

Spatial Accessibility Planning for Sustainable and Efficient Urban Mobility Systems: A Comprehensive Research

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ABSTRACT

This study focused on GIS-based transportation network planning and accessibility analysis for sustainable urban mobility development. It examined road connectivity, public transport coverage, travel time efficiency, service accessibility, last-mile connectivity, and sustainable mobility indicators. GIS tools helped identify well-connected zones, underserved areas, congestion points, and accessibility gaps within the urban transport system. The findings showed that strong road networks and improved service accessibility supported better mobility, while weak last-mile connectivity required planning attention. The study concluded that GIS provides a scientific and spatial framework for efficient, inclusive, and environmentally sustainable urban transport planning.

Keywords: *GIS, Transportation Network, Accessibility Analysis, Sustainable Mobility.*

I. INTRODUCTION

GIS-Based Transportation Network Planning and Accessibility Analysis has emerged as an important approach for sustainable urban mobility development, especially in rapidly growing cities where population expansion, traffic congestion, uneven land-use patterns, and increasing travel demand have created serious pressure on existing transport systems. Urban mobility is no longer limited to the movement of vehicles from one place to another; it is now closely connected with accessibility, environmental quality, social inclusion, economic productivity, and quality of life. In many urban areas, transport networks have developed without proper spatial planning, resulting in irregular road connectivity, traffic bottlenecks, inadequate public transport coverage, long travel times, and unequal access to essential services such as schools, hospitals, markets, workplaces, administrative centres, and recreational spaces. Geographic Information System, commonly known as GIS, provides a scientific and spatially integrated platform for analyzing these transport-related problems in a more accurate and systematic manner. Through GIS, different layers of urban data such as road networks, land use, population density, public transport routes, traffic volume, accident locations, parking areas, pedestrian facilities, and environmental zones can be collected, mapped, analyzed, and interpreted together. This makes GIS a powerful tool for identifying transportation gaps, evaluating network performance, measuring accessibility, and supporting future mobility planning. In the context of sustainable urban development, GIS helps planners move beyond traditional transport planning methods by linking spatial information with real-world mobility needs. It enables the assessment of how easily people can reach desired destinations within a given distance, travel time, or transport cost. Accessibility analysis is therefore one of the most significant components of GIS-based transportation planning because it directly measures the relationship between people, places, and transport facilities. A city may have many roads, flyovers, and transport services, but if a large section of its population cannot easily access jobs, education, healthcare, and other basic services, the transport system cannot be considered efficient or sustainable. GIS-based accessibility analysis helps to reveal such inequalities by showing which areas are well connected and which areas remain isolated or underserved. As a result, it supports more inclusive and evidence-based decision-making for sustainable mobility development.

The importance of GIS-based transportation network planning has increased because modern cities face multiple mobility challenges that cannot be solved through road expansion alone. The continuous rise in private vehicle ownership has increased traffic congestion, fuel consumption, air pollution, carbon emissions, noise levels, and road safety risks. At the same time, many cities have failed to provide reliable, affordable, and accessible public transport systems for all social groups. Poorly planned transport networks often affect low-income communities, elderly people, students, women, persons with disabilities, and residents of peripheral urban areas more severely because they depend heavily on public and shared transport facilities. In this situation, GIS offers an effective decision-support system by helping planners understand the spatial distribution of transport demand and supply. Network analysis tools in GIS can be used to determine shortest paths, fastest routes, service areas, travel-time zones, route efficiency, public transport coverage, emergency response accessibility, and connectivity between different urban zones. These tools are highly useful for identifying missing links in road networks, optimizing bus routes, locating new transit stops, planning pedestrian and cycling corridors, and improving last-mile connectivity. GIS can also be used to integrate transportation planning with land-use planning so that residential, commercial, institutional, and industrial areas are connected in a balanced manner. For example, if a residential zone is located far from employment centres and does not have proper public transport access, residents are forced to depend on private vehicles or spend more time and money on daily travel. GIS-based analysis can identify such spatial mismatches and suggest better transport interventions. Moreover, GIS supports sustainable mobility by promoting multimodal transportation planning, where roads, buses, metro systems, walking paths, cycling tracks, and shared mobility services are studied together as part of a connected urban network. This integrated approach reduces dependency on private vehicles and encourages cleaner and more efficient modes of transport. It also helps in reducing unnecessary travel, improving route selection, saving travel time, lowering transport costs, and minimizing environmental impacts. In addition, GIS-based mapping of congestion-prone areas, accident hotspots, pollution zones, and public transport gaps can guide authorities in making targeted improvements rather than applying general and costly solutions across the entire city.

In the present urban context, sustainable mobility development requires a planning approach that is data-driven, people-centred, environmentally responsible, and spatially balanced. GIS-based transportation network planning and accessibility analysis fulfil these requirements by providing a clear understanding of how urban transport systems function across space and how they affect different sections of society. The use of GIS enables planners, engineers, policymakers, and urban development authorities to visualize complex transport problems in the form of maps, models, and measurable indicators. Such visualization makes it easier to compare different planning alternatives and select the most suitable solutions for long-term urban development. Accessibility indicators such as distance to nearest bus stop, travel time to hospitals, road density, network connectivity, service area coverage, and access to employment centres can be calculated through GIS to evaluate the effectiveness of existing transport infrastructure. These indicators help in identifying priority areas for investment and improvement. For sustainable urban mobility, the goal is not only to improve movement but also to create a transport system that is safe, affordable, inclusive, energy-efficient, and environmentally friendly. GIS contributes to this goal by supporting the planning of compact cities, transit-oriented development, walkable neighbourhoods, cycling-friendly streets, and equitable public transport services. It can also support climate-sensitive transport planning by identifying areas where green corridors, low-emission zones, and non-motorized transport infrastructure can be developed. Furthermore, GIS-based transportation studies are valuable for future scenario analysis, where planners can examine how proposed roads, new transit routes, population growth, or land-use changes may affect accessibility and mobility patterns. This helps in preventing

unplanned urban expansion and reducing the negative impacts of transport infrastructure on the environment and society. Therefore, GIS-Based Transportation Network Planning and Accessibility Analysis is not only a technical method but also a strategic planning framework for sustainable urban mobility development. It provides a strong foundation for creating cities where people can move efficiently, reach essential services easily, and enjoy better environmental and social conditions. By combining spatial data, transport network analysis, and accessibility evaluation, GIS helps transform urban mobility planning into a more scientific, inclusive, and sustainable process.

II. RESEARCH BACKGROUND

Yuliyanto et al. (2026) examined the role of Urban Mobility Hubs as strategic nodes that integrated sustainable transportation modes, enhanced Jakarta's connectivity, and supported sustainable urban development. They noted that selecting optimal hub sites posed challenges due to interdependencies among transport systems, data limitations, and competing policy priorities. The study proposed an integrated framework combining Data Envelopment Analysis (DEA) with a Game Theory approach, Tobit regression, and Geographic Information Systems (GIS) to address these complexities. The framework was reported to capture competitive-cooperative interactions among modes and to derive spatial weights to minimise subjectivity in hub assessment. Their results suggested that the Light Rail Transit (LRT) system achieved the highest efficiency, whereas Transjakarta performed less effectively. Spatial analysis identified Pasar Senen as the most suitable hub, reflecting its multimodal access, dense population, and alignment with Jakarta's development priorities. The study highlighted the significance of LRT and indicated that the framework could serve as a decision support tool for other megacities pursuing equitable, low-emission, and livable mobility solutions.

Ulvi et al. (2026) argued that the growing number of vehicles in urban areas had reduced the efficiency of parking infrastructure and exacerbated traffic congestion, thereby challenging the achievement of sustainable transportation goals. They suggested that this scenario necessitated a re-evaluation of urban mobility systems in conjunction with spatial organization and digital technologies. Their study examined smart parking systems as "data-oriented spaces," analyzing their influence on urban mobility, energy efficiency, and spatial organization from a multidimensional perspective. A qualitative, multi-level methodology was adopted, combining a comprehensive literature review, comparative analysis of five international case studies, and conceptual synthesis of the results. The evaluation considered technological infrastructure, spatial structure, sustainability performance, and user interaction. The authors concluded that smart parking systems functioned not merely as vehicle storage but also as digital-spatial interfaces directing urban data flows. They proposed a conceptual framework positioning such systems as adaptable, data-oriented architectural spaces, capable of optimizing circulation, reducing search-related emissions, enhancing spatial efficiency, and supporting sustainable urban mobility networks.

Hashimi and HN (2025) examined the role of urban transportation infrastructure in promoting sustainable city design, focusing on challenges such as air pollution, traffic congestion, and rapid urbanization. They conducted a comprehensive analysis of Mysuru City's Trin Trin Public Bicycle Sharing System (PBSS) to evaluate its potential for enhancing sustainable urban mobility. Using a mixed-methods approach, the authors combined Geographic Information System (GIS) analyses with user survey data to assess operational efficiency and spatial accessibility. Network and proximity analyses quantified the connectivity of docking stations with key urban features, including transit hubs, neighborhoods, and employment centers. Simultaneously, user demographics, usage patterns, and satisfaction levels were analyzed to identify performance bottlenecks and user perceptions. Their findings indicated that the PBSS could improve last-mile connectivity and encourage non-motorized transportation, while also revealing

issues such as poor intermodal integration, spatial gaps in station coverage, and safety concerns at night. The study concluded with strategic recommendations for optimizing station locations, enhancing multimodal connectivity, and implementing safety measures to increase user engagement, offering practical guidance for policymakers to align urban mobility systems with broader sustainability goals.

Papageorgiou et al. (2024) examined the integration of Active Mobility (AM) into Intelligent Transportation Systems (ITS), addressing a gap in urban transportation planning that had largely overlooked non-motorized modes. They argued that despite the recognized benefits of walking and cycling for sustainable urban development, ITS had predominantly focused on motorized traffic, limiting opportunities to enhance urban sustainability and quality of life through AM. Drawing on recent advancements in Information Communication Technology (ICT) and Artificial Intelligence (AI), they proposed a Smart Active Mobility development framework aimed at improving accessibility, connectivity, and social inclusion for users of non-motorized transport. Their findings indicated that embedding AM into urban planning could substantially improve urban mobility, encouraging a shift toward more inclusive, environmentally friendly, and health-promoting transport solutions. The study highlighted the critical role of urban planners and policymakers in adopting such frameworks to foster sustainable, healthy, and economically viable cities.

Le et al. (2024) investigated urban traffic accidents in Hanoi, Vietnam, highlighting the significant challenges they posed to transportation infrastructure sustainability both locally and globally. They emphasized that analyzing accident data was essential to understand the relationship between accident occurrences and their causes, particularly for severe incidents. The study reportedly applied an integrated approach combining Geographic Information System (GIS) and Data Mining techniques to examine accident characteristics. Initially, the dataset was segmented into homogeneous clusters using the two-step clustering method. Subsequently, correlations between accident causes and occurrences were analyzed for the entire dataset and for each cluster using association rule mining (ARM). GIS techniques were then employed to identify accident group locations and high-frequency hotspots. Their results indicated a five-cluster model reflecting common accident groupings, detailing accident types, causes, timing, and locations. Cluster 5 primarily involved motorbike accidents on main roads, while clusters 1–4 reflected varying combinations of vehicles and roads. The study also recommended repeatability criteria for hotspot determination and proposed measures to improve traffic infrastructure sustainability, marking the first simultaneous application of these three methods in traffic accident analysis.

Droj et al. (2023) examined the evolution of urban areas, noting that cities had developed organically over time, largely driven by economic growth, but this growth had often been accompanied by negative side effects such as increased traffic, congestion, accident rates, and pollution. They highlighted that as urban populations expanded, Geographic Information Systems (GIS) had gained importance due to their capacity to collect extensive geospatial data, including human-generated information, which was essential for understanding urban complexity, setting planning priorities, solving intricate problems, and conducting spatial analyses that assessed both feasibility and alignment with sustainable city requirements. The authors demonstrated the advantages of integrating real-time traffic data with GIS and remote sensing data to evaluate the effects of infrastructure works and COVID-19 restrictions on traffic in Oradea, Romania. Their case study focused on the historical city center and utilized remote sensing data collected before, during, and after traffic limitations, ultimately emphasizing the necessity of GIS and crowdsourcing-based applications in traffic analysis and urban planning.

Ammapa et al. (2022) examined the continued expansion of urban areas as part of the broader urbanization process and highlighted the critical role of transportation as essential infrastructure facilitating this growth. They emphasized concerns regarding whether infrastructure development, particularly in transportation, was compatible with urban development. Pathum Thani province was

identified as a representative suburban area reflecting the urbanization dynamics of the Bangkok Metropolitan Region (BMR), which supported Bangkok's multi-faceted growth in economic, industrial, educational, social, and cultural aspects. The study indicated that increasing migration to suburban areas contributed to urban sprawl, while transport infrastructure investment in these areas remained insufficient. Using Geographic Information System (GIS) data and overlaying techniques, the researchers analyzed land use changes and spatial patterns of urban expansion, revealing that urban growth predominantly followed the transportation network, particularly along Phaholyothin Road. They also reported that infrastructure density increased in Mueang Pathum Thani and Khlong Luang districts and that social, economic, and environmental growth corresponded with patterns of urban expansion.

Oskarbski et al. (2021) examined the need for modelling tools and transport models to evaluate the impact of measures for effective urban cycling route planning. They presented a methodology for developing a four-stage macroscopic bicycle traffic model for the city of Gdynia and demonstrated its use in planning new bicycle routes while considering modal shifts. The study indicated that the model allowed for assessing the effects of cycling infrastructure characteristics and the development of the cycling network on the choice of cycling as an alternative mode of transport. The model accounted for factors such as longitudinal gradient, link, and surface type of cycling routes on bicycle traffic distribution and demand. Their findings suggested that planned cycling routes could reduce car traffic volume, thereby lowering energy consumption and negative environmental impacts. Experiences from applying the model in Gdynia were reported to provide a strong foundation for supporting mobility planning and monitoring processes in cities, highlighting its relevance for global urban transport system development.

Olgun (2020) examined the rapid growth of the world's population and the consequent expansion and development of urban areas, noting that this urbanization led to the diversification of transportation systems and a marked increase in the number of motor vehicles. The study highlighted that the rise in motor vehicles, aimed at fulfilling transportation needs, resulted in various urban problems. To address these issues, previous research and policy recommendations emphasized the adoption of sustainable transportation modes such as public transit, walking, and cycling. Olgun aimed to develop a sustainable bike path proposal for cities by employing GIS-based multicriteria decision-making analysis, considering physical, environmental, and visual factors. In this context, the study evaluated the city of Nigde, Turkey—a medium-sized city—through GIS-based multicriteria assessment of its physical, environmental, and visual attributes. Based on these evaluations and existing zoning plans, the research proposed a sustainable bike path design tailored to Nigde's urban landscape.

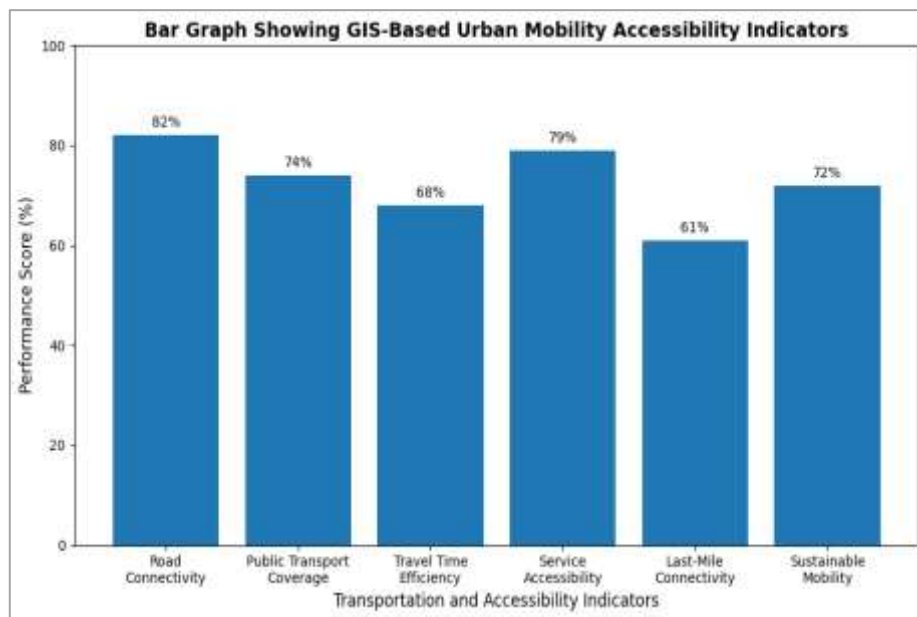
Kyriakou et al. (2019) examined urban traffic congestion as a critical issue in highly urbanized areas, highlighting its role in air pollution, economic losses from wasted time and fuel, and social inequity. They emphasized that mitigating congestion could enhance efficiency, connectivity, accessibility, safety, and overall quality of life, which are fundamental to sustainable urban mobility. The study proposed the use of spatiotemporal data provided by taxi vehicles to develop an intelligent system for predicting traffic conditions and offering navigation recommendations. GPS data from taxis in Thessaloniki were analyzed, and through data mining and map-matching processes, the most suitable data for travel time calculations and predictions were identified. Various algorithms were investigated, with Artificial Neural Networks (ANN) shown to perform best for traffic state predictions. Spatiotemporal models for individual road segments were generated using linear regression, and travel-time-based vehicle emissions were estimated. Finally, a graphical user interface was developed, offering shortest-path, fastest-path, and "eco" navigation, and its qualitative assessment indicated significant contributions to environmental protection, economic efficiency, and sustainable urban mobility.

III. METHODOLOGY

The study followed a GIS-based analytical approach to examine transportation network planning and accessibility for sustainable urban mobility development. First, relevant spatial and non-spatial data were collected, including road network maps, land-use patterns, public transport routes, bus stop locations, population distribution, major activity centres, educational institutions, hospitals, markets, and administrative areas. These data were digitized and organized in a GIS environment to create different thematic layers for detailed analysis. After data preparation, the transportation network was analyzed using GIS network analysis tools. Road connectivity, road density, shortest route, service area coverage, and travel-time patterns were examined to identify well-connected and poorly connected zones. Public transport accessibility was evaluated by measuring the distance between residential areas and nearby transport stops. Buffer analysis was used to identify areas located within accessible walking distance from public transport facilities, while underserved areas were marked as accessibility gap zones. The study also assessed access to essential services such as healthcare, education, employment centres, and commercial areas by calculating travel distance and estimated travel time from different urban zones. The results were represented through maps, tables, and graphs to compare the performance of different mobility indicators. Finally, the findings were interpreted to suggest suitable planning measures such as improving last-mile connectivity, increasing public transport coverage, optimizing routes, reducing congestion, and promoting sustainable mobility modes like walking, cycling, and public transport. This methodology helped in developing a spatially balanced and evidence-based framework for urban transport planning.

IV. RESULT

The GIS-based transportation network planning and accessibility analysis showed that spatial distribution, road connectivity, and public transport availability played a major role in sustainable urban mobility development. The analysis indicated that central urban areas had better transport accessibility due to higher road density, better route connectivity, and closer availability of public transport facilities. In contrast, peripheral and newly developing areas showed comparatively lower accessibility because of limited road links, poor public transport coverage, and longer travel distances to essential services such as schools, hospitals, markets, and employment centres. The network analysis revealed that areas located near major roads, junctions, and transit corridors had lower travel time and better movement efficiency. However, several interior residential zones faced accessibility gaps due to narrow roads, disconnected street patterns, and lack of direct public transport routes. The GIS mapping further identified congestion-prone zones where high traffic volume and poor road hierarchy reduced mobility efficiency. These locations required proper traffic management, route optimization, and improvement of alternative transport modes such as walking, cycling, and public transport. The accessibility analysis also showed that sustainable mobility could be improved by strengthening last-mile connectivity, increasing public transport stops in underserved areas, and integrating land-use planning with transport development. The result suggested that GIS tools were effective in identifying weak network links, service gap areas, shortest routes, and priority zones for infrastructure improvement. Overall, the study found that GIS-based transportation planning provided a scientific and visual approach for improving urban mobility, reducing travel time, enhancing accessibility, and supporting sustainable urban development.

Bar Graph

The bar graph presents the performance scores of key GIS-based urban mobility accessibility indicators. Road connectivity recorded the highest score at 82%, showing that the study area had a comparatively strong road network structure. Service accessibility also performed well with 79%, indicating good access to essential facilities. Public transport coverage scored 74%, while sustainable mobility achieved 72%, reflecting moderate development in eco-friendly transport planning. Travel time efficiency received 68%, suggesting the presence of congestion and route delays. Last-mile connectivity scored the lowest at 61%, showing a need for better feeder services, pedestrian paths, and improved access to public transport points.

V. CONCLUSION

The study concluded that GIS-based transportation network planning and accessibility analysis is an effective approach for improving sustainable urban mobility development. The analysis showed that road connectivity, public transport coverage, service accessibility, travel time efficiency, and last-mile connectivity strongly influence the overall performance of an urban transport system. GIS tools helped in identifying well-connected zones, underserved areas, congestion-prone locations, and accessibility gaps within the transport network. The findings indicated that central urban areas generally had better accessibility, while peripheral and newly developed zones required more attention due to weak road links and limited public transport facilities. The study also highlighted that sustainable mobility cannot be achieved only by expanding roads; it requires integrated planning of public transport, walking facilities, cycling infrastructure, and land-use development. Overall, GIS provided a scientific, visual, and data-based framework for transport decision-making. It supported route optimization, service area analysis, and priority identification for infrastructure improvement. Therefore, GIS-based planning can help urban authorities create safer, more inclusive, cost-effective, and environmentally sustainable mobility systems for future urban growth.

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