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MULTIFACTOR ANALYSIS OF MASS TRANSIT DIGITALIZATION IN THE FIVE LARGEST CITIES IN THE REPUBLIC OF BULGARIA

Summary. The digitalization of urban mass passenger transport is a critical pillar of sustainable urban transformation, offering substantial potential to enhance the efficiency, convenience, and environmental sustainability of transport services. With the growing populations in urban zones and the escalating demand for mobility, the integration of intelligent transport systems and digital technologies has become a necessity. Global exemplars such as Helsinki and Singapore showcase the tangible benefits of implementing Mobility-as-a-Service platforms, electronic fare collection systems, and Internet-of-things-driven solutions. In Bulgaria, the digitalization process is still in its early stages. Nonetheless, successful examples have emerged, such as the integrated ticketing system in Sofia and the electrification of Burgas' public vehicle fleet. Despite these advancements, pronounced disparities persist across cities, coupled with persistent challenges, including financial constraints, a shortage of expert capacity, and regulatory barriers. This study is a comprehensive multifactor analysis of the extent of digitalization in Bulgaria's five largest cities: Sofia, Plovdiv, Varna, Burgas, and Ruse. The methodology follows a seven-stage process: establishing objectives, defining indicator categories, collecting data from diverse sources, evaluating and normalizing the factor variables, assigning weights based on expert assessments, calculating composite scores, and interpreting the results. The employed approach amalgamates quantitative and qualitative data assessed on a five-point scale and addresses both technological and socio-economic dimensions. The analysis focuses on seven pivotal factors influencing digitalization: service quality, accessibility, safety and security, affordability, environmental sustainability, technological solutions, and infrastructure. These dimensions serve as the foundation for evaluating the digital maturity of urban transport systems across the studied cities and inform strategic recommendations for the sector's sustainable evolution.

1. INTRODUCTION

The digitalization of urban mass transit represents a cornerstone of contemporary urban transformation, which aims to enhance the efficiency, convenience, and sustainability of public transport services. As urban populations continue to expand and mobility demands intensify, intelligent transport systems and digital innovations are becoming increasingly indispensable in optimizing transport

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networks and reducing environmental footprints [1, 2]. Reference [3] overviews various methods for evaluating the benefits and costs of public transportation, including the deployment of intelligent transportation systems, environmental technologies, and the societal implications of digitalization.

Over the past decade, numerous cities across Europe and beyond have implemented successful digital public transport solutions. For example, Helsinki's Mobility-as-a-Service platforms offer integrated route planning, ticketing, and shared mobility options [4]. Singapore has also made significant strides by using smart traffic management systems and electronic charging, which have decreased congestion and improved traffic flow [5]. Such initiatives are enabled by rapid advancements in technologies such as the Internet of Things, artificial intelligence (AI), and cloud computing, which allow for the collection and analysis of large datasets to inform decision-making [6].

Particular attention has been paid to the costs of applying artificial intelligence methods in urban public transport, with the aim of increasing the efficiency, sustainability, and effectiveness of services, including route planning and optimization [7, 8]. A trend in smart cities and sustainable mobility is the creation of digital twins, which help manage the complexity of the urban environment and allow for simulations and optimizations of transport processes in real time [9].

Another important aspect of digital transformation is ensuring accessibility for people with disabilities. Modern technologies allow for the automatic recognition of passengers with special needs through cards, wearable devices, or mobile applications, as well as the activation of assistance functions, such as automatic ramps, voice messages, and extended boarding times. Such real-time navigation with accessible information and automatic communication with staff, including notifications for assistance requests, is also provided [10, 11].

In Bulgaria, the digital transformation of urban transport remains in its early developmental phase but holds considerable potential for advancement. Sofia distinguishes itself with an integrated ticketing system and intelligent traffic signal networks [12], while Burgas has undertaken efforts to electrify its vehicle fleet and utilize Internet of Things solutions for route optimization [13]. Nonetheless, substantial disparities in digital progress persist among major Bulgarian cities.

The literature review reveals that key enablers of successful digitalization in public transport include the availability of modern technological infrastructure, support from both public and private sectors, access to financing, and institutional adaptability to emerging technologies [14, 15, 16], alongside policy governance mechanisms [17]. At the same time, significant challenges remain, including limited financial resources, a shortage of qualified personnel, and regulatory hurdles [18].

The present study is a multifactor analysis of the current state and future prospects of urban mass transit digitalization in Bulgaria's five largest cities: Sofia, Plovdiv, Varna, Burgas, and Ruse. This research employs both quantitative and qualitative indicators to evaluate the degree of digitalization in each city, identify major challenges, and provide targeted recommendations for further development.

2. METHODS

2.1. Methodology for the multifactor analysis of urban transport digitalization

In the context of urban mass transit, multifactor analysis provides a structured analytical framework to examine how various parameters influence the level of digitalization and the effectiveness of transport services.

The multifactor analysis process includes seven main steps, presented in Fig. 1.

Step 1. The primary aim is to assess the impact of selected factors on the advancement of digitalization in urban mass transport within Bulgaria's five largest cities, with a specific focus on quality of service, accessibility, and technological development.

Step 2. The fundamental indicator categories are defined based on an extensive review of relevant literature and international best practices.

Step 3. Data are sourced from public domain materials—including official reports, statistical databases, and scientific publications—as well as through expert interviews and targeted surveys. Quantitative and qualitative sources are combined.

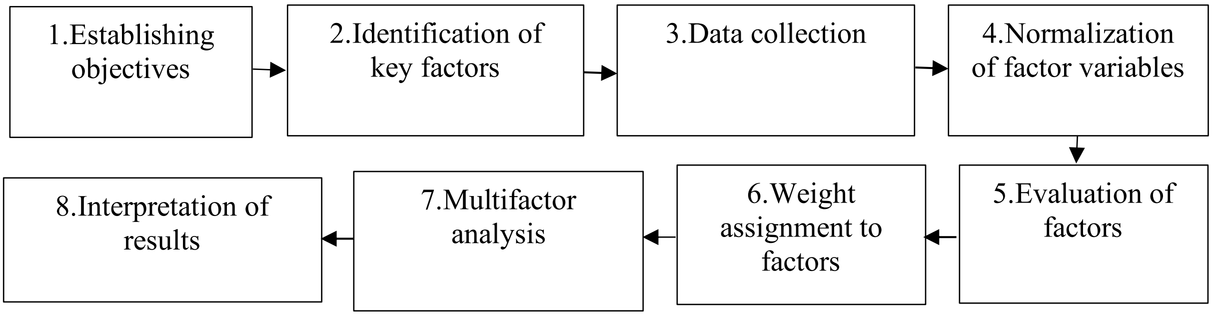

Fig. 1. Block diagram of the main steps in the multifactor analysis for the digitalization of urban passenger transport

Step 4. To ensure comparability, normalization procedures are applied to rescale all values into a unified range [0;1] by X_{norm}.

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}}, \qquad (1)$$

where: X_{min} − the minimum value;
X_{max} − the maximum value;
X − the current value of the variable.

Step 5. Factors are evaluated.

For each city, each factor is evaluated on a standardized five-point scale on which 1 indicates a very low level and 5 indicates a very high level. The scores are informed by quantitative data and expert judgment.

Step 6. Weights are assigned to factors.

The weight of each factor is determined via a structured survey of transport and digitalization experts. The results are analyzed using the mean values approach.

Step 7. The multifactor analysis is applied.

The overall digitalization preparedness score (P) for each city is calculated using the following formula:

$$P = \sum_{i=1}^{n} w_i F_i, \qquad (2)$$

where: n − the number of analyzed factors (e.g., economic, technological, social, and policy-related);
w_i − represents the assigned weight of factor *i*, reflecting its relative significance for the composite score, where $\sum w_i = 1$);
F_i − the normalized score of factor i on a scale from 1–5, where 1 denotes a very low level and 5 denotes a very high level of attainment.

Scores (Fi) may be assigned on a scale ranging from 1–5, or another suitable scale contingent upon the methodology employed.

Step 8. The results are analyzed in depth, leading to the formulation of conclusions and strategic recommendations.

3. RESULTS AND DISCUSSION

3.1. Key factors for assessment

Identifying the key factors underpinning the digitalization of public transport systems is essential to understanding the effectiveness of their implementation. Service quality is one of the primary determinants influencing citizens' choice of transport mode. Indicators such as average waiting time (actual vs. scheduled), passenger satisfaction with digital services (%), and system responsiveness to user reports submitted via digital channels are central to this factor. A systematic review [19] highlights multiple indicators for evaluating the quality of digital public services, including information provision, usability, user satisfaction, and cost-efficiency. These elements are critical to assessing the maturity of digitalization in public transport. Conceptual frameworks and practical recommendations for assessing and improving service quality in digital urban economies are discussed in [20]. The European standard EN 13816 [21], developed by the European Committee for Standardization, defines eight core criteria for assessing public transport service quality, including accessibility, information, time, comfort, safety, and environmental performance. This standard serves as a foundational basis for the development of quality indicators adopted widely across Europe.

Accessibility in a digital context refers to the ability of all citizens – regardless of age, disability, or digital literacy – to effectively utilize transport services. According to [22], transport exclusion constitutes a significant social challenge, and digital tools can mitigate this through multimodal interfaces, disability-inclusive navigation, and multilingual accessibility.

A number of authors have addressed passengers' safety and security in public transport, as well as methods for assessing risks. These key factors encompass physical protection for passengers and cybersecurity dimensions intrinsic to digital systems. With increasing reliance on electronic payments, real-time data, and automated monitoring, safeguarding personal data and digital infrastructure is becoming more crucial [23, 24]. Cybersecurity is also a key aspect of trust in digital services.

Affordability is another essential indicator to consider. It relates to the pricing structure of public transport, including single-ticket costs, subscription options, and their alignment with household income levels. Digital technologies also introduce dynamic pricing models that can optimize demand and operational efficiency [25].

Environmental sustainability is the extent to which cities incorporate electric vehicles and green technologies into their public fleets. This factor reflects both commitment to carbon neutrality and the integration of clean energy systems [26].

Technological solutions encompass a broad range of innovative digital tools deployed in urban transit, including system automation, intelligent transport system infrastructure, e-ticketing, real-time vehicle tracking, mobile applications, and the use of big data and AI for service optimization [27].

No less significant is the infrastructure that captures the technological and physical readiness of the transport network, as well as its capacity. Digital solutions depend on a robust, modern, and well-maintained infrastructure, encompassing roads, bus stops, terminals, signaling systems, and communication platforms, all of which must be digitally integrated. The need for such adaptations, including investment in intelligent transport systems, electric charging stations, and smart terminals, is well-documented [28, 29].

The digital transformation of urban mass transit encompasses not only the adoption of innovative technologies but also systemic improvements in service quality, equity of access, safety, and sustainability. Based on the literature review and best practice analysis, the following seven key factors have been identified as the pillars of this transformation:

- Service quality: Includes average waiting times, digital user satisfaction, and responsiveness to digitally reported issues. Digital tools enable precise service management through apps, e-ticketing, and real-time tracking.
- Accessibility: Concerns universal access to the transport service regardless of age, disability, or digital proficiency. Digital interfaces and assistive technologies promote equitable use and social justice.
- Safety and security: Encompasses both physical safety and cybersecurity. The protection of personal data, payment systems, and operational software is vital.
- Affordability: Involves evaluating fare pricing, subscription models, and their alignment with population income levels. Digitalization enables flexible pricing and broader payment options.
- Environmental sustainability: Measures the integration of electric vehicles and eco-technologies, aiming to reduce emissions. Digital systems implementation supports monitoring and optimization of green transport.
- Technological solutions: Covers process automation, intelligent transport systems, big data analytics, and AI applications. These are at the core of digital transformation and a basis for innovation and sustainable development.

- Infrastructure readiness: Refers to the condition and capacity of the urban transport - roads, stops, terminals, signaling, etc. Successful digitalization requires a modern, maintained and technologically integrated infrastructure.

Together, these seven pillars form a comprehensive framework for assessing the degree of digital transformation within urban transport systems and can serve as guiding criteria for strategic planning, monitoring, and optimization.

A structured survey was conducted among 10 domain experts specializing in transport systems and digitalization to determine the relative importance of each factor. Each expert was provided with a matrix listing the seven identified key factors and was asked to assess their significance on a scale from 1–10, where 10 indicates the highest level of importance.

The collected responses were normalized to ensure comparability and consistency. The resulting factor weights are presented in Table 1.

Table 1

Normalized weights of key factors

N	Factor	Weight
w_1	Service quality	0.3
w_2	Accessibility	0.1
w_3	Safety and security	0.2
w_4	Affordability	0.1
w_5	Environmental sustainability	0.2
w_6	Technological solutions	0.05
w_7	Infrastructure readiness	0.05

3.2. Multifactor Analysis of Urban Mass Transit Digitalization in Bulgaria's Five Largest Cities

This study examines the characteristics of public transportation systems in the five largest cities in the Republic of Bulgaria (Sofia, Plovdiv, Varna, Burgas and Ruse).

All five cities operate bus transport systems. Notably, four of them (all but excluding Plovdiv) have incorporated electric buses into their fleets, reflecting a shift toward more sustainable mobility models (Table 2). Trolleybus systems remain operational in all cities except Plovdiv, where this mode of transport has been fully decommissioned and its contact network dismantled.

Table 2

Population, area, and types of urban public transport in Sofia, Plovdiv, Varna, Burgas, and Ruse (2024)

City	Population	Area, km^2	Population density (inhabitants/km^2)	Available types of urban transport
Sofia	1,295,931	492	2634	Bus, trolleybus, tram, metro
Plovdiv	329,489	102	3230	Bus
Varna	327,424	238	1376	Bus, trolleybus
Burgas	195,719	253	774	Bus, trolleybus
Ruse	137,159	187	733	Bus, trolleybus

Sofia stands alone in operating a metro network, in addition to trams, trolleybuses, and buses, positioning its urban transit system as the most technologically advanced in the country. Furthermore, all five cities are designated nodes within the Trans-European Transport Network [30].

The comparative demographic and infrastructural overview indicates significant variation in population densities and modal diversity across the five cities. Sofia demonstrates the most diversified and technologically advanced transport network, including all four major modes of mass transit. In contrast, Plovdiv has relied solely on bus transport since its trolleybus infrastructure was dismantled.

At the end of 2024, the population of Bulgaria was 6,437,360 people, 35.5% of whom lived in the largest five cities. The proportions of the population living in these cities are shown in Fig. 2.

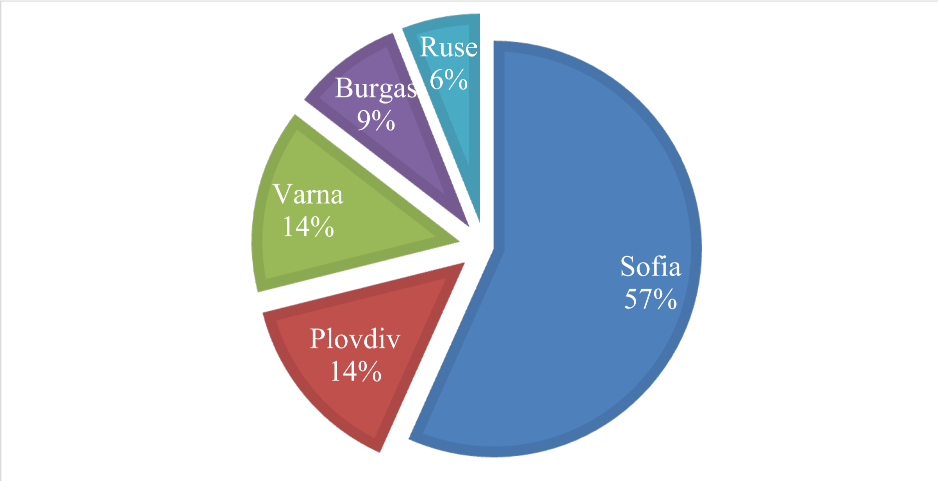

Fig. 2. Population ratio in the five largest cities in Bulgaria

In this study, an expert survey was conducted among 10 specialists in transport and urban planning. Each expert was provided with a table with key factors determining the quality and efficiency of public transport. The assessment was carried out on a five-point scale (1 = the lowest score, 5 = the highest score; Table 3).

Table 3

Evaluations of Key Factors and Composite Digitalization Scores

Weight	0.3	0.1	0.2	0.1	0.2	0.05	0.05	Compo-site score
City	Quality of service	Accessi bility	Safety & security	Afforda-bility	Environ-mental sustainability	Technolo-gical solutions	Infrastruct ure	
Sofia	4.50	3.50	4.23	4.5	4.55	4.67	4.33	4.36
Plovdiv	1.50	1.50	2.83	4.17	1.67	1.83	1.33	2.08
Varna	3.29	3.43	3.43	4.17	3.71	3.43	3.14	3.60
Burgas	4.14	4.29	4.29	4.57	4.57	4.43	4.57	4.35
Ruse	2.71	3.33	4.00	4.00	4.00	3.17	3.00	3.55

Sofia ranks highest with a composite score of 4.36, reflecting its advanced integration of digital infrastructure. The capital is the only city with a functioning metro system, and its tram, trolleybus and bus network is integrated through an electronic ticketing system, mobile applications for passengers, GPS-based vehicle tracking, and smart stops. A particularly strong score in technological solutions (4.67) underscores Sofia's position as a national benchmark in digital transport transformation, including traffic management systems and real-time data collection.

Plovdiv registered the lowest score (2.08), signaling serious deficiencies in both overall quality and digitalization. Following the elimination of the trolleybus system, the absence of electric buses and the lack of an integrated digital infrastructure have led to low environmental sustainability and technological solution scores. There is minimal use of digital solutions, as there are no real-time applications, traffic analysis systems, or integrated electronic tolling. Although a smart ticketing system was initiated, its flawed design rendered it an expensive experiment with negligible added value. The technological solutions score is only 1.83, the lowest of all the cities analyzed.

Varna achieved a solid score of 3.60, suggesting significant potential for leadership among medium-sized cities. Existing GPS tracking, digital signage, and a partially electrified fleet provide a foundation for growth, though the full integration of digital fare and planning systems remains pending. Nevertheless, the score for technological solutions (3.43) indicates a solid foundation for further development.

Burgas, with a score of 4.35, demonstrates exceptional progress in digitalization. The city has implemented electronic fare systems, smart stops, and mobile applications, and it operates a fleet of electric and eco-friendly vehicles. With a technological solutions score of 4.43, it closely follows Sofia in terms of technological adoption and provides a successful mid-sized city model.

Ruse, with a composite score of 3.55, shows moderate advancement with potential for growth. While electric and trolley buses are operational, gaps remain in digital infrastructure, specifically concerning the lack of integrated ticketing and comprehensive mobile services. The technological solutions score (3.17) indicates the need for targeted investments in digitalization, as the existing base offers potential for strategic development. The presence of electric buses and trolleybuses provides a good example of environmentally sustainable transportation in a smaller city.

After collecting the individual assessments, we processed the results using the average method (Fig. 3).

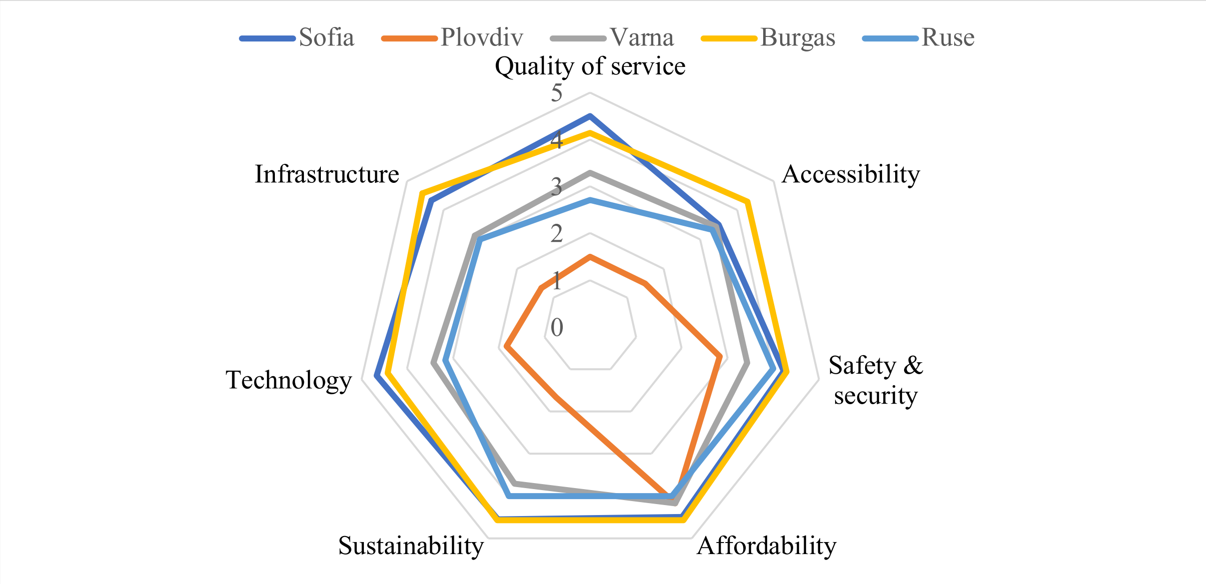

Fig. 3. Radar chart of key factor evaluations across the five investigated cities

Based on the results of the multifactor analysis, a set of tailored recommendations has been developed for each city to support the advancement of urban mass transit digitalization over the medium term (Table 4).

In addition to the city-specific proposals, broader strategic guidelines have been formulated based on expert interviews, literature analysis, and international best practices. These recommendations are intended to be universally applicable across all urban regions engaged in the digital transformation of public transport.

- Develop interoperable digital systems that are economically viable, scalable, and based on advanced technologies, including AI and machine learning;
- Establish a robust regulatory framework for transport digitalization, featuring clearly defined national and municipal standards, interoperability requirements, and data protection provisions;
- Implement multimodal travel information systems that consolidate data from urban, suburban, rail, air, and waterborne transport, providing real-time, optimized routing options to users;
- Enhance automation and digitalization processes through the deployment of sensors, Internet of Things devices, intelligent traffic control systems, and smart stops with a focus on safety, security, and sustainable development;
- Utilize digital solutions to improve transport system resilience, including in the context of natural disasters, operational disruptions, cyber threats, and peak demand scenarios;
- Create digital twins of urban transit systems to enable traffic simulations, scenario analysis, capacity forecasting, and infrastructure adaptation planning;

- Integrate open data platforms and APIs to enable third-party developers and private sector stakeholders to build complementary applications and mobility services;
- Invest in the training and reskilling of transport sector personnel to ensure effective operation and management of next-generation digital systems;
- Guarantee digital accessibility, ensuring that platforms, applications, and devices are usable by persons with disabilities, elderly citizens, and other vulnerable groups;
- Establish a framework for continuous monitoring and impact assessment, using key performance indicators to evaluate the outcomes of digitalization initiatives.

These recommendations should be aligned with national and EU-level strategic documents, including the European Green Deal, the EU Strategy for Sustainable and Smart Mobility, and Bulgaria's policies for digital transition in the transport sector.

Table 4

City-Level Recommendations for Advancing Urban Transit Digitalization (Medium-Term Horizon)

City	Recommendations for enhancing digitalization
Sofia	- Expand intelligent transport systems by integrating AI-based predictive traffic analytics; - Develop fully integrated Mobility-as-a-Service platforms; - Strengthen cybersecurity protocols for digital infrastructure.
Burgas	- Enhance mobile applications to support real-time navigation, mobile payments, and multimodal journey planning; - Introduce a unified "smart ticket" valid across all modes of transport; - Establish an open-access data platform for the transport network.
Varna	- Integrate existing digital systems into a unified operational platform; - Implement mobile ticketing and contactless payment solutions; - Increase the number of stops equipped with electronic information displays.
Ruse	- Develop an electronic fare collection system; - Launch a mobile application providing real-time transport information; - Implement GPS tracking across the entire vehicle fleet.
Plovdiv	- Establish a foundational digital infrastructure, including e-ticketing, GPS navigation, and stop-based display systems; - Deploy a centralized transport management system; - Promote digital innovation through public-private partnerships.

4. CONCLUSIONS

This study presents a multifactor analysis of the digitalization of urban mass transit systems in Bulgaria's five largest cities: Sofia, Plovdiv, Varna, Burgas and Ruse. Drawing on expert evaluations of key dimensions - namely, service quality, accessibility, safety, affordability, environmental sustainability, technological advancement, and infrastructure - the research delivers a comparative assessment of each city's digital maturity in the public transport domain.

The findings reveal that Sofia and Burgas are frontrunners in the digital transformation of public transit, owing to their deployment of integrated technological solutions, robust infrastructure, and focus on sustainable mobility strategies. Ruse and Varna show solid progress, though accelerated implementation of digital tools is needed to enhance multimodality and environmental performance. Plovdiv, in contrast, lags considerably behind, particularly in terms of digital infrastructure and low-emission mobility, necessitating an urgent reassessment of its modernization strategy.

The analysis underscores the importance of a systemic and strategic approach to digitalization, involving policy coordination, regulatory support, and technological innovation. Beyond the recommendations for individual cities, this study outlines comprehensive national guidelines focused on developing interoperable digital ecosystems, implementing information platforms for multimodal travel, and ensuring the network's cyber resilience.

Ultimately, the successful digitalization of public transport should be viewed as a central pillar of sustainable urban development that requires committed action by local authorities, technology partners, and society. Only through coordinated efforts and sustained investment in digital mobility can Bulgaria meet the evolving needs of its urban populations, achieve climate neutrality, and enhance the quality of life in its cities.

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