rbn to provide intracity and intercity transportation. At the same time, the average price of the service is 200 R/person with the number of passengers transported 160 million people per year. The share of wages in the industry is 15% of total production costs, and material costs are 40% (including fuels and lubricants, repairs and spare parts) of total production costs (Federal State Statistics Service, https://kemerovostat.gks.ru/; 11,12 Kiselyov, 2011). The industry operates under conditions of full-fledged taxation (average rates of taxes on value added, property, profit, deductions to social funds, etc.). Investments in the project are carried out with state support, the maximum amount of subsidies is 5 Rbn and the maximum amount is 5 Rbn of private investments at 20% per annum, the inflation rate is 10%. It is also supposed to be possible to credit current project financing costs at a rate of 15% per annum for 5 years. Let the innovative technology of production of passenger motor transport services in the region be described by the following set of values of technological parameters γ_1=1.5, τ 1=1, v_1=1, π 1=1, σ_1=1, φ_1=0.7, p_1=0.9. This technology can describe the following aspects of innovation and technological transformations. The acquired innovative fleet of vehicles is estimated at a cost of 50% more than the existing one, due to the use of new computer technologies and artificial intelligence elements on it. At the same time, due to the use of more advanced engines and fuel, the material consumption (the average cost of fuel, repairs and spare parts) is reduced by 10%, and the complexity of maintenance – by 30%. The remaining innovative effects can mutually compensate for each other. For example, to manage an innovative set of vehicles, fewer professionals are required, but more highly qualified, which requires their training and increased wages. The capacity of vehicles may be slightly lower than the available funds, which, on the other hand, makes it possible to increase the comfort and, consequently, the average cost of the price of the service provided. In this regard, the coefficients τ_1, v1 $_1$, π_1, σ_1 are equal to one, which means that they are unchanged compared to similar characteristics of the "old" technology. It is necessary to assess the comparative economic effect of the application of the new technology, in terms of its impact on the life cycle of the described project, the optimal values of the volume of its investment, production and financing. To answer this question, on the basis of an optimization two-criteria mathematical model (Kirenberg, 2021), we will carry out a computational experiment using automated tools described in (Medvedev, 2020,, Chapter 2).

The figure shows the dependencies of the added value *J* of the project on the planning horizon *T* for various variants of the implementation of innovative technology according to the technological parameters γ_1, φ_1, p_1. In Figure 1 , the graphs shown correspond to the following scenarios: basic (1) – γ_1=1, φ_1=1, p_1=1; (2) – γ_1=1.5, φ_1=1, p_1=1; (3) – γ_1=1.5, φ_1=0.7, p_1=1; (4) – γ_1=1.5, φ_1=0.7, p_1=0.9; (5) – γ_1=1.5, φ_1=0.7, p_1=1. Moreover, scenario (2) corresponds to the case of non-repayment of the project on the entire

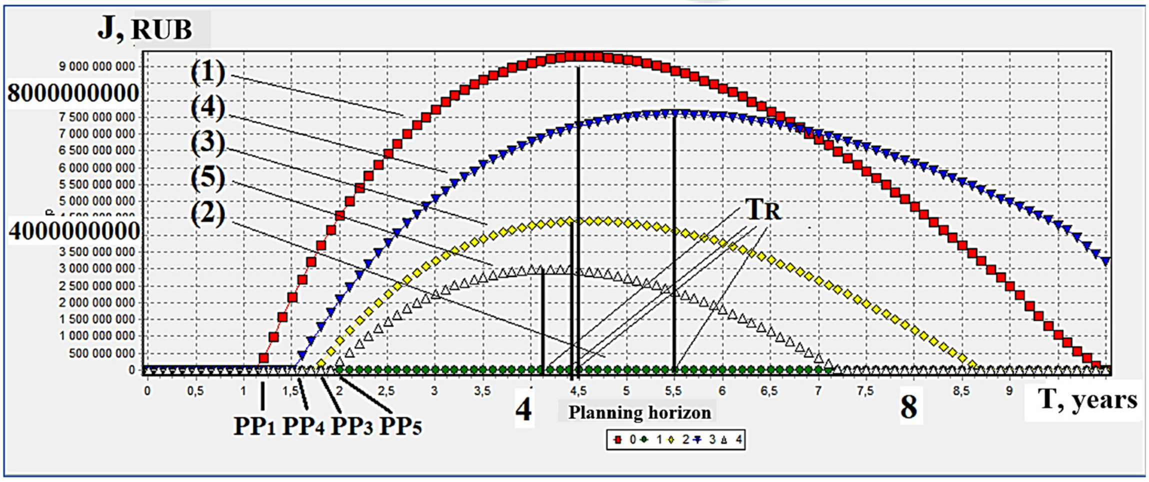

Figure 1: Dependencies of the added value of the project on the planning horizon T (life cycles).

planning horizon. The graphs presented in the figure allow us to determine the optimal parameters of the life cycles of an innovative project in the transport industry under various scenarios of their implementation. These parameters include the maximum potential of the project (schedule extremes), payback periods *PP*, optimal periods T_R of reinvestment planning. A comparative analysis of the above graphs allows us to visually assess the impact of an innovative project on the economic efficiency and life cycle of the production of passenger transportation services. Note that the use of the described tools makes it possible to make sound investment, production and financial decisions not only in the case of the production of one type of transport service described above, but also when considering options for the functioning of the transport industry focused on the provision of n>1 types (groups) of services, for example, railway, air, river transport and other types of transport services.

4 CONCLUSIONS

The paper presents a system-analytical concept that allows for an automated quantitative assessment of the economic efficiency of projects (including innovative ones) for the development of the transport industry in the region, without conducting expensive marketing experiments. In the proposed formulation, the key tasks of substantiating and making optimal decisions by managers of the mesoeconomical level, manufacturers, investors, financiers and other participants in projects for the development of the transport industry of the region related to:

- determination of optimal volumes and proportions of production of various types of products (services);
- determination of the tax potential of production (the amount of tax and non-tax fees collected by management structures);
- justification for investors of the optimal volume of investment costs, as well as the investment attractiveness of the industry in the territory;
- identification of the economic potential of innovation, taking into account the optimal volume of investments in the transport industry, the production of transport services and, thereby, the justification of its development strategy.

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