Digital transformation in transport infrastructure energy efficiency: smart cities and sustainable mobility

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Abstract. In the context of today's rapidly changing urban environment, digital transformation and the concept of smart cities are becoming important components for sustainable mobility and efficient transport infrastructure. This article is a research study on the trends and prospects of the digital transformation of Russia's transport complex, as well as the role of smart cities in ensuring sustainable mobility in this context. It analyzes key aspects of the integration of digital technologies into transport infrastructure, including the use of the Internet of Things and autonomous vehicles. Advantages and risks of digitalization are discussed, including issues of cybersecurity and data privacy. The paper also highlights the importance of developing joint strategies and regulatory frameworks for smart-city development and sustainable mobility. This research suggests an important assumption that modern cities can achieve outstanding results in sustainable mobility and transport infrastructure efficiency through digital integration and smart city development.

1 Introduction

In the contemporary landscape characterized by burgeoning environmental challenges and mounting demands for the efficacious management of resources, the transport sector emerges as an area of strategic significance for digital transformation, one that holds the potential to make a substantial contribution toward the enhancement of energy efficiency and the sustainability of transport infrastructure. The comprehension and scrutiny of the digital transformation occurring within the industry constitute pivotal components in the formulation of strategies aimed at ameliorating energy efficiency and guaranteeing the sustainability of mobility in the present-day intelligent urban environments [1].

The investigation, which sets its sights on the identification and analysis of the principal trends associated with the digital transformation of the transport complex in the Russian Federation, stands as an exigent research endeavor. The accomplishment of this task necessitates a thorough and methodical approach. Consequently, this article is underpinned by the premise that the digital transformation of the transport sector is a multifaceted phenomenon encompassing diverse facets and vectors of development, with its influence on

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the energy efficiency of transport infrastructure arising from a plethora of multifarious factors [2].

In the wake of the ever-growing imperative to optimize energy consumption and curtail the environmental footprint, the transport sector is transitioning into a pivotal sphere where digital innovation has the potential to usher in substantial beneficial transformations [3]. It is worth emphasizing that the efficiency of transport directly reverberates onto energy efficiency, thereby exercising a direct influence on sustainable mobility.

The primary objective of this paper resides in grasping the intricate interrelations between the digital transformation of transport and its impact on energy efficiency within the context of intelligent urban centers and sustainable mobility. In the course of this research endeavor, the utilization of analytical techniques and the scrupulous analysis of an extensive corpus of data assume a pivotal role in the identification of salient trends and the assessment of the actual ramifications of digital transformation on energy efficiency within the domain of transport infrastructure. Thus, the study underscores the importance of studying and understanding the interplay between digital transformation, energy efficiency, and sustainable mobility as an integral facet of the overarching drive to devise more effective strategies for the management and development of transport. In alignment with this proposition, the investigation posits that the comprehension of the principal aspects of the digital transformation of Russia's transport complex and its impact on energy efficiency would serve to unveil the opportunities and challenges intrinsic to this process, providing valuable recommendations for the enhancement of sustainable mobility and energy efficiency within the intelligent urban centers of today [4].

2 Methods

The study developed a comprehensive methodology that included a thorough analysis of data and an extensive literature review to identify key trends in the digital transformation of the transport complex of the Russian Federation. The research methods covered quantitative analysis of data on implemented projects and programs in the digitalization of transport infrastructure, as well as qualitative research, which includes an analysis of situations of successful implementation of digital innovations in the transport sector.

3 Results and Discussion

I. Trends in the digital transformation of the transport complex in Russia

Within the contemporary digital era, the transport complex of Russia finds itself undergoing profound and intricate alterations that reflect a spectrum of multifaceted trends related to digital transformation. Rooted in cutting-edge information technologies and digital innovations, these trends are oriented towards enhancing the efficiency and sustainability of transport infrastructure.

Foremost among the pivotal trends in the digital transformation of Russia's transport sector is the integration of smart technologies into the various facets of transport infrastructure. This entails the deployment of sensor systems, the Internet of Things, artificial intelligence (AI), and data analytics to enhance the monitoring and administration of transportation. These technologies furnish contributions toward augmenting safety, mitigating congestion, and optimizing the allocation of resources within the transport system [5].

A salient facet of the digital transformation of Russia's transport complex centers on the development of the smart city system, which constitutes a concept geared towards the fusion
of transport and urban infrastructure through the application of digital technologies. These smart cities aspire to construct an integrated milieu that fine-tunes mobility and energy consumption while elevating the quality of life for the populace.

Another significant trend characterizing the digital transformation of Russia's transport complex resides in the advancement of autonomous and unmanned vehicles. These pioneering innovations open up novel prospects in the realm of transportation safety and the abatement of environmental impact. Autonomous vehicles, by nature, have the potential to be more resource-efficient and environmentally sustainable.

Digital transformation likewise exerts its influence on transport logistics, cargo management, and port and rail infrastructure. By harnessing digital technologies, logistics processes can be streamlined, forecasts and management of cargo flow can be refined, thus yielding a more efficient utilization of resources and a reduction in costs [6].

However, despite the myriad advantages brought about by the digital transformation of Russia's transport sector, it is not without its perils. Cybersecurity looms as an increasingly pressing concern as the proliferation of digital devices and the associated data create potential vulnerabilities susceptible to cyber attacks and data breaches. Another challenge manifests in the imperative to invest in digital infrastructure and workforce training, a prerequisite to ensure the successful realization of digital transformation. This necessitates a substantial allocation of resources and concerted efforts on the part of governmental entities, corporations, and educational institutions.

II. Opportunities and risks of the digitalization of transport infrastructure

The digitization of transport infrastructure offers substantial prospects for enhancing the efficiency and sustainability of the industry, but it concurrently engenders a plethora of prospective risks that necessitate rigorous attention and analysis.

One of the paramount opportunities inherent in the digitization of transport infrastructure lies in the amelioration of road safety. The integration of sensor systems and artificial intelligence facilitates more precise movement monitoring and the anticipation of potential emergencies. Autonomous vehicles, in particular, hold the potential to curtail human errors and accidents, a pivotal contribution to road safety. Another prospect revolves around the optimization of transport logistics. The utilization of digital technologies empowers the enhancement of route planning, the optimization of freight transportation, and the reduction of transport expenses. This fosters the judicious utilization of resources and the mitigation of adverse environmental impact [7].

Nonetheless, cybersecurity emerges as a salient risk within the ambit of digitizing transport infrastructure. As the proliferation of interconnected devices and data exchanges intensifies, the susceptibility to cyber attacks commensurately escalates. Violations of data and system security bear the potential for grave consequences, including accidents and the unauthorized disclosure of personal data. Another risk lies in the potential overreliance on technology. In instances of digital system malfunctions or cyber attacks, the routine operation of transport infrastructure may be imperiled. Hence, it is imperative to formulate strategies for system backup and security measures [8].

The challenge of financial investment further complicates the digitization of transport infrastructure. The implementation of new technologies necessitates a substantial fiscal commitment, a potential impediment for many countries and organizations, particularly smaller and developing nations [9]. Despite these risks, it is of paramount significance to underscore that the digitalization of transport infrastructure presents colossal opportunities for the enhancement of the transport system, cost reduction, and heightened resilience. Nonetheless, to realize these opportunities successfully, meticulous planning, vigilant cybersecurity oversight, and the development of pertinent legal and regulatory frameworks become imperative.

III. Smart cities and sustainable mobility in the context of the digital transformation
Amid the contemporary challenges arising from escalating urbanization and the burgeoning population in cities, the concept of smart cities emerges as a pivotal facet of digital transformation, exerting a profound influence on the sustainability of mobility and the quality of life of urban inhabitants. Smart cities stand as an innovative paradigm that aspires to deliver enhanced governance and ameliorated mobility within the confines of today's sprawling metropolises [10].

A central pillar of smart cities is the integration of digital technologies into urban infrastructure. This encompasses the development of the IoT, the establishment of sensor networks, and the deployment of smart devices designed to accumulate and scrutinize data concerning urban landscapes and urban mobility. This reservoir of information serves to optimize the management of urban resources, facilitate the strategic planning of transportation routes, and create a more comfortable living environment for city residents.

Smart cities are increasingly dedicating their efforts to the establishment of intelligent transport management systems. The introduction of autonomous vehicles and smart transport systems exerts a mitigating influence on traffic congestion while elevating the efficiency of road infrastructure. Leveraging data analytics and artificial intelligence, smart cities are capable of offering their citizens personalized routing options and insights pertaining to transportation services. Furthermore, an unwavering focus on sustainable mobility and environmental conscientiousness is a hallmark of smart city strategies. Priorities include augmenting the utilization of public transportation, reducing carbon emissions, and fostering the development of electric vehicles, resulting in enhanced air quality and a reduction in detrimental environmental repercussions [11].

However, the landscape of smart cities is not devoid of its share of challenges and risks. One of these concerns revolves around privacy and data protection issues. The accumulation and analysis of substantial volumes of data regarding residents and their movements invariably raises concerns regarding privacy and data security. Cities are compelled to institute robust policies and security measures to safeguard the personal information of their citizens. Financial constraints and infrastructure issues represent another formidable challenge. The development and implementation of digital technologies mandate substantial financial investments and infrastructural upgrades, a hurdle that can be particularly daunting for many cities, especially those of a smaller or developing nature. Additionally, hurdles linked to standardization and interoperability among different cities and nations loom large. The absence of universal standards and regulations has the potential to impede the exchange of data and experiences between cities, impinging on the global progression of smart cities. Nevertheless, smart cities epitomize a promising model for the cultivation of sustainable mobility within the framework of digital transformation. They contribute significantly to the enhancement of citizens' quality of life, the alleviation of transportation issues, and the mitigation of adverse environmental impacts. To effectively actualize this concept, it is imperative to account for the attendant challenges and risks, formulate appropriate strategies, and foster international collaboration for the sharing of best practices and the establishment of common standards.

4 Conclusions

The realm of innovation encompassing the digital transformation of transport infrastructure and the evolution of smart cities stands as an expansive and multifaceted domain with far-reaching implications for the efficiency, sustainability, and quality of service within transport systems. These initiatives offer avenues for the enhancement of road safety, the alleviation of traffic congestion, and the optimization of urban mobility, ultimately culminating in an improved standard of living for urban inhabitants.
Nonetheless, a set of challenges looms in the horizon, comprising cybersecurity, data privacy, and the imperative to secure funding for infrastructure development. The effective execution of digital transformation necessitates meticulous planning, adherence to regulatory and legal prerequisites, and a profound consideration of the needs and interests of citizens. It is of utmost importance to underscore that digital transformation and the conception of smart cities possess the potential to emerge as pivotal instruments in the pursuit of sustainable mobility and the mitigation of global environmental and transport-related challenges. The realization of this potential demands a collective endeavor on the part of nations, organizations, and citizens, underpinned by a commitment to continuous monitoring and the dynamic adaptation of policies and technologies in resonance with the evolving landscape.

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