SUSTAINABLE AND INTELLIGENT URBAN MOBILITY: A CASE STUDY OF BEIJING

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ABSTRACT

In the 21st century, climate change continues to unfold as an increasingly alarming phenomenon. Confronted with this issue, both individual cities and governmental authorities at the global level are taking measures to address the problem, setting goals, and implementing initiatives to promote sustainable and intelligent mobility. The aim of this article is to identify contemporary solutions in the field of intelligent and sustainable urban mobility that contribute to the development and improvement of city functionality. The article describes the concept of sustainable and intelligent mobility within the context of urban development and presents selected modern solutions, using Beijing as an example, such as magnetic levitation railways, autonomous buses, and Mobility as a Service (MaaS) platform. These solutions can be categorized into three groups: electric mobility, public transportation, and low-mobility societies. Additionally, a SWOT analysis was conducted to highlight the strengths and weaknesses of electric autonomous vehicles, as well as the opportunities and threats associated with their use. The results of the analysis reveal numerous advantages and opportunities, as well as potential drawbacks and threats, related to the use of electric and autonomous vehicles for transporting people, for instance, to work or school.

Keywords: sustainable mobility, intelligent mobility, modern solutions, autonomous vehicles, electric vehicles.

INTRODUCTION

In the strategies of many cities, a key objective is the adoption of modern mobility solutions to reduce negative environmental impacts, improve air quality, and enhance the comfort of residents (Muller-Eie & Kosmidis, 2023). Due to urbanization, city authorities must continuously implement modern solutions that ensure more efficient use of urban space, minimize traffic congestion, and provide quick and convenient access to various forms of public transportation (Pankratova, 2023). These efforts not only contribute to environmental protection and the achievement of sustainable development principles but also create conditions that foster economic and social

development in cities (Gulc & Budna, 2024).The implementation of modern solutions depends on numerous factors. Zhang et al. (2023) identified groups of factors influencing urban innovation and development, which include:

- ***Environmental factors*** – quality of the environment, geographical location, and city size (Nikiforova et al., 2024);
- ***Social factors*** – population structure, governance, and service measures (Aitimov et al., 2015);
- ***Economic factors*** – economic level, industrial structure, and technological innovation (Kovalev, 2022).

Urban development is an ongoing process that requires a holistic approach and the prudent use of available resources and opportunities (Angelidou et al., 2022; Vijay & Sathish, 2024). In this context, urban transportation plays a pivotal role, as it is a critical factor in the social, economic, and infrastructural development of cities (Kulbaeva et al., 2023). However, its dynamic growth is often associated with numerous environmental and social challenges (Matej et al., 2021). The main issues related to the development of urban transportation include:

- ***Increased air pollution*** – transportation is a dominant source of emissions that pollute the air, soil, and water (accounting for approximately 24% of global CO2 emissions) (Cepeda et al., 2017);
- ***Rising urban populations*** – currently, 55% of the global population resides in cities, and this figure is expected to increase to 68% by 2050 (Marvuglia et al., 2020);
- ***Negative impacts of high noise levels*** – in large megacities, road noise often exceeds 55 dB during the day (Jacyna et al., 2017).

In the context of urban development, a primary concern is the increase in air pollution caused by society's excessive reliance on cars (Nakamura & Hayashi, 2013). According to Sun et al. (2019), cars account for approximately 7% of global greenhouse gas emissions and up to 50% of total emissions in the transportation sector. Griffiths et al. (2021) note that the total number of passenger cars worldwide is expected to increase by one-third by 2040. Addressing these challenges is a long-term priority for many cities and represents a significant undertaking (Ilyushin & Afanaseva, 2020). One potential way to mitigate the problems caused by urban transportation is the adoption of solutions within the framework of sustainable and intelligent urban mobility concepts. The aim of this article is to identify modern solutions in the field of intelligent and sustainable urban mobility that contribute to the development and improvement of city functionality.

Literature Review

The concept of sustainable and intelligent mobility involves the integration of innovative transportation solutions that simultaneously address economic, social, and environmental aspects, promoting efficient and sustainable forms of travel and improving residents' quality of life. According to Cepeliauskaite et al. (2021), intelligent mobility refers to the use of modern technologies and efficiently operating transportation systems to facilitate movement and enhance the efficiency of urban transport. Tomaszewska and Florea (2018) define intelligent mobility as the development of logistics and transportation activities through the use of smart digital technologies (Soldatova et al., 2024). The adoption of the latest technological solutions would not be fully successful without the support of sustainable mobility, which is defined as a stronger foundation for public transportation, the implementation of better mobility opportunities, and efficient urban logistics without emissions (Gasanov, 2024; Turan et al., 2024). Sustainable mobility also implies changes in residents' communicative behavior (Comi et al., 2018; Alperovich, 2023) and consideration of climatic and environmental issues (Laporte et al., 2018). An attempt to categorize solutions in the field of sustainable and intelligent mobility was proposed by Holden et al. (2020), who identified three concepts: a) electric mobility, b) public transportation, c) low-mobility society.

The first concept signifies a transition from vehicles powered by traditional fossil fuels (Yermagambet et al., 2021) to electric vehicles powered by renewable energy sources, with continuous improvements in their efficient use (Ilyushin & Martirosyan, 2024). Examples of solutions include electric vehicles (Alanazi, 2023); hydrogen-powered vehicles (Hassan et al., 2023); and electric bicycles and scooters (Aarhaug et al., 2023; Özer, 2025).

The second concept focuses on urban public transportation, aiming to increase its popularity through a range of conveniences, such as: electronic ticketing (Masson et al., 2017; Grishchishen and Oganova, 2022); the construction of Park & Ride facilities (parking lots located outside the city center) (Ortega et al., 2021; Tran et al., 2025); Bike & Ride facilities (bike parking near metro stations, for example) (Hamidi et al., 2019); and Mobility as a Service (MaaS) platforms (Dyczkowska et al., 2023).

The third concept involves the overall reduction in the number and distance of car and airplane trips. Possible solutions for this purpose include: the creation of pedestrian zones; increased parking fees; and the promotion of urban transportation through various campaigns (Szpilko et al., 2023).

MATERIAL AND METHODS

To achieve the stated objective, a mixed-method approach was chosen, combining source analysis and the case study method. The research was conducted in 2024 and consisted of several stages. ***Stage 1.*** At this stage, the authors selected information sources (monographs, scientific journal articles, and conference materials) necessary to achieve the research objective. The search was conducted using the following English keywords: "sustainable mobility," "smart mobility," "modern solutions," "unmanned vehicles," and "electric vehicles." ***Stage 2.*** The primary research method was the case study approach, aimed at examining the features and complexities of a specific case. The resulting case study, titled "Modern Solutions for Sustainable and Intelligent Mobility in Beijing," included materials dedicated to the analysis of selected modern solutions for sustainable and intelligent mobility in the city of Beijing. ***Stage 3.*** An additional research method was the SWOT analysis, focused on studying the use of a modern public transportation solution, namely, electric autonomous buses for commuting. Through this analysis, the authors identified the strengths and weaknesses, as well as the opportunities and threats, associated with the use of this solution.

RESULTS AND DISCUSSION

1. Case Study: "Modern Solutions for Sustainable and Intelligent Mobility in Beijing"

An analysis of open sources indicates that the implementation of the latest innovations in sustainable and smart mobility has become a key objective for cities worldwide. One of the regions leading in terms of progress is China's megacities, particularly its capital, Beijing. Beijing, the capital of the People's Republic of China, covers an area of 16,406 km² and has a population of 21.8 million residents. It plays a pivotal role as the country's primary political, educational, cultural, and historical center, home to significant universities and institutions. According to recently published rankings, such as the Global Top 100 SMILE Cities 2022-2023 and the Global New Smart City (SMILE Index), three of China's largest cities ranked among the top ten in terms of "smart" city development (Akhmetshin et al., 2024). Beijing secured the third position as a leading hub for smart cities, where advanced technologies are used to efficiently manage urban infrastructure and enhance residents' quality of life. In the IMD Smart City Index 2023, Beijing ranked 12th in terms of urban efficiency development. Compared to its 20th position in 2019, this demonstrates significant progress and investments in infrastructure. This underscores the city's commitment to developing intelligent solutions. Currently, Beijing is undergoing substantial changes driven by globalization trends, continuing its transformation into a smart city while improving residents' quality of life. This observed evolution brings diverse, multicultural, and international perspectives. However, alongside business activities and globalization, social, economic, and environmental challenges have emerged, including issues related to public transportation safety and efficiency, such as preventing the use of transportation for illegal purposes (Akimzhanov et al., 2018; Kutsev, 2023). Given the city's achievements and its relatively high rankings, it can be concluded that the implemented solutions and improvements are satisfactory. Based on the three narratives proposed by Holden et al. (2020), these solutions can be classified as follows (Table 1).

Table 1. Sustainable and Smart Mobility Solutions in Beijing.

Narrative	Solutions
Electric Mobility	Electric hydrogen buses, electric buses, autonomous taxis, electric taxis, e-bikes, e-aircraft
Transport 2.0	Maglev railway, autonomous trains, self-driving buses, metro, scooters, bicycles
Low-Mobility Society	Pedestrian zones with minimal emissions, infrastructure access fees, strict emission standards, government programs such as Mobility as a Service (MaaS), e.g., smart pedestrian bridges or smart streetlights

Note. Data compiled from analysis of sustainable and smart mobility solutions in Beijing.

The most common mode of transportation in Beijing is the city bus, which is the cheapest option compared to the metro or railway. It transports approximately 9.6 million passengers daily, operating on 1,020 routes that cover the city center, suburbs, and remote provinces, including nighttime services. Additionally, buses serve popular tourist attractions, making it easier for visitors to explore the city. Beijing is committed to environmental sustainability and

has introduced hydrogen-powered buses. The city currently operates 20 hydrogen buses equipped with the latest hydrogen fuel cell systems, capable of traveling up to 400 kilometers on a single refueling. These buses primarily serve employees commuting to industrial zones during morning and evening hours. Each bus is 12 meters long and can accommodate 50 passengers. Some companies have purchased these vehicles for their specific needs. In 2022, 150 hydrogen buses were introduced and used during the Winter Olympics. China is the undisputed leader in electric bus production, accounting for 95% of the world's total. It is also at the forefront of their use in public transportation. By the end of 2022, the Ministry of Transport announced that 77% of all urban buses in the country are "new energy vehicles," including purely electric vehicles, plug-in hybrids, and vehicles powered by alternative fuels such as hydrogen or methanol (Kazankapova et al., 2024). Electric vehicles now make up 84% of the total transportation fleet, compared to just 22% in 2015, when 78% of buses ran on fuel or gas, according to the World Resources Institute. These changes have improved environmental quality and reduced air pollution. As a result, Beijing, the capital of China, was removed from the list of the world's 200 most polluted cities in 2019. Beijing also offers metro travel, including Line 10, the world's longest metro line at 690 kilometers, which continues to expand dynamically. The metro's ring structure connects the city's four major areas, serving over 10 million passengers daily. Intelligent solutions for urban mobility include the magnetic levitation (Maglev) railway. Each Maglev train can carry over 1,300 passengers and reach a maximum speed of 100 km/h. China aims to master high-speed Maglev technology to create the world's fastest ground-based public transportation system, with speeds of up to 603 km/h.

Another intelligent mobility solution is autonomous trains, which can reach speeds of 350 km/h and accommodate 564 passengers. This is the world's first intelligent high-speed railway, where the train operates autonomously, with the driver only monitoring door operations, obstacles, and emergency situations. The carriages are equipped with 5G signals, smart lighting, and 2,718 sensors for real-time data collection. Each seat features a touch control panel and wireless charging. Facial recognition technology is used at stations to simplify baggage handling and check-in. The railway lines are designed using intelligent transportation system analysis to predict demand, significantly reducing the use of carbon-emitting vehicles. In recent years, two-wheeled vehicles such as bicycles and scooters have gained popularity. Bike-sharing companies have simplified the rental process, allowing users to rent bikes anywhere in the city. People use both traditional pedal-powered bicycles and electric bikes powered by batteries. In 2019, Beijing introduced its first 6.5-kilometer bike lane, providing a safe, fast, and comfortable travel option. City authorities are working to improve bike routes and parking facilities, modernize and expand the public bike-sharing system, and integrate cycling with public transportation to meet societal needs.

Due to heavy traffic, the future may belong to electric vehicles that travel through the air. These vehicles, resembling drones, can carry two passengers and hover at heights of 5 to 25 meters. Currently, prototypes are being tested, with legal regulations being the main barrier to their widespread adoption (Trofimov, 2023). Another innovative solution is autonomous electric taxis, which enhance safety and efficiency while minimizing environmental impact. Currently, 116 such vehicles operate in the city, with user satisfaction rates exceeding 95%.

The city government has mandated that all regular taxis transition to renewable energy by the end of 2025, making this solution a potential global prototype. Another example is the autonomous electric bus that operates between a secondary school and Renmin University of China, covering an 8-kilometer route. Only authorized individuals, such as students and staff, can use this service. While autonomous vehicles represent the future of transportation, safety concerns currently require onboard staff to take control in emergencies. In the context of low-mobility societies, several solutions have been implemented, such as low-emission zones and air quality control programs. Over a thousand sensors have been installed to monitor pollution levels. In 2016, an advanced network of sensors, including laser radar and high-resolution satellite remote sensing, was established to promote sustainable mobility by developing rail and pedestrian transport while reducing the use of internal combustion engine vehicles. These efforts have made Beijing a more livable city, emphasizing public transportation, walking, and renewable energy vehicles.

Other solutions include government programs (Vaslavskiy, 2021), such as phasing out old vehicles and replacing them with new ones, modernizing the bus fleet, and enforcing strict emission standards. Factories have been closed, and heating systems upgraded to reduce coal consumption. Investments in air quality improvement continue to grow annually, making Beijing a model for other cities worldwide. A modern solution supporting sustainable and intelligent mobility is the Mobility as a Service (MaaS) platform. Promoting green transportation is key to reducing carbon emissions by 2030. MaaS aims to integrate all transportation services into a single ecosystem, including public transport (buses, metro, and railways) and shared mobility (walking, cycling, and car-sharing). Residents can register on platforms like Amap or Baidu Maps to earn carbon credits, which can be exchanged for public transport vouchers, shopping discounts, or tree-planting initiatives, attracting new users (Akhmetshin et al., 2024). In China, chaotic pedestrian behavior, such as crossing streets against traffic signals, often leads to tragic accidents. "Smart

pedestrian bridges" offer a solution. These bridges, located above roads, interact with pedestrians and can store energy to power streetlights. Equipped with environmental and traffic sensors, they encourage use by rewarding points that can be redeemed for city services. Another solution is an app that encourages residents to use eco-friendly transportation or walk by planning routes and providing real-time information on traffic, roadworks, and route changes. Connected to the city's smart infrastructure, the app helps prevent congestion and overcrowding (Vaslavskaya et al., 2023). As part of intelligent solutions, Beijing has introduced "smart streetlights." These intelligent lamps, first deployed in 2016, feature surveillance cameras, Wi-Fi transmitters, small communication stations, and device charging capabilities. They help coordinate vehicle and road operations, particularly at 28 intersections along a 10-kilometer route. By monitoring traffic and pedestrian movement, they enable quick improvements and enhance safety.

2. Autonomous Electric Buses – SWOT Analysis

The use of autonomous electric buses for commuting to work or school has numerous advantages and disadvantages. A SWOT analysis was conducted to provide a comprehensive assessment of this modern solution. Table 2 presents the SWOT analysis of autonomous electric buses.

Table 2. SWOT Analysis of Autonomous Electric Buses.

Strengths	Weaknesses
Environmental improvements (enhancing the image of educational institutions or businesses); Zero-emission transportation (electric/hydrogen-powered); User convenience through network connectivity (apps); Faster and more organized transportation, Generates interest among people/tourists/society.	Higher operational costs; Difficult to implement due to legal restrictions; Requires appropriate infrastructure – stops, charging stations; Limited testing of the system in real-world conditions; Limited number of users; Battery recycling challenges; Limited usage time – driving and charging durations; Expensive replacement of parts with limited lifespan and availability.
Opportunities	Threats
Contribution to the development of sustainable and smart mobility; Increased safety for commuting to work/school; Popularization of the solution after additional testing and research; Collective transportation reducing individual commutes and traffic congestion.	Government policies affecting vehicle regulations; Job losses for drivers; Negative public attitudes toward change.

Analyzing the results, it can be concluded that autonomous electric buses for commuting to work or school offer environmental benefits, enhancing the image of educational institutions or businesses. The use of apps that provide convenience and faster, more organized transportation can generate interest within the community. There is potential to influence the development of sustainable and intelligent mobility and improve commuting safety. However, higher operational costs, implementation challenges due to legal restrictions, the need for appropriate infrastructure, and a limited user base may pose significant challenges (Moro et al., 2024; Polovchenko, 2024). Additionally, threats such as government policies, job losses for drivers, and negative public attitudes toward change (Bobkov & Shichkin, 2024) must be considered. Nevertheless, with technological advancements and increasing city involvement in combating climate change (Ageed et al., 2021), it is expected that autonomous electric vehicles will become more widespread globally, playing a critical role in the future of public transportation. Cities worldwide are implementing various initiatives to promote sustainable mobility solutions and reduce transportation-related emissions (Laporte et al., 2018). These efforts include both local and global initiatives, as cities collaborate, share best practices, and learn from one another. Moreover, technological advancements play a key role in this process, enabling the implementation of innovative solutions such as intelligent transportation systems that enhance efficiency and safety (Tomaszewska & Florea, 2018; De Alencar et al., 2023). Today, cities are continuously evolving and striving to adopt the latest and most efficient technological solutions to improve residents' quality of life (Glebova et al., 2022). Urban development can be understood as both material development, including elements such as constructing new buildings or improving road infrastructure, and intangible development, encompassing aspects like interpersonal relationships within groups or various social environments shaped by cultural dynamics (Masson et al., 2017; Kachay, 2023; Serova, 2023). Depending on the goals, user needs, availability of financial

resources, and the unique characteristics and challenges of each city, the implementation of modern solutions may prove ineffective in one location while delivering expected results in another (Fornasier et al., 2022; Ates & Akin, 2024). It is crucial for city authorities to develop tailored solutions that may focus on technological (e.g., electric mobility), organizational (legal regulations), or purely economic (financial mechanisms) aspects.

CONCLUSIONS

Cities around the world are increasingly focusing on improving communication and the flow of people. In response to growing challenges such as street congestion, air pollution, and the need for fast and comfortable transportation for residents, cities are implementing modern solutions. In Beijing, China, numerous solutions in the field of sustainable and intelligent mobility have been adopted, including magnetic levitation railways, autonomous buses, and Mobility as a Service (MaaS) platform. These solutions can be categorized into three groups: electric mobility, public transportation, and low-mobility societies. One of the key solutions is the development of autonomous electric vehicles. These vehicles offer a range of benefits, including reduced emissions, improved road safety, and optimized use of road infrastructure. Additionally, autonomous vehicle technology can enhance the efficiency of public transportation through automated traffic management and route optimization. The prospects for the development of autonomous electric vehicles are promising not only for Beijing but also for the world at large. As environmental awareness grows and the need to reduce emissions becomes more pressing, electric vehicles are gaining popularity. Furthermore, advancements in autonomous technology enable more efficient and safer use of vehicles, which could lead to reduced traffic congestion and improved quality of life in cities. However, achieving full success also requires a shift in public consciousness and the promotion of pro-environmental behavior, which demands close collaboration between local authorities, communities, and the private sector. Only through a holistic approach and the involvement of all stakeholders can a more sustainable future for urban mobility be realized.

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