GIS-Based Urban Transportation Planning: Enhancing Sustainability, Efficiency, and Accessibility in Smart Cities

Yogesh Rahi

M. Tech. in Transportation Engineering, CBS Group of Institutions, Jhajjar, Haryana.

Shubender

A.P Civil Department, CBS Group of Institutions, Jhajjar, Haryana.

ABSTRACT

Urban transportation systems are vital for the socio-economic development of cities, but rapid urbanization has led to various challenges such as congestion and pollution. Geographic Information Systems (GIS) have emerged as a critical tool in addressing these issues by enabling the integration of spatial and non-spatial data for efficient transportation planning. GIS facilitates route design, accessibility evaluation, infrastructure optimization, and policy assessment, supporting sustainable urban mobility. The integration of emerging technologies like AI, IoT, and Digital Twins further enhances its capabilities, making transportation systems more efficient and environmentally sustainable. This framework aids in addressing transportation equity, operational accuracy, and environmental impacts.

Keywords: *Urban Transportation, GIS, Accessibility, Sustainable Mobility, Digital Twins.*

I. INTRODUCTION

Urban transportation systems are fundamental to the socio-economic development of cities, influencing accessibility, mobility patterns, environmental sustainability, and quality of life. With rapid urbanization and population growth, cities across the world are experiencing increasing pressure on transportation infrastructure, leading to congestion, pollution, inequitable access, and inefficient mobility systems. In this context, Geographic Information Systems (GIS) have emerged as a powerful tool for transportation network planning and accessibility analysis, enabling planners to integrate spatial and non-spatial data for informed decision-making. GIS-based transportation planning supports the development of sustainable urban mobility by facilitating efficient route design, accessibility evaluation, infrastructure optimization, and policy assessment (Zaroujtaghi et al., 2025). GIS technology allows for the visualization, analysis, and modeling of transportation networks by integrating multiple data sources such as road networks, land use patterns, population density, and real-time traffic data. It enables planners to evaluate accessibility in terms of travel time, distance, and connectivity, thereby identifying underserved areas and improving transport equity. Accessibility analysis is particularly crucial in sustainable urban mobility planning, as it ensures that all population groups, including marginalized communities, have adequate access to essential services such as healthcare, education, and employment. Studies have shown that GIS-based accessibility models can significantly enhance the effectiveness of transportation systems by identifying spatial disparities and guiding targeted interventions (Zagorskas & Turskis, 2024). Recent advancements in GIS have further strengthened its role in transportation planning through integration with emerging technologies such as Artificial Intelligence (AI), Internet of Things (IoT), and Digital Twins (DT). For instance, Lis and Mądziel (2026) demonstrated how Digital Twin frameworks combined with GIS and real-time traffic data can optimize urban mobility by dynamically controlling traffic flows. Their study highlighted that traditional infrastructure-based solutions alone are insufficient to address urban congestion, and real-time data-driven approaches are essential for achieving sustainable mobility outcomes. Similarly, the integration of GIS with Intelligent Transport Systems (ITS) has been shown to improve operational efficiency and reduce travel time, as evidenced by Qoradi et al. (2021), who reported significant reductions in waiting time through GIS-based ITS implementation.

Another critical aspect of GIS-based transportation planning is its ability to support economic efficiency and operational accuracy. Kłos and Sobota (2026) emphasized the importance of precise spatial measurements in public transport systems, noting that even minor inaccuracies in inter-stop distances can lead to significant financial losses and inefficiencies in scheduling. Their GIS-based methodology demonstrated high accuracy and scalability, highlighting the importance of spatial precision in large-scale transportation networks. Moreover, GIS facilitates scenario analysis and simulation, allowing planners to evaluate the impacts of different transportation strategies before implementation. Sustainability is a central concern in modern transportation planning, and GIS plays a key role in integrating environmental considerations into decision-making processes. Transportation systems are major contributors to greenhouse gas emissions, and reducing their environmental impact is essential for achieving sustainable development goals. Farnood (2025) developed a GIS-based framework combined with system dynamics modeling to assess Transit-Oriented Development (TOD) strategies and parking policies. The findings indicated that increasing density near transit hubs, reducing parking availability, and promoting active transportation modes such as walking and cycling can significantly reduce car dependency and emissions. Similarly, Hadipour et al. (2020) used GIS and genetic algorithms to evaluate environmental impacts within transportation networks, identifying areas with high pollution levels and suggesting land-use adjustments to improve environmental sustainability. Despite its numerous advantages, the adoption of GIS in transportation planning faces several challenges. Liu et al. (2023) found that although GIS models are widely recognized for their potential, their actual implementation remains limited due to issues such as lack of user-friendly interfaces, insufficient data availability, and the need for specialized expertise. Additionally, ethical concerns related to data privacy and equitable access to technology must be addressed to ensure inclusive and responsible use of GIS. Nevertheless, ongoing advancements in geospatial technologies and increasing availability of real-time data are expected to enhance the usability and effectiveness of GIS-based transportation planning. Furthermore, GIS-based approaches enable the integration of multiple dimensions of transportation planning, including economic, social, and environmental factors. Droj et al. (2022) demonstrated how GIS can be used to analyze the complex relationships between traffic congestion, public transportation, and urban development. Their study highlighted the importance of improving public transport accessibility and density to reduce congestion and enhance urban mobility. By incorporating spatial analysis, simulation models, and real-time data, GIS provides a comprehensive framework for addressing the multifaceted challenges of urban transportation systems.

II. RESEARCH BACKGROUND

Lis and Mądziel (2026) investigated the integration of Digital Twins (DT) with real-time traffic optimization systems to improve urban mobility management in Smart Cities. They developed a calibrated microsimulation model of the Pobitno Roundabout in Rzeszów, which was validated using the GEH statistic and served as the central component of the proposed DT framework. The study examined not only static scenario analyses but also introduced an Adaptive Inflow Metering (AIM) logic that interacted with IoT sensor data to dynamically control traffic. The authors analyzed traditional geometrical upgrades, such as turbo-roundabouts, and observed that these measures alone often failed to maintain acceptable levels of service during peak traffic, frequently resulting in LOS F. They further demonstrated that the DT framework enabled the testing of "Software-in-the-Loop" (SiL) solutions, where Python-based algorithms dynamically adjusted inflow parameters to prevent gridlock. The study concluded that combining physical infrastructure enhancements with real-time digital optimization was critical for achieving sustainable, low-emission urban transport.

Kłos and Sobota (2026) investigated the economic and operational implications of spatial accuracy in metropolitan public transport systems, proposing a standardized GIS-based approach to measure inter-stop distances. They addressed the geometric limitations inherent in legacy GTFS data and introduced a replicable workflow that integrated open spatial data with infrastructure-specific maneuvering constraints. Their method was validated in the Górnośląsko-Zagłębiowska Metropolis (GZM), where it reportedly achieved precision nearly identical to manual field measurements (MAPE ≈ 0.02%) while offering greater scalability than conventional odometer- or satellite-based techniques. The study indicated that even minor measurement errors of approximately 2.5% in legacy datasets could propagate into substantial budget misallocations, potentially amounting to tens of thousands of PLN per line annually. The authors concluded that accurate distance computation represented a critical factor in enhancing cost efficiency and schedule reliability within large-scale transit networks, highlighting the practical significance of integrating advanced spatial analytics into public transport planning and operations.

Zaroujtaghi et al. (2025) examined the integration of Geographic Information Systems (GIS) in transportation planning through a systematic, PRISMA-guided longitudinal review, covering research from 2004 to 2024. They noted that prior reviews had focused on specific facets, such as transit applications and open-source geospatial tools, but this study addressed the broader thematic domains, data models, methodologies, and outcomes of GIS-based transportation research. By analyzing 241 peer-reviewed articles using mixed methods, they identified key trends, including heightened attention to sustainability, equity, stakeholder engagement, and the adoption of advanced technologies. They reported that prominent areas included land use–transportation coordination, accessibility, artificial intelligence, real-time monitoring, and policy evaluation. The study highlighted that expanded data sources, such as real-time sensors and 3D models, along with advanced modeling techniques, facilitated multifaceted, evidence-based decision-making. Nonetheless, challenges related to data limitations, ethical considerations, and required expertise persisted, especially in developing regions, and they recommended future research prioritize responsible technology adoption and inclusive capacity building.

Farnood (2025) examined the challenges faced by urban transportation systems in reducing car dependency and greenhouse gas emissions while promoting sustainable growth. The study highlighted the lack of integrated modeling approaches that captured both spatial and temporal dynamics in transport planning. To address this gap, Farnood developed a novel framework combining System Dynamics (SD) and Geographic Information Systems (GIS) to evaluate the sustainability of Transit-Oriented Development (TOD) strategies and parking policies at two brownfield redevelopment sites in Montreal. The framework incorporated spatial metrics, including proximity to transit, parking availability, and active transportation infrastructure, within dynamic feedback loops. Through scenario analysis, a comparison was made between a baseline reflecting existing conditions and an intervention scenario emphasizing higher density near transit, reduced parking ratios, and enhanced walkability and cycling infrastructure. The findings suggested that integrating TOD principles with targeted parking restrictions and investments in active mobility could significantly reduce car ownership and emissions, providing a conceptual foundation for location-sensitive, feedback-driven urban planning tools.

Zagorskas and Turskis (2024) examined the accessibility of bike infrastructure, including bikeshare stations and bike lanes, in New York City, focusing on sociodemographic factors. They employed a combination of buffer analyses, the Bicycle Equity Index (BEI), and binary logistic regression to evaluate the spatial distribution of bike lanes and bikeshare stations, highlighting the significance of equitable access. The BEI methodology was reported to incorporate variables such as minority population, poverty, age groups, and zero-vehicle households to assess equity, while binary logistic regression was used to identify significant predictors. Their findings indicated that households without vehicles, age-dependent populations, and minority communities significantly influenced the availability of bikeshare stations. The study was noted to offer valuable insights for urban planners, policymakers, and transportation authorities in addressing sociodemographic disparities and improving inclusivity. It was concluded that the research contributed to understanding the factors shaping bike infrastructure access and informed targeted interventions for fostering a more equitable and sustainable urban transportation system.

Liu et al. (2023) investigated the application of GIS models in urban mobility planning across Europe, noting that although GIS models were widely recognized for their potential, the extent of their actual use among European mobility planners and the user experiences associated with them remained unclear. They argued that GIS model development risked being driven more by technical capabilities and data availability than by user needs. To address this, they conducted a survey among transport departments from 42 cities in 21 European countries, receiving 51 valid responses. Their findings suggested that while current GIS models were considered useful for supporting urban mobility planning, over 60% of the surveyed cities had not adopted them. Liu et al. highlighted that improvements in user-friendliness, particularly for non-experts, and better access to non-traditional data, such as real-time or neighborhood-level data, were crucial for wider adoption. They also indicated growing interest in models integrating social and environmental considerations.

Droj et al. (2022) examined the impact of traffic on local and regional economies, environmental pollution, and public discomfort, noting that congestion, accidents, and roadworks were major sources of frustration for urban populations. They observed that urban congestion had become a widespread phenomenon, particularly on main city arteries during peak hours or when additional constraints, such as traffic accidents or construction, slowed traffic. The study indicated that certain roads were more prone to congestion than others and emphasized that both congestion and overall urban traffic were influenced by multiple factors represented by complex geospatial data and spatial relationships. The authors integrated mathematical models, real-time traffic data, network analysis, and simulation procedures to analyze public transportation in Oradea and its effects on urban traffic. They also adapted a mathematical model to simulate travel choices of city and surrounding village populations. Their results suggested that reducing traffic and its adverse effects could be achieved by enhancing public transport density and accessibility.

Qoradi et al. (2021) investigated the potential of integrating an intelligent transport system (ITS) with a geographic information system (GIS) to enhance the efficiency of campus transportation at King Saud University in Riyadh, Saudi Arabia. They reported that prior to implementing the GIS-based ITS, the waiting time for university buses was distributed as less than 5 minutes (19% of respondents), 5–10 minutes (48%), 10–20 minutes (30%), and more than 30 minutes (3%). Additionally, 62% of female students were unaware of the bus arrival time at their homes, while 38% had knowledge of it. After the deployment of the ITS, which sent alerts before bus arrivals, the waiting time for female students decreased considerably, averaging 14 minutes, plus 10 minutes for the bus to travel between homes. The total pickup time for female students remained constant at 24 minutes; however, the system achieved a daily trip time saving of 43 minutes, demonstrating the effectiveness of the GIS-based ITS intervention in optimizing campus transport operations.

Hadipour et al. (2020) emphasized that transportation had long been recognized as a critical infrastructure and a foundation for development, which had drawn the attention of managers and planners. However, they observed that while urban transport planning often focused on accessibility and dynamic aspects, its environmental impacts had been largely neglected. They investigated the city of Petaling Jaya, a significant religious-tourist metropolis, and highlighted the need for efficient transport management that would not conflict with other developmental sectors, particularly the environment. The study identified environmental indicators related to transportation and selected five key indicators, which were then spatially analyzed using GIS maps of the transport network and expert opinions. They reported that the results were processed through MATLAB using a genetic algorithm to evaluate each cell of the network. Their findings indicated that 40% of network cells were environmentally inappropriate, 35% moderately suitable, and 25% sound. They concluded that relocating certain land uses, particularly residential areas, to less polluted zones could significantly improve environmental conditions in the urban transport network.

III. KEY FINDINGS FROM STUDY

Author & Year	Objective	Methodology	Key Findings
Lis & Mądziel (2026)	Improve urban mobility using Digital Twins	Microsimulation + IoT + Adaptive Inflow Metering	Real-time optimization reduced congestion; DT more effective than infrastructure changes alone
Kłos & Sobota (2026)	Improve accuracy in transport distance measurement	GIS-based spatial analysis workflow	Achieved ~0.02% error; improved cost efficiency and scheduling accuracy
Zaroujtaghi et al. (2025)	Review GIS evolution in transportation	PRISMA-based systematic review (241 studies)	Highlighted trends in AI integration, sustainability, and accessibility
Farnood (2025)	Evaluate sustainable transport strategies	GIS + System Dynamics modeling	TOD and reduced parking decreased emissions and car dependency
Zagorskas & Turskis (2024)	Analyze bike infrastructure accessibility	GIS buffer analysis + regression + BEI	Identified socio-economic disparities in bike infrastructure access
Liu et al. (2023)	Assess GIS adoption in mobility planning	Survey across 42 cities	Over 60% cities not using GIS; need for user-friendly tools
Droj et al. (2022)	Analyze urban traffic and public transport	GIS + simulation + mathematical modeling	Improved public transport reduces congestion and pollution
Qoradi et al. (2021)	Enhance campus transportation efficiency	GIS-based Intelligent Transport System	Reduced waiting time and improved operational efficiency
Hadipour et al. (2020)	Evaluate environmental impact of transport networks	GIS + genetic algorithm	40% network environmentally unsuitable; need for planning improvements

IV. CONCLUSION

GIS-based transportation network planning and accessibility analysis have proven to be highly effective tools for addressing the complex challenges of urban mobility. The reviewed studies demonstrate that GIS enables accurate spatial analysis, efficient transportation modeling, and informed decision-making, contributing to improved accessibility, reduced congestion, and enhanced sustainability. Integration with advanced technologies such as Digital Twins, AI, and IoT further enhances the capability of GIS in real-time traffic management and smart city applications. Additionally, GIS supports equitable transportation planning by identifying spatial disparities and enabling targeted interventions for underserved communities. However, challenges such as data limitations, lack of technical expertise, and limited adoption remain barriers to its widespread implementation.

V. FUTURE SCOPE

Future research in GIS-based transportation planning should focus on the following areas:

- **Integration with AI and Machine Learning:** Development of predictive models for traffic flow, demand forecasting, and real-time optimization.
- **Real-Time Data Utilization:** Enhanced use of IoT sensors, GPS data, and mobile data for dynamic traffic management.
- **Equity-Focused Accessibility Models:** Incorporating socio-economic and demographic factors to ensure inclusive mobility planning.
- **3D GIS and Digital Twin Development:** Advanced simulation environments for testing infrastructure and policy scenarios.
- **User-Friendly GIS Platforms:** Simplifying GIS tools to encourage adoption by non-experts and policymakers.
- **Sustainable Mobility Planning:** Integration of environmental indicators to reduce emissions and promote green transport.
- **Policy and Governance Frameworks:** Development of standardized guidelines for GIS implementation in urban planning.
- **Smart City Integration:** Linking GIS with smart infrastructure systems for holistic urban mobility management.

Overall, GIS will continue to play a pivotal role in shaping sustainable, efficient, and inclusive urban transportation systems in the future.

REFERENCES

1. Lis, M., & Mądziel, M. (2026). Green Transportation Planning for Smart Cities: Digital Twins and Real-Time Traffic Optimization in Urban Mobility Networks. *Applied Sciences*, *16*(2), 678.
2. Kłos, M. J., & Sobota, A. (2026). Measuring Inter-Stop Distances to Improve Scheduling, Costing, and Enhance Sustainable Urban Mobility. Sustainability, 18(2), 556.
3. Zaroujtaghi, A., Mansourihanis, O., Tayarani, M., Mansouri, F., Hemmati, M., & Soltani, A. (2025). A Systematic Review of GIS Evolution in Transportation Planning: Towards AI Integration. *Future Transportation*, *5*(3), 97.
4. Farnood, A., Eicker, U., Cucuzzella, C., Gopakumar, G., & Khorramisarvestani, S. (2025). Sustainability assessment framework for urban transportation combining system dynamics modeling and GIS; a tod and parking policy approach. *Smart Cities*, *8*(4), 107.
5. Zagorskas, J., & Turskis, Z. (2024). Enhancing sustainable mobility: Evaluating new bicycle and pedestrian links to car-oriented industrial parks with ARAS-G MCDM approach. *Sustainability*, *16*(7), 2994.
6. Liu, X., Payakkamas, P., Dijk, M., & de Kraker, J. (2023). GIS models for sustainable urban mobility planning: Current use, future needs and potentials. Future Transportation, 3(1), 384-402.

7. Droj, G., Droj, L., & Badea, A. C. (2022). GIS-based survey over the public transport strategy: An instrument for economic and sustainable urban traffic planning. *ISPRS International Journal of Geo-Information*, *11*(1), 16.
8. Qoradi, M. D., Al-Harbi, M. S., & Aina, Y. A. (2021). Using GIS-based intelligent transportation systems in the enhancement of university campus commuting in a smart city context. *Arabian Journal of Geosciences*, *14*(9), 742.
9. Hadipour, M., Mirzaaghaee, M., Pourebrahim, S., Mokhtar, M., & Naderi, M. (2020). Environmental optimization of urban transportation network, using GIS and genetic algorithm. *Arabian Journal of Geosciences*, *13*(5), 208.