# ESTABLISHING A SYSTEM OF TRANSPORT SPACE INDICATORS AS A BASIS FOR MANAGING THE MACRO-TERRITORIES SPATIAL DEVELOPMENT

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***Abstract***

The article covers the aspects of transport networks from the point of view of the spatial paradigm and defines the main priority directions of their development, taking into account the modern requirements of society. The article is devoted to the main aspects and the role of forming a system of indicators of transport space in the context of society's transition to the sustainable development principles. The article analyzes foreign methods for assessing the effectiveness of territories development. Conceptual model of the system of indicators of transport development of territories is proposed. Ontologies are used as the basis for an explanation of key concepts to obtain the objective assessments of the current state of the transport space, the prospects for its development and the impact on the competitiveness of the entire territory. The article offers a comprehensive approach to the description of transport in large territories based on the systematization of transport indicators assessment.

**Key words:** transport accessibility, transport availability, sustainable development, macro-territory, indicators of transport space

## 1. INTRODUCTION

Russia is a country with a huge territory. On the one hand, this is a strong fact that indicates its possible power, but on the other hand, it is the cause of its problems and limitations in development. It is obvious that there were and will always be imbalances in the economic development of territories. And the question of the best possible development of a territory remains relevant. This requires an adequate tool for assessing the role and development of a territory on a national scale. The purpose of this article is to form a system of transport space indicators, their integral content (scope) in the context of sustainable development of territories. As the subject of the study, the authors selected characteristics that reflect the main content of the transport space - “Transport accessibility” and “Transport availability” of territories.

Spatial development of the territory of a macroregion includes at least the development of three infrastructures: energy, information and transport (Vokhmyanina et al., 2018). But it is the development of transport infrastructure that determines the progress of the territory. And one of the primary roles is assigned to the formation of the transport framework, as a powerful basic potential for the prosperity of both an individual region and the country as a whole.

For the purpose of sustainable development of territories where various administrative and territorial entities are located, the transport space related to them should be integrated, unified and able to "link" territories, and this means the need to manage the development and functioning of transport infrastructure as a macro-regional transport system covering adjacent regions of the country. However, today we see different modes of servicing territories even in neighboring regions: there is no pairing of regional documents for managing the development of systems (Zhuravskaya et al., 2014).

The world has accumulated a wealth of experience in developing territories due to the priority organization of the transport network, where its advanced development is dominant, and the network configuration of the network contributes to a high level of development of the territory and more favorable conditions for placing production on the periphery (Petrov et al., 2013).

However, the question remains whether the development of territories is polarized or uniform. The article is devoted to systematization of indicators of transport accessibility and availability of territories on the basis of ontologies.

## 2. LITERATURE REVIEW OF THE CURRENT STATE OF RESEARCH

Recently, both in the West and in Russia, the idea of equitable access and use of transport infrastructure has become more active (Kuratova, 2014). Issues of spatial development of territories are receiving increasing attention, both in the scientific environment and at the level of administrative and political planning and regulation, and strategies for spatial development of countries and regions are emerging. First of all, this concerns European spatial planning, in particular, the study of the original interpretive model of European space, called Territorial Frames – TFs (Environmental and territorial modelling for planning and design, 2018), a special multi-scale infrastructure grid that connects "local" territories with "global" ones and which can represent an activating element of processes and policies for the spatial development of human settlements, the processes of valorization of the productive, naturalistic and landscape sectors. At the beginning of 2019, Russia also adopted the spatial development Strategy of the Russian Federation for the period up to 2025, the approval of which was preceded by a long public discussion of its concept. Spaces of those scales that allow us to build the most appropriate mechanisms for managing the development of productive forces in modern Russia are of particular interest in the strategy.

In the scientific sphere, a huge number of works are also focused on the issues of spatial development of territories - 0.5 % of articles from all scientific publications published on the E-library platform (data are as of July 25, 2019). However, it is noteworthy that the research is very narrow in scope. These are works dedicated either to the organization of road traffic (Dragileva, 2017), or studies related to certain sectors of the national economy (for example, agriculture (Kuratova, 2007), forestry (Efremov, 2009), etc.), or works dedicated to specific geographical regions (Melnik et al., 2017; Kiselenko, 2018; Bykov, 2017) or the urban environment (Sidorov, 2017; Mazur, 2017) Thus, most studies in this area are dealing with industries, regions, or individual phenomena of interaction between transport and the environment. There is almost no research on the broad fundamental issues of sustainable spatial development of macro-territories.

The expansion of national transport policy, including aspects of strategic infrastructure development, management of its functioning, as well as the full range of consequences, increases the need for systematic research using various methods and tools for analysis, assessment, forecasting and decision-making on the interconnected development of transport systems and socio-economic systems. Adequate decision support systems at the appropriate spatial level are required. Therefore, national and transnational transport models take on major importance.

Work (Ivanov, 2019) focuses on the main strategies for configuring transport networks. General types of transport network settings are proposed as a starting point for setting up more complex network layouts, and the concept of shipment consolidation as a key approach to implementing economies of scale in transport is considered. In addition, various transport network configuration parameters and their balancing are analyzed in order to configure effective network layouts.

Research (Di et al., 2018) is focused on the problem of network design. Taking a well-defined measure of accessibility, this document addresses a new problem of discrete network design for urban areas, in which some concepts, including the available flow, the trip time budget function, and the principles of user balance and optimizing the system with a trip time budget. Deterministic models of two-level programming are defined to maximize the flow available to the network. The upper level focuses on selecting potential links in a pre-defined set of candidates, while the lower level assigns all threads in a super network with the principles of user balance or system optimization with a limited travel time. Moreover, to cope with the uncertain potential requirements in reality, the problem of interest is further formulated as two-stage stochastic programming models. Effective heuristic algorithms based on the probabilistic search algorithm have been developed to solve the proposed models.

Environmental impacts also extend beyond regional and national borders, and transport policies that affect these environmental impacts cover all spatial levels. Study (Integrated Spatial and Transport Infrastructure Development, 2016) illustrates new approaches to solving the conflict impacts of transport infrastructure, such as economic growth and environmental damage. The main goal is to jointly develop the transport potential of the transport corridor by ensuring optimal economic benefits and spatial integration while reducing the negative impact on the environment at the local and regional levels. These issues are highlighted from an interdisciplinary point of view.

The study (Wang Yu et al., 2018) is devoted to a multi-level approach to the design of a virtual transport network (VTN). This design is a key part of VTN-based network management, where network management is performed by managing different VTNs across different areas. The multi-layer approach to virtual transport network design provides better performance compared to traditional single-layer design.

The analysis shows that the main flow of foreign publications on transport development concerns transport networks. The essential features of transport development in Russia require reflection of these issues in the proposed study. At the same time, when developing transport models, it is not necessary to strive for a complete analogy of other countries, since, on the one hand, there is no possibility, and on the other hand, there is no need to equalize the transport accessibility of Russian territories to the same extent as abroad. Our objective is to increase transport availability and accessibility within the territories of various types and levels. This involves searching for effective ways to influence transport on the final economic results, taking into account environmental factors.

When analyzing the effectiveness of transport systems, technologies and algorithms for assessing the territory in terms of their ability to meet the existing transport demand are of primary interest. It is territorial (in the broad sense of this term) restrictions that determine the development opportunities of the territory and, ultimately, the quality of life on it (Trofimenko et al., 2013). The absence of a coordinate system, restrictions, indicators (criteria) for evaluating the effectiveness of transport systems that take into account their multimodality is explained by the lack of adequate methods for quantifying the demand for transport services. Therefore, it is an important and interesting task to get a system of indicators of transport space for assessing the territory development.

## 3. TRANSPORT ACCESSIBILITY AND AVAILABILITY ARE THE MAIN INDICATORS OF THE TRANSPORT SPACE OF TERRITORIES

Transport accessibility is a measure of the ability of a territory to be reached, or it is the ability to reach other territories by means of transport. The methodology of equated indicators already exists, and there is a need to diversify transport opportunities in terms of availability. For example, there are places and territories where there is only one type of transport, and this is not the same as having several types of transport. There is no understanding of the extent to which the costs of multimodality (the interaction of different modes of transport) are required. Based on the use of only an economic resource, it is difficult to determine the effectiveness of transport network solutions. It is required that the system of indicators is sufficient in terms of cash needs, based on costs, and if so, it suits the cheap solutions, and one mode of transport is always cheaper. On the scale of the macroregion, it is necessary to have a decision on the feasibility of justifying borders for combining transport modes.

The system is always characterized by the presence of several criteria and only one of them is used. We need a special transport criterion that can partially represent a multi-criteria solution.

How can such a decision be justified? This is the way: project - cost - justification method, but transport is the worst amenable to this algorithm. Economic efficiency comes down to cost-effectiveness.

The purpose of this study is to develop a system of indicators of transport space in the context of sustainable development. Taking into account that 3 spheres of human activity are equally important in the theory of sustainable development: economy, ecology and social sphere, the authors propose three blocks of enlarged indicators that affect transport availability and accessibility of the territory:

- technical and economic indicators of the territory TEcI (Technical and economic indicators of the territory): TEcI = { TEcI1, TEcI2, … };
- socio-political indicators SPI (Socio-political indicators):
SPI = { SPI 1, SPI 2, … };
- environmental and geographical indicators of the territory EnGI (Environmental and geographical indicator): EnGI = { EnGI 1, EnGI 2, … }

We assume that all these indicators are equal. However, to determine transport availability and accessibility, a certain experience (mathematical toolkit) has been accumulated, which is well combined with the method proposed by the authors, but requires some improvement.

The category "transport availability" is introduced in order to show a certain capital value that has a value-based significance. It is important to see the range where interchangeability of transport modes or their simultaneous representation is absolutely justified, despite the high cost. In addition to the block of technical and economic indicators, it is necessary to take into account the blocks of socio-political indicators and geographical and environmental indicators, which should also be based on. In addition, let's remember the categories of Dialectical materialism - space and time, which we will focus on when developing the Transport criterion of the territory.

So, referring to the transport availability of the territory, the authors found that "traditional" indicators such as the density of the road network and the coefficients of Engel, Golts, Uspensky, Vasilevsky are directly related to each other and are measured in kilometers.

In the article (Savushkin et al., 2019), scientists summarized the indicators of network density, denoting the transport indicator of spatial development of the region in $x$, and the indicator of transport availability of socio-economic development of the region by the formula:

$$V = \frac{x}{a}, \tag{1}$$

where $a$ is the socio-economic indicator of the region used to assess its development.

Calculation of the complex index of network density is performed by analogy with the formula (1). In this case, the geometric mean of two or three corresponding indicators is used as the denominator [21]. For example, the following formula can be used:

$$v = \frac{x}{\sqrt[3]{a_S a_P a_G}} \quad (2)$$

where $a_S$, $a_P$, and $a_G$ are indicators of the area, population, and economy of the region, respectively.

To measure the contribution of cargo and passenger transport modes, the indicator of equated transportation output *w* is calculated using the formula:

$$w = G + kP, \quad (3)$$

where *G* is the cargo turnover, *P* is the passenger turnover, and *k* is the coefficient for converting passenger-kilometers (pass. km) to ton-kilometers (tkm).

Speaking about the complex indicator of the density of the network of different transport modes, it is worth noting that there are the methodology of equated indicators, so 1 km of the operational length of various types of transport to 1 km of the length of railways is determined by the formula:

$$k_{\text{equated}} = \frac{L_t}{L_{rw}}, \quad (4)$$

where, with the consideration of the comparison of the levels of carrying and freight capacity of highways, $k_{\text{equated}}$ has a different value:

- for an improved motorway, $k_{\text{equated}} = 0.45$,
- for roads with normal hard surface $k_{\text{equated}} = 0.15$,
- for a river route, $k_{\text{equated}} = 0.25$,
- for the main gas pipeline $k_{\text{equated}} = 0.30$,
- for medium-diameter oil pipelines $k_{\text{equated}} = 1.0$.

However, further diversification of transport options in terms of availability is necessary. For example, there are places and territories where there is only one type of transport, and this is not the same as having several types of transport. In the current context it is important to consider the multimodal nature of the transport network, and hence the transport availability areas, as a transport indicator in this territory.

In (Savushkin et al., 2019), it is proposed to calculate the complex transport indicator of various types of transport using the formula (5):

$$\bar{x} = \sum_{i=1}^{n} \bar{q}_i h_i \quad (5)$$

where *n* is the number of modes of transport, $h_i$ is the transport indicators, and $q_i$ is the highest efficiency indicator for each type of transport.

So, transport availability, measured in kilometers, is referred to the indicator of spatial development of the territory. And transport accessibility, measured in units of time (hours), is classified as a time indicator. Thus, we obviously see the categories of dialectical-materialistic philosophy based on the concepts of space and time – the main forms of existence of matter. We will also take into account movement as a way of existence of matter as the third basic philosophical category for the formation of a system of transport space indicators.

Now the results of this reasoning are presented in tabular form in the form of 9 enlarged blocks of indicators:

**Table 1.** Indicators of the transport space of territories

| Blocks of indicators of transport development of the territory | Basic Philosophical categories used as the basis for the indicators | | |
|---|---|---|---|
| | **Space** is the form of existence of Matter | **Time** – the form of existence of Matter | **Movement** – the mode of existence of Matter |
| Basic categories of transport development | **TRANSPORT AVAILABILITY**, network density, km | **TRANSPORT ACCESSIBILITY**, hour | **SPEED**, km/h |
| Geographical and environmental indicators, ***EnGI*** | For example: Network density indicator measured by the ratio of the length of the operational length of the network to the area of the territory (formula 1) | For example: Periods of restoration (self-restoration) of the natural environment from negative impacts of transport | For example: Sector speed of the territory, as the weighted average of sector speeds on various modes of transport (formula 5) |
| Socio-political indicators, ***SPI*** | For example: transport availability of population, measured by the ratio of network operating length to the population size (formula 1) | For example: Transport accessibility indicator for passenger transport | For example: Passenger traffic capacity Passengers/h |
| Technical and economic indicators, ***TEcI*** | For example: Transport availability of goods, measured by the ratio of the operational length to the volume of traffic in a given territory (formula 1) | For example: Transport accessibility indicator for freight transport | For example: Carrying capacity, (load capacity) – the largest number of tons of cargo that can be transported on the territory's transport network per unit of time |

| | | | |
|---|---|---|---|
| Integral indicator | Comprehensive indicator of network density, that takes into account the area, number and volume of production (formula 2)<br>Comprehensive indicator of the density of the network of various types of transport, in equated km.: (formula 5). | Comprehensive indicator of transport accessibility | Production capacity of a transport system: Equated transportation output per unit of time: $N = \frac{w}{T}$ |

Thus, the paper proposes a typology of indicators based on the one hand on the subject-content disclosure of philosophical categories: spacetime, movement, and on the other hand, on the principles of sustainable development of territories.

Research (Volkova et al., 2018) shows that the state of the territory's road network and indicators of its socio-economic development are interrelated. With the slightest positive changes in the road infrastructure, the indicators of the macroregion's transport space improve and the level of well-being of its residents increases.

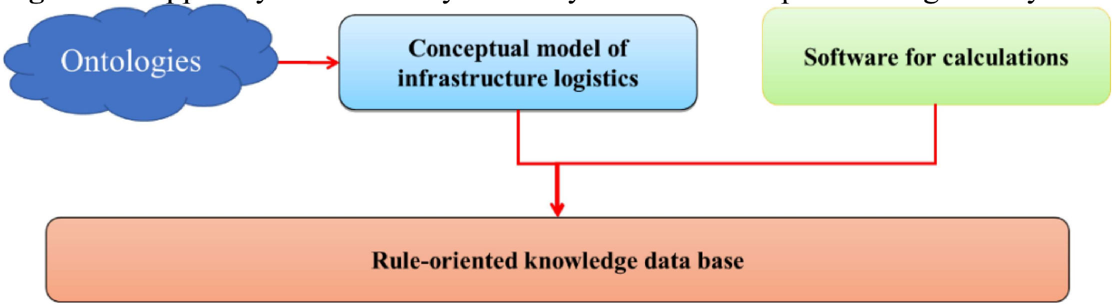
However, nowadays natural and territorial landscape is overlaid with technology platforms and is getting reshaped by them. Examples: large aviation hubs with a landing frequency of 1 plane in 35 seconds, 600-kilometer transport availability, high-speed railway - no more than 2 hours of availability. The speed on Chinese high-speed railway today is 300-330 km/h. The Japanese have reached a speed of 500 km/h, but so far only one route per day, as it is obvious that the entire infrastructure needs to be changed completely. Changes are also possible thanks to the "last mile" technology, in which a passenger calls a taxi from a train car.

Technological platforms should also be used to solve the problem of insufficient development of mathematical and algorithmic tools for forecasting and scenario modeling of the development of large transport systems of territories, with due account for long-term social and economic consequences. Ontologies are used in the development and design of knowledge-based systems to generate the indicators stated by the authors. Therefore, you can use knowledge that has been tested in practice. This, in turn, guarantees the high quality of the created indicator system, as well as its potential integrability with already developed systems.

## 4. MODELS OF SOCIO-ECOLOGICAL AND ECONOMIC PROCESSES IN THE TRANSPORT SPACE OF MACRO-TERRITORIES

The creation of mathematical models of socio-ecological and economic processes and their use for the analysis of the system of indicators of transport space is a very relevant and quite complex task. The support system is implemented as a knowledge-based system (Fig. 1)

**Figure 1.** Support system for analysis and synthesis of transport and logistics systems



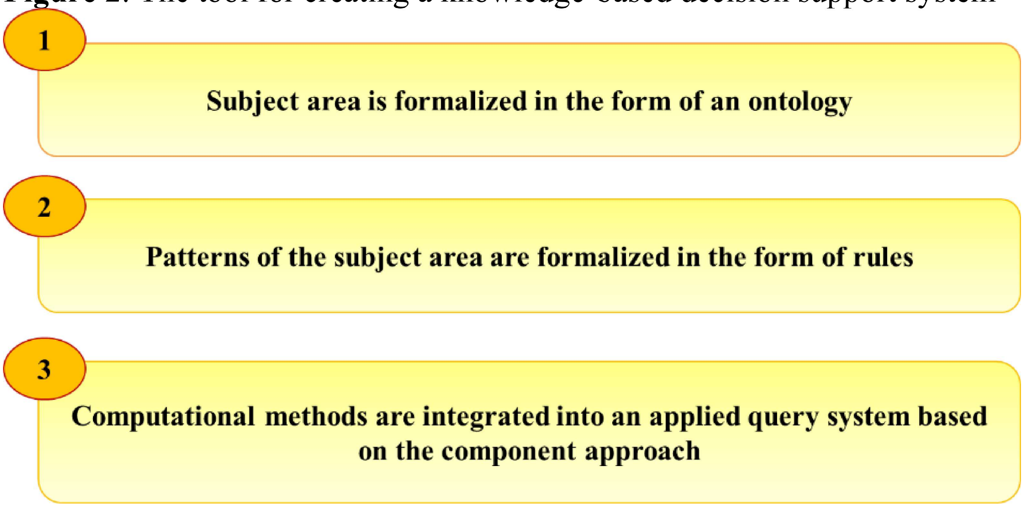

Source: authors

Knowledge-based systems are computer programs designed to replicate the work of experts in specific areas of knowledge. Common properties that unite all knowledge-based systems are:

- attempts to represent knowledge in an explicit form;
- reasoning system that allows you to get new knowledge.

The use of specialized methods for constructing ontologies allows you to extract information to create a conceptual model of a system of indicators from a wide variety of information sources. New elements of such model and rules that use them can be quickly added to existing knowledge bases (Fig. 2.)

**Figure 2**. The tool for creating a knowledge-based decision support system



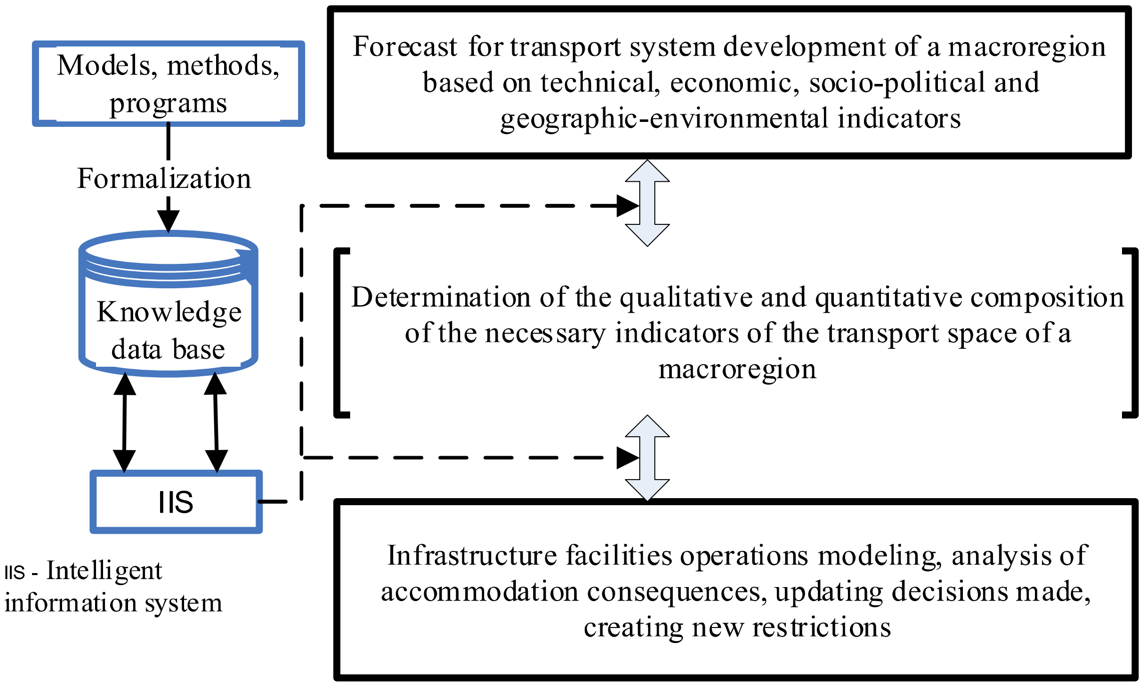

Source: Nikolaychuk et al., 2018

Today, ontological pictures are more mobile forms of organizing ideas about objects in a situation of many processes and when it is necessary to link them to each other. They address at least 3 groups of problems:

1. Interdisciplinary communication of specialists at the borders of subject areas.
2. Communication of leaders without delving into the details of research models.
3. Ensuring the transition from a functioning mode to a development mode.

Thus, based on the existing ontologies of transport and logistics, environmental and social processes in the macro-region, a conceptual model of the transport space indicator system is being developed. This model allows you to describe all the main indicators, which is confirmed by the use of modern applied ontologies from the subject area under consideration (Fig. 3).

**Figure 3**. Indicator research methodology




The current level of mathematical, information and intellectual methods of information processing, together with the large amounts of data accumulated to date, reflecting various aspects of socio-ecological and economic systems, determine the great potential for further development of models of the "Region" type both from a theoretical point of view and in the field of software development.

The further course of software development would be the implementation of ideas on a new information technology basis, including the use of artificial intelligence methods, support for distributed computing, and a web-based way of interacting with users.

**5. BRIEF CONCLUSION**

Transport systems are the basis for ensuring the spatial development of territories of various types and levels. In this regard, for the purposes of development management, it is necessary to create a system of indicators for the transport space. In view of the universal and defining role of transport systems in spatial development, we propose a typology of indicators based on their substantive disclosure of such fundamental categories as space, time, and movement. Indicators that reflect technical and economic, geographical and environmental, and socio-political criteria for the development of the system are distributed in relation to them.

And of course, the work on forming a system of indicators for the transport development of regions should continue. The advantage of this study is to systematize the basic categories of the transport network: transport accessibility and availability, taking into account the philosophical approach and on the basis of sustainable development of territories. The approach presented in this paper is adequate to the current conditions of development of both a particular region and the country as a whole. Generalization of the approach proposed here is a conceptual model of the transport space based on ontologies of transport and logistics, economic, social and environmental processes in macroregions.

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