Analysis of transport system stability

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Abstract. The article considers the description of the internal sustainability of regional road transport systems through parameters that reflect potential and realised opportunities in regional freight transport operations. There is the author's vision of the regional road transport system for the transport of goods by road as a target-oriented set of elements, including vehicles, transport infrastructure, technical devices, equipment, and employees, organisational structures that ensure the achievement of management objectives in the transport sector of the region. They conclude that an important element in the management of the functioning and developing road transport in the region is considering the factors that determine the internal sustainability of the system. The paper provides the author's definition of the internal sustainability potential of the regional road transport system. It proposes an approach to assess the internal sustainability of regional road transport systems based on the elements of regional transport system capacity, such as infrastructure capacity, operational capacity and freight demand capacity in the region. Researchers developed a system of indicators to assess each capacity element from the perspective of the internal sustainability of the system. The article focuses on the study of system stability based on the assessment of deviations from equilibrium states that ensure the stability of the system within its baseline parameters and characteristics, and its adaptability to deviations from the baseline values. It uses regional statistics to assess the internal sustainability of regional road transport systems and describes their internal instability factors. The authors present a visualisation of a model for assessing the internal sustainability of a regional transport system.

1 Introduction

Road freight transport plays a key role in ensuring the security of goods supply chains. The transport volume of road transport is the leading indicator among other modes of transport. According to data for 2019, road transport accounted for 68% (5,735 million tonnes) of total freight transport in Russia. In the European Union, the situation is similar: 51% of all goods are transported by heavy goods vehicles. The USA has a 63% share of road transport [1]. The consequence of the country's underdeveloped logistics and transport infrastructure is the high share of transport costs in the price of the final industrial product. For example, the global average share of transport and logistics services in GDP as a whole is around 13%. In Russia, the value of this indicator is more than 16% and varies considerably depending on the region.

Managing the sustainable development of transport systems in Russia's regions depends on their specifics due to the high differentiation in the development of infrastructure parameters, resource endowment, and the level of adaptability to the influence of external and internal factors.

Regional road transport systems for road freight transport can be described as a target-oriented set of elements, including vehicles, transport infrastructure, technical devices, equipment, and employees, organisational structures ensuring the achievement of management objectives in the area of road freight transport in the region.

The functioning of regional road transport systems for freight delivery has a high level of differentiation, significant differences both in the structure of transported freight and in the composition and dynamics of transport enterprises and transport infrastructure development in the Russian regions.

In a highly competitive environment, the road freight transport industry is significantly influenced by external factors. The sectoral market reacts rather sharply to economic crises. For example, Rosstat noted a significant deterioration in land transport performance in 2020 (minus 72.7%) [2]. The sustainable functioning of regional transport market participants creates prerequisites for the sustainability of the regional transport system, which is considered to be one of the key factors of regional development [3]. However, the functioning of regional transport systems also depends substantially on internal stability factors, which include both the availability and condition of transport infrastructure in the region and the organisational parameters and quality of the workforce involved in transportation. Assessing the resilience of road transport systems requires, in turn, the creation of models of their functioning, with the description of adaptability,

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flexibility to the influence of factors, and the magnitude of resilience as the main properties.

2 Materials and methods

Transport is not only an infrastructural branch of a country's economy, but also an element of the integration mechanism that forms the basis of a transport system at the appropriate level. It is possible to distinguish national as well as regional transport systems of a country depending on the scope of coverage. A sustainable, stable regional transport system is one of the key conditions for the development of the regional economy, ensuring positive effects such as stable supply chains; the possibility of transport at constant tariffs over a long time; the development and provision of value-added services to users, etc. A sustainable transport system as defined by the EU Council of Transport Ministers refers to a system that meets the conditions of accessibility, clarity and efficiency, and balanced regional development. There is no consensus among researchers on the assessment of the category of sustainability, including in the transport sector. However, some scholars believe that sustainability revolves around responsible economic, social and environmental management [4]. Furthermore, corporate sustainability should also provide long-term value to stakeholders [5,6].

The authors propose to understand the sustainability of a socio-economic system as the ability to ensure the successful fulfilment of the main target function. If an enterprise is regarded as a socio-economic system, its target function will be defined according to the specific nature of its activity, for example, in transport - the transportation of goods. Transport sector development programmes reflect the targets at the regional level. Then, the sustainability of a regional freight transport system is the state where the system is able to provide an economically justified volume of traffic while being affordable, efficient, balanced and adaptable. In our view, the sustainability of regional transport systems depends on the state and dynamics of the material and physical (transport infrastructure, rolling stock, etc.) and cost structure (demand, supply of services) of operational activities in the region, which leads to a stable outcome of transport operation in the region.

The state of the regional transport system can be evidenced by the following indicators: freight intensity of the gross regional product (GRP); transport network capacity by mode of transport on major freight traffic routes; commercial speed of main commodity flows; level of containerisation of transported freight; share of transport costs in the price of products in economic sectors; safety level of transport infrastructure facilities, etc.

In our view, it is also possible to describe the category of sustainability in transport by capacity utilisation parameters when there is an assessment of internal sustainability, i.e. the stability / stationarity of the system and its parameters. In this case, capacity is the totality of sources, abilities, capacities, means, unrealized reserves that can be activated and used to achieve the goal of sustainable development in the activities of an economic entity [7,8]. There are various approaches to determining the composition of enterprise potential presented in the works of Russian and foreign researchers [9,10]. When describing sustainable development, we can distinguish the elements of capacity as social, economic, functional and market [11,12]. However, this approach does not consider the specifics of regional transport systems, and the factors that determine the characteristics of the description of external and internal sustainability, which does not allow taking into account the specifics of different levels of transport regulation and management of Russia's regions.

When developing a mechanism for assessment of the sustainability of the regional transport system, it is necessary to pay special attention to the choice of indicators that consider sector specifics and characterise the potential used to ensure the stable functioning of the transport services market. To assess the sustainability of a regional road transport system, we propose to use indicators that reflect the stationarity of the use over time of the various elements of capacity. The system of indicators recommended for assessing each of the capacity elements from the perspective of target sustainability is given below. To assess the internal sustainability of a regional road transport system, the article proposes an approach based on a description of infrastructure potential (I), operational capacity growth potential (T), and regional transport demand potential (O), ultimately providing performance indicators of the regional road transport system. Therefore, the proposed approach can be represented as follows (Figure 1).

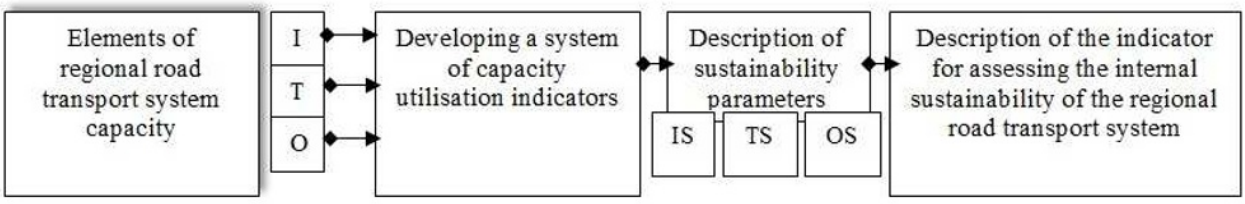

Figure 1. Main steps in developing an assessment of the internal sustainability of a regional road transport system

Based on this approach, it is possible to assess the internal sustainability of a regional road transport system along the following main parameters proposed in this paper: IS - infrastructural internal sustainability, which describes the stationarity of transport infrastructure use in the region; TS - operational sustainability, which reflects the ratio of road transport performance of the region to the available infrastructure; OS - outcome

sustainability, which describes the ratio of operational transport performance to economic parameters in a competitive environment of the region. To assess internal sustainability, there is a data set reflecting the performance of the regional transport system and the regional economy (statistical data for the period).

For the infrastructural sustainability (IS) parameter, we suggest using the following available statistics: IS_1 - share of paved roads as a percentage of the total length of public roads; IS_2 - share of improved roads as a percentage of the length of paved roads; IS_3 - density of public roads in the region; IS_4 - share of roads that meet regulatory requirements, %. For the parameter of operational sustainability (TS), we should use TS_1 - freight traffic growth rate; TS_2 - freight turnover growth rate; TS_3 - freight traffic per unit of public road density in the region; TS_4 - freight traffic volume per unit of public road density in the region. To assess the sustainability of the road transport system performance in the region (OS), we can use load capacity indicators OS_1 - the volume of freight transported by road transport per unit of gross regional product; OS_2 - freight turnover of road transport per unit of gross regional product; OS_3 - share of road transport in gross value added in the region. Assessing the significance of the indicators involves the use of mathematical analysis of statistical data.

The evaluation scheme proposed in the article includes the following stages:

1. First, there is the generation of a set of raw statistical data for several years in the regions of Russia under analysis.
2. For each k-th (k=1...K) region and i-th (i=1...I) indicator of the j-th (j=1...J) sustainability parameter, we calculate the standard deviation $\sigma_i^k{}_j$, maximum a_{ijmax} and average values.
3. We calculate the significance level (x_{ij}) of the i-th indicator within the j-th dimension of sustainability (infrastructure, operational and outcome sustainability) according to the K-region formula:

$$x_{ij} = \frac{\sum_{i=1}^{I} a^k{}_{ijmax} \cdot \sigma_{ij}^k}{\sum_{k=1}^{K}\sum_{i=1}^{I} a^k{}_{ijmax} \cdot \sigma_{ij}^k} \quad (1)$$

where σ_{ij} is the standard deviation of the analysed indicator for the period k-region within the limits of the calculation of the j-parameter of sustainability.

4. This fllowed by the assessment of the j-th sustainability parameter (S) of the k-th regional road transport system:

$$S^k = \sqrt[I]{\sum_{i=1}^{I} x_{ij} \cdot \sigma_i^k{}_j} \quad (2)$$

5. Then the significance level (X_j) of the j-th parameter of sustainability (infrastructure, operational and outcome sustainability) is calculated for K-regions and for all indicators:

$$X_j = \frac{\sum_{k=1}^{K}\sum_{i=1}^{I} a^k{}_{ijmax} \cdot \sigma_{ij}^k}{\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{i=1}^{I} a^k{}_{ijmax} \cdot \sigma_{ij}^k} \quad (3)$$

6. A comprehensive indicator of the internal sustainability (stationarity) of the regional road transport system is determined for the k-th region:

$$U^k = \sum_{j=1}^{J} Xj \cdot S^k \quad (4)$$

This approach assesses the internal sustainability of the regional road transport system. The closer the score is to 0, the less susceptible the system as a whole and its individual parameters are to instability/unsteadiness factors. It is possible to calculate the levels of internal sustainability, its boundaries and the optimal distribution of regions into intervals using the well-known Sturgess formula (without limits on the number of intervals), considering the indicator values for the regions where public reporting is available. Comprehensive assessment is appropriate as part of a comparative analysis of the internal sustainability of regional road transport systems.

3 Results and discussion

The article assesses the internal sustainability of regional road transport systems on the basis of the developed approach. We used statistical data for the years 2015-2019. The analysis uses transport statistics from the Moscow region, St. Petersburg, the Leningrad region and the Omsk region. A comprehensive sustainability assessment based on all parameters of the sustainability calculation (infrastructural, operational and outcome sustainability) for the regions selected for analysis is shown in Table 1.

Table 1. Comprehensive indicator for internal sustainability of regional transport systems

k-region	*IS1*	*IS2*	*IS3*	*IS4*	*TS1*	*TS2*	*TS3*	*TS4*	*OS1*	*OS2*	*OS3*
Moscow region	0.06	0.06	0.87	11.59	7.73	11.39	7.66	7.51	16.77	12.95	0.98
Saint Petersburg	0.03	0.02	0.43	1.07	3.86	8.72	6.53	3.47	9.73	8.94	0.61
Leningrad region	0.05	0.06	0.37	1.14	3.42	4.62	2.68	2.28	4.66	4.25	0.57
Omsk region	0.06	0.05	0.12	3.72	1.99	4.47	4.05	1.67	5.95	4.27	0.48

The parameters for infrastructure, operational sustainability and result stability, as well as a comprehensive assessment of system sustainability, are shown in Figure 2-3 and Table 2.

Table 2. Internal sustainability assessment of regional transport systems by parameter, scores

k-region	S^k			X_j			U^k
	IS	TS	OS	IS	TS	OS	
Moscow region	0.45	8.44	5.97	0.08	0.60	0.32	7.03
Saint Petersburg	0.13	5.25	3.75				4.37
Leningrad region	0.18	3.13	2.24				2.62
Omsk region	0.19	2.79	2.30				2.43

We obtained the score for the parameters and the comprehensive assessment in scores. The lower the number of points a regional transport system scores, the more sustainable it is. Thus, an assessment of sustainability parameters indicates that transport infrastructure appears to be the most stable in all of the regions analysed. Operational sustainability is the most fluid due to the instability of freight demand in the regions, the construction of toll roads and the impact of other factors. Also the marked instability is reflected in the outcome indicators.

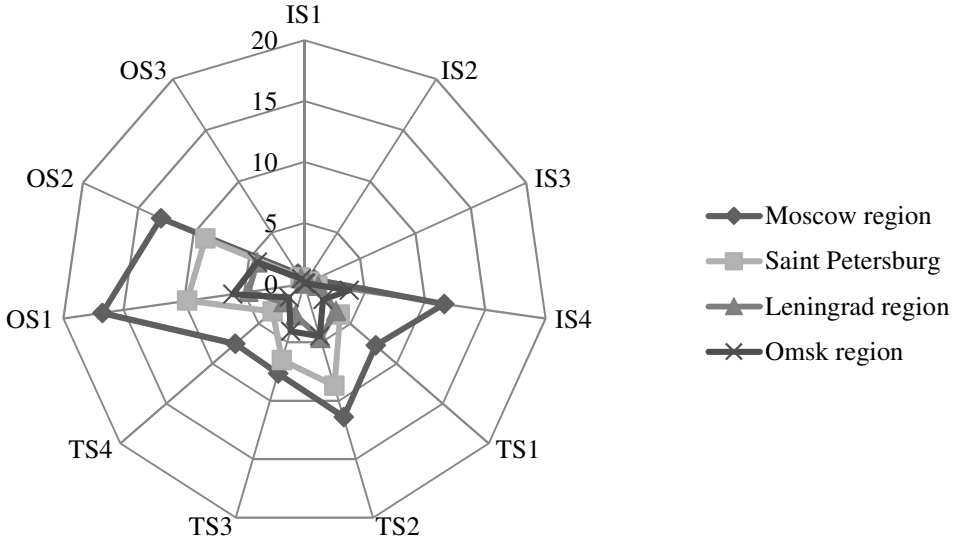

Figure 2. Assessing the sustainability of regional road transport systems according to indicators

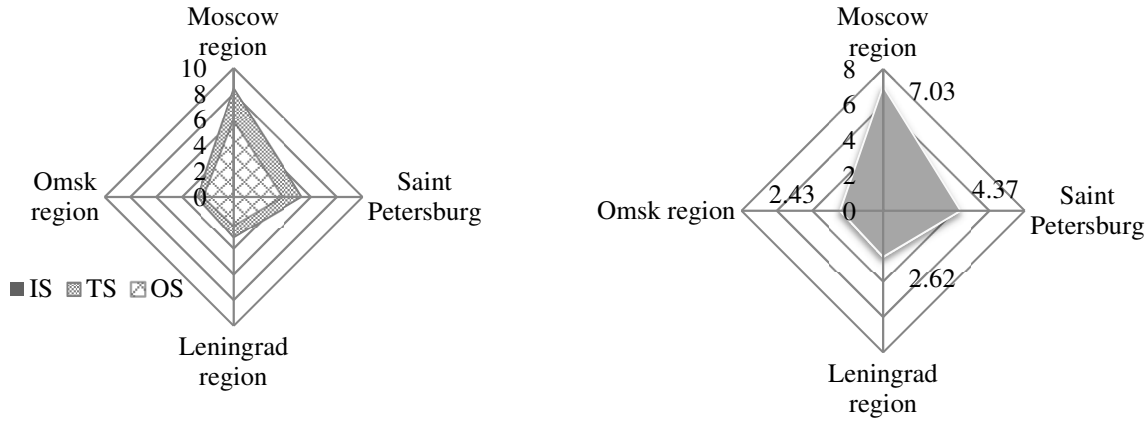

Figure 3. Assessing the internal sustainability of regional road transport systems (based on three parameters and a comprehensive score)

Among the regions analysed, the road transport system in the Moscow region exhibits the highest internal instability parameters, while the unsteady use is also characteristic of the transport system in St. Petersburg. Among the four regions considered, the Leningrad and Omsk regions have the lowest internal variability. The approach used allows for a comparative assessment of the stationarity of regional transport systems.

4 Conclusions

Among other things, managing the development of the country's regions requires assessing the state of the regional transport system and analysing its potential. The value of the gross regional product, the level of inter-regional integration, transport mobility of the

population and a number of other socio-economic indicators depend on the state of the regional transport system. Considering internal sustainability as the target state of a regional transport system, we propose to assess it by calculating utilisation potential, a category that includes elements of infrastructure capacity, operational capacity and transportation demand potential of the region. The methodology proposed for assessing the internal sustainability of a regional transport system is based on the use of public statistics. The article calculates a sustainability indicator using the example of statistical data reflecting the conditions and results of regional road transport. The results of the calculations identified factors for improving the internal sustainability of transport systems in regions such as St. Petersburg, Leningrad, Moscow and Omsk.

On the other hand, the size of the country and the level of differentiation of regions in terms of natural, climatic and geographical conditions make it relevant to allocate regions into clusters, depending on the state of the factors determining the parameters of the regional transport system. Further research could focus on defining criteria for allocating regions into clusters depending on their condition, dynamics and degree of influence on regional transport systems. Addressing this issue will clarify the results of the comparative analysis as part of the rationale for management decisions to improve the sustainability and capacity development of the country's unified transport system.

References

1. E. Liachovičius; V. Skrickij, A. Podvizhko, *Sustainability*, **12**, 7259. (2020) doi.org/10.3390/su12187259.
2. *Rosstat named the most unprofitable industries of 2020,* Retrieved from: https://ria.ru/20210306/ubytok-1600175311.html
3. N.G. Gavrilenko, S.A. Borodulina, *IOP Conference Series: Materials Science and Engineering,* **918(1),** 012236. (2020)
4. V.D. Gerami, I.D. Shidlovskiy, *Management and Business Education* **2**, (2020) doi.org/10.33983/2075-1826-2020-2-77-90
5. A.A. Dulzon, *Philosophical Thought,* **3,** 131-148, (2017) doi.org/10.7256/2409-8728.2017.3.22139
6. A. Zenya, O. Nystad, *Sustainability,* **10 (12),** 4661 (2018) doi.org/10.3390/su10124661.
7. C. Sirsi, *Business Strategy and the Environment,* **25 (2),** .120-133 (2014). doi.org/10.1002/bse.1861.
8. P. Zbierowski *Journal of Positive Management* **2(1)** (2011) doi.org/10.12775/JPM.2011.009
9. V. Stanich *Workforce Planning and Organizational Structure* 605-619 (1978). doi.org/10.1007/978-1-4613-4622-7_45.
10. D. Hond, Frank. *Organisation and Environment* **19(3)**, 415-418, (2006), doi.org/10.1177/1086026606292475
11. N.K. Skvortsova, L.A. Filimonova *Economics and Law.* 07, 77-84, (2020): doi.org/10.37882/2223-2974.2020.07.32.
12. J. Mensah, S. Ricart Casadevall, *Cogent Social Sciences*, **5:1,** doi.org/10.1080/23311886.2019.1653531
13. S. Borodulina, T. Pantina *Springer.*, *Cham*. 806-819, (2020) doi.org/10.1007/978-3-030-57450-5_68