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The Life Cycle Cost as a Criterion for Innovative Transport and Logistics Services Selecting for the Smart Cities Sustainable Development

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Abstract: This article addresses the active development of passenger rail transport in agglomerations using the Moscow agglomeration as an example. The authors outline the directions for the development of the transport services market and conclude the necessity of implementing innovative transport and logistics services. It identifies consumer segments for these services within agglomerations and presents a methodological approach to assessing the economic efficiency of suburban passenger transport services based on life cycle cost theory to promote sustainable development in smart cities. The authors emphasize the need to take into account the interests of consumers within the framework of the proposed methodological framework. The developed approach makes it possible to take into account the economic interests of the participants of the passenger transportation market in the railway segment as part of the railway infrastructure of the smart agglomeration.

1 INTRODUCTION

The rapid pace of urbanization, coupled with innovative technologies and solutions, enables the realization of ambitious projects aimed at sustainable development in smart cities and agglomerations. These projects encompass various aspects aimed at improving urban residents' quality of life through modern technologies. Currently, different countries are actively collaborating to exchange experiences and implement various initiatives and projects under this concept. These initiatives may vary depending on specific regions or cities, as well as on the level of funding and support from local and federal authorities. The "Smart City" project requires a comprehensive approach that includes cooperation among government structures, the private sector, and civil society. The implementation of the "Smart Agglomeration" project demands even more resources and closer collaboration among all stakeholders involved.

Primarily, these initiatives pertain to infrastructure projects and transportation systems. Smart transportation systems have been partially implemented in agglomerations through road transport by introducing traffic management systems that utilize traffic data to optimize public transport routes and reduce congestion (Seuwou, 2020). Charging stations for electric vehicles and electric buses have been established in metropolitan areas, facilitating a transition to more environmentally friendly modes of transport and green technologies while improving air quality in cities. Electronic tickets are being actively introduced across all forms of public transport in metropolitan areas and agglomerations as part of the popular Mobility as a Service (MaaS) technology (Butler, 2021).

The rapid urbanization and populations migration to megacities and agglomerations, along with continuously increasing passenger mobility demands amid rising expectations for transportation service quality – considering social, economic, and

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environmental standards – heighten the significance of transport-logistics services within transportation infrastructure. This situation necessitates new approaches to implementing innovative projects (Tariq, 2024). The complex issue of balanced and harmonious development within urban agglomeration transportation systems is exacerbated by varying rates of innovation adoption and conflicting interests between transportation companies and citizens regarding radical transformations in urban environments influenced by the Fourth Industrial Revolution (Kerzner, 2017). In Russia's railways during 2023, 1.196 billion passengers were transported (+ 5.4% compared to 2022), with suburban communication accounting for 1.074 billion passengers (+ 4.6%) (Chuverina, 2022).

One factor stimulating the development of rail communication has been the formation process of large urban agglomerations. Their creation represents a contemporary global trend. The growth of corporations' enterprises, establishment of industrial parks, production capacities alongside service sector infrastructure development, has led to population concentration resulting in major metropolitan super-agglomerations (such as Moscow's urban agglomeration), one of the largest globally.

The capital's railway system is a unique transportation network serving as the primary passenger artery for the country. Daily operations see over two million passengers departing from stations across this network with nearly 5,000 suburban trains running regularly. During peak hours within Central Transport Hub intervals between electric train departures can be as short as 2.5 minutes. In Moscow's urban agglomeration, combined individual passenger routes constitute 68% of its transport-logistics system. Experts predict that by 2030 Moscow's population will increase by 14% (+ 2.9 million people). However, growth points generating passenger traffic exhibit varying indicators, for instance: Kurovskoe: + 2 %, Mozhaysk: + 5 %, Khimki: + 34 %, Pushkino: + 27 %, Zhukovsky: + 42 %, Ramenskoye: + 62 %, Domodedovo: + 100.4 % (Bubnova, 2024). Consequently, cities with differing passenger traffic generation metrics require distinct scenarios for developing suburban communication (see Fig. 1).

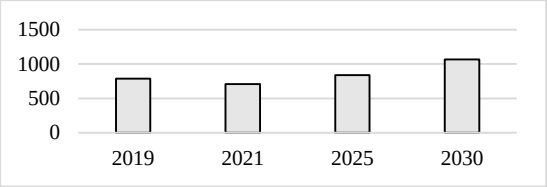

Figure 1: Passenger traffic volumes of the Central Transport Hub (CTH) with a forecast up to 2030, million passengers. Source: compiled by the authors.

The forecast of the performance of the suburban complex according to the basic variant of the development of the CTH until 2030 (in millions of passengers) is shown in Figure 2.

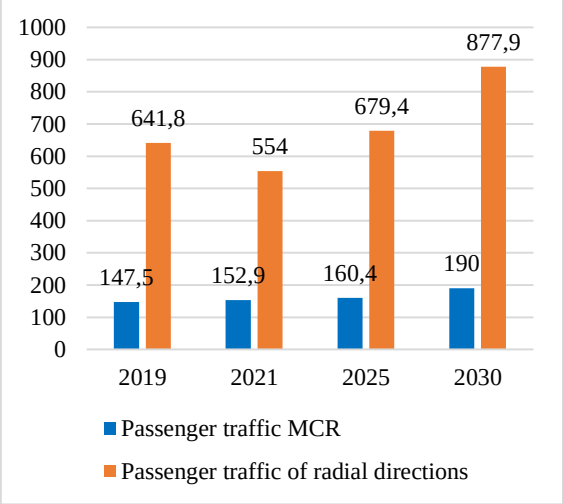

Figure 2: Forecast of Suburban Transport Complex Performance Indicators for the Base Development Scenario of the Moscow Central Ring (MCR) until 2030, million passengers. Source: compiled by the authors.

The increase in passenger traffic considering the extension of the Moscow Central Diameters (MCD), is projected to be 35 % by 2030 compared to 2019, 51 % compared to 2021, and 27 % compared to 2025 (Podsorin, 2023).

A situation has arisen where, on one hand, the population of agglomerations is growing, thereby increasing demand for suburban rail transport services. On the other hand, there are barriers to the implementation of innovations, including innovative types of transport and logistics services, due to the unprofitability of suburban transport and the necessity for substantial capital investments (Garrone, 2016).

The suburban passenger rail complex is integrated into all spheres of public life, therefore its development assumes particular importance (Horngren, 2015). In this context, existing standard methods for assessing the effectiveness of innovative types of transport and logistics services are insufficient.

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2 MATERIALS AND METHODS

The development of the suburban transport services market aimed at ensuring seamless connectivity, increasing travel speeds, and implementing intelligent transport systems significantly contributes to achieving sustainable development goals not only within the transport sector but also for the region as a whole.

Thus, developing a scientific framework for evaluating the effectiveness of innovative transport services and justifying their implementation within sustainable development projects in smart agglomerations has become particularly important under current conditions. This underscores the high relevance of the research topic.

This study proposes utilizing a logistics approach to assess innovative types of transport and logistics services in smart agglomerations due to significant passenger flows and information availability. It is essential to distinguish innovative types of transport and logistics services that incorporate digital components and are provided based on digital services.

Innovative technologies and digital services are actively being implemented in suburban transportation, positively impacting service quality and demand for these transport options (Kirk, 2016).

The drivers of innovation technology development in the suburban passenger rail complex include funding sources (see Figure 3) and new user segments for innovative types of transport and logistics services (see Figure 4).

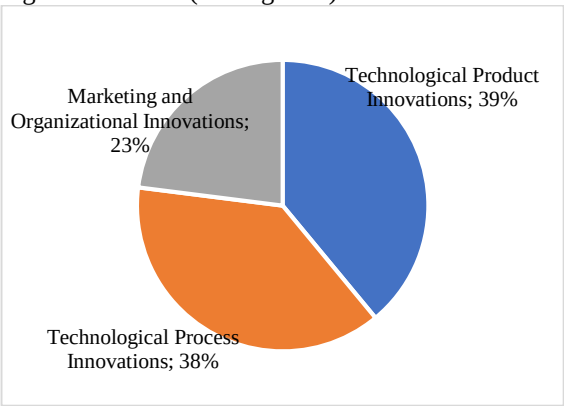

Figure 3: Innovative Projects in the Suburban Passenger Complex (+ 25 % compared to 2022) Source: compiled by the authors.

The Russian Railways (JSC "RZD") places significant emphasis on the implementation of innovative projects, as illustrated in Figure 3. Given that the number of innovative projects increased by 25 % in 2023, it can be concluded that there is considerable interest in these initiatives from Russian railways (Tereshina, 2023).

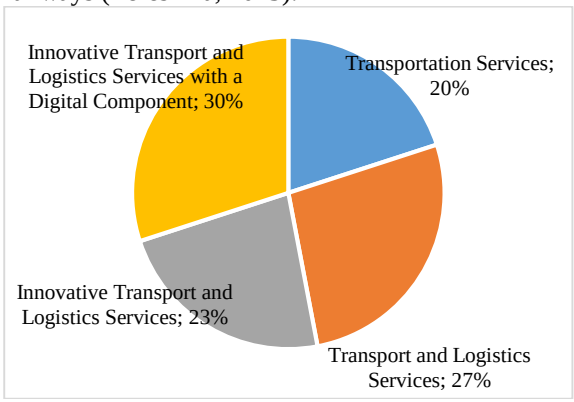

Figure 4: Segmentation of Passengers by Preference for Transport and Logistics Services Source: compiled by the authors.

New consumer segments within the suburban passenger rail transport complex are increasingly oriented towards the innovative and digital technologies use. As illustrated, consumers in this sector are interested in highly comfortable transportation services that necessarily include high-speed internet and other digital offerings. Thus, the focus is on providing services that significantly enhance quality, which is also reflected in their cost.

3 RESULTS AND DISCUSSION

In general, the life cycle cost of innovative transport and logistics services will be determined by considering investments in innovative types of transport and logistics services, expenses related to their provision, investments for the implementation and development of digital platforms, as well as costs for maintaining, servicing, and operating these platforms. The criterion for deciding on the implementation of a particular option for transport and logistics services is the minimization of life cycle costs.

In railway transport, absolute efficiency indicators are typically used to assess the effectiveness of innovative projects. In certain cases, comparative efficiency indicators are employed (for example, determining the life cycle cost of complex technical systems) (Kumar, 2017). Given the complexity of defining performance indicators for innovative transport and logistics services and the high investment costs involved, there is a need to

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develop a new methodology based on life cycle cost theory, which has been accomplished.

The methodology for assessing the life cycle cost of innovative types of transport and logistics services within the framework of selecting such services for sustainable development in smart cities is schematically presented in Figure 5.

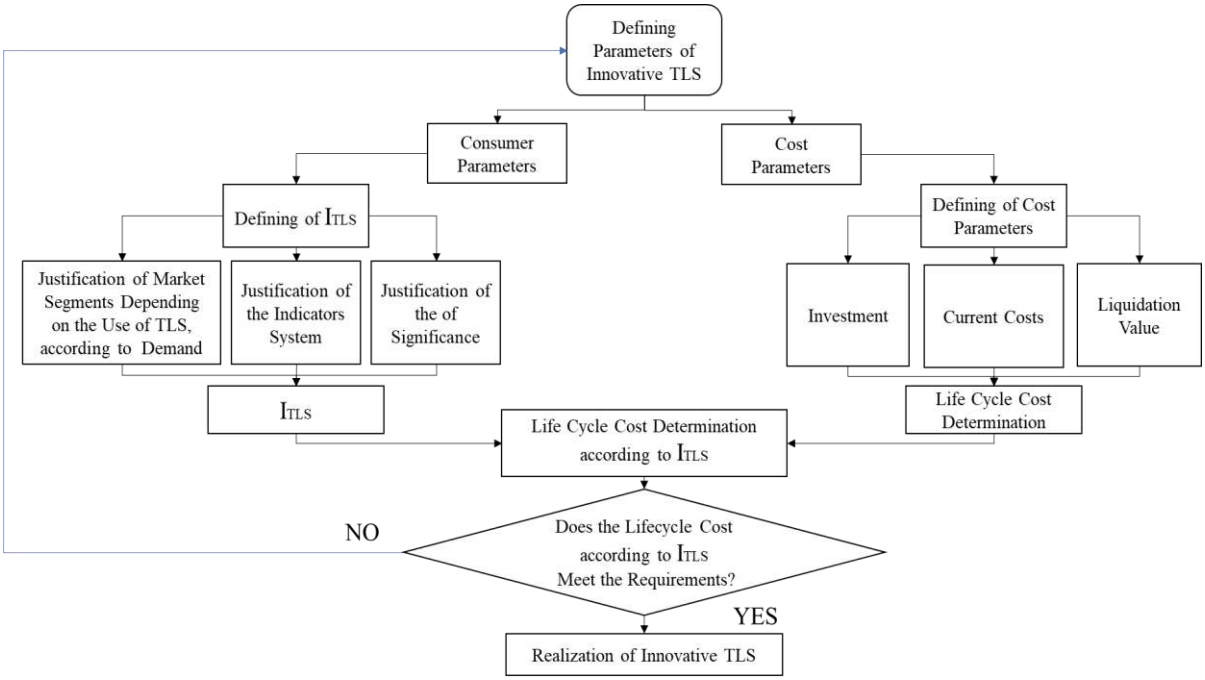

Figure 5: Methodology for Assessing Life Cycle Cost in the Selection Mechanism for Innovative Transport and Logistics Services for Sustainable Development of Smart Cities (abbreviations: ITLS – the transport and logistics service index, TLS – the transport and logistics service). Source: compiled by the authors.

The key element of the proposed methodology within the selection mechanism for innovative transport and logistics services aimed at sustainable development in smart cities is the life cycle cost criterion of these services, according to the transport and logistics service index. The minimum life cycle cost serves as the selection criterion for innovative transport and logistics services to be implemented within the framework of sustainable development in smart cities.

The transport and logistics service index (ITLS), when assessing life cycle costs in the selection mechanism for innovative transport and logistics services for sustainable development in smart cities, can be determined using the following formula:

$$I_{TLS} = \frac{Q_{for}^{ITLS}}{Q_{for}^{Ref}} \cdot \alpha_{for} + \frac{Q_{on\ the\ way}^{ITLS}}{Q_{on\ the\ way}^{Ref}} \cdot \alpha_{on\ the\ way} + \frac{Q_{after\ the\ trip}^{ITLS}}{Q_{after\ the\ trip}^{Ref}} \cdot \alpha_{after\ the\ trip},$$

where:

$Q_{for,on\ tne\ way,after\ the\ trip}^{ITLS}$ – the quality of passenger transport and logistics services in the implementation of innovative transport and logistics services before, on the way, after the trip;

$Q_{for,on\ the\ way,after\ the\ trip}^{Ref}$ – the reference quality of passenger transport and logistics services before, on the way, after the trip;

$\alpha_{for,on\ the\ way,after\ the\ trip}$ – the importance of the service for the consumer before, on the way, after the trip.

The evaluation of transport and logistics services for the implementation of innovations in the transport and logistics sector was conducted on the route "Moscow – Mytishchi" along the "Moscow – Pushkino" corridor. The investment volume required for the acquisition of four units of rolling stock is estimated to be approximately 19 billion rubles. Based on the calculations performed using the proposed methodology the following data were

obtained regarding the dynamics of transport and logistics service indices when implementing various types of transport and logistics services: transport services – 0.543, transport and logistics services – 0.759, innovative transport and logistics services – 0.976 and innovative transport and logistics services with a digital component – 1.070.

The data presented indicate that innovative transport and logistics services with a digital component are the most attractive (consumer parameter index – 1.070). An index greater than one suggests that the quality of transport and logistics services, including even innovative transport and logistics services, is lower than that of innovative transport and logistics services with a digital component.

As a result of assessing the life cycle cost of various types of transport and logistics services, it was found that on the "Moscow – Mytishchi" route, without considering the transport and logistics service index, the discounted life cycle costs are as follows: for transport services – 7,007.20 million rubles; for transport and logistics services – 7,028.92 million rubles; for innovative transport and logistics services – 9,874.66 million rubles; for innovative transport and logistics services with a digital component – 9,882.18 million rubles.

The high life cycle cost associated with more technologically advanced transport and logistics services is attributed to their high capital intensity. When accounting for the transport and logistics service index, the life cycle costs are as follows: for transport services – 12,905.26 million rubles; for transport and logistics services – 9,266.52 million rubles; for innovative transport and logistics services – 10,114.31 million rubles; for innovative transport and logistics services with a digital component – 9,235.20 million rubles. The assessment of current costs can be conducted using various methods; in this case, the authors used the economically reasonable cost method. It should be noted that an increase in life cycle costs does not represent an assessment of expenses incurred in executing these projects but rather an evaluation of efficiency – that is, a criterion for comparative effectiveness that characterizes the feasibility of implementing a particular option–and this increase is related to bringing projects with different capital intensities into a comparable format.

The assessment of life cycle costs of innovations using the proposed methodology while considering consumer parameters indicates that implementing innovative transport and logistics services with a digital component proves to be most advantageous. Thus, employing this methodology will allow not only for consideration of carrier company expenses but also for addressing passenger needs regarding innovations and enhanced quality in transportation services based on a logistical approach.

4 CONCLUSION

As a result of the study, the authors drew several conclusions:

Urbanization processes are an integral part of the modern society life, necessitating the development of a transport and logistics system based on agglomeration.

New segments of the transport market focused on innovative transport and logistics services, including those with digital components, reflect the need to use the transport and logistics index as part of the mechanism for selecting such services aimed at the sustainable development of smart cities.

The choice of life cycle cost as a criterion characterizing the expediency of implementing specific options is dictated by its (life cycle cost) universality.

When assessing life cycle costs as part of the assessment of innovative transport and logistics services, it is important to take into account the impact of the transport and logistics services index on the adequate satisfaction of consumer needs regarding the quality of services provided.

The calculation of the costs of the innovation lifecycle, taking into account the index of transport and logistics services, makes it possible to assess the effectiveness of innovation both from the point of view of the carrier company and from the point of view of the consumer.

The proposed methodology serves as a universal tool requiring specific adaptation to transportation modes, users (market participants in passenger transportation), or agglomerations.

The assessment of the costs of the innovation lifecycle using this methodology, taking into account consumer parameters, shows that the introduction of innovative transport and logistics services with digital components is indeed the most profitable.

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