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Geospatial Innovations for Intelligent Transport and Smart Mobility Systems (ITSMS) Revolution: A narrative review

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Abstract
This review examines how geospatial innovations enhance ITSMS. The specific aim is to identify key geospatial elements and functions, including cohesive data management, cutting-edge analytics, and ethical decision-support systems, that enable innovative transport and mobility. A qualitative synthesis of literature from 2015 to 2025, as indexed in Scopus. AI and related local databases were used. Findings revealed that integrating GIS, Geospatial Artificial Intelligence (GeoAI), Global Navigation Satellite Systems (GNSS), IoT-sensing, and high-resolution technologies improves real-time traffic efficiency, accessibility, and resilience, while supporting automation and smart-city mobility initiatives. This review positions geospatial innovation as a policy-relevant foundation for sustainable ITSMS.

Keywords: GeoAI; Geoinnovation; Geospatial intelligent transport; Sustainable mobility

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1.0 Introduction

Intelligent transport and smart mobility systems (ITSMS) are key to modernising transportation. They leverage real-time data, digital connectivity, and automation for safer, more efficient, and responsive networks. Malaysia's ITS Blueprint (2019–2023), led by the Ministry of Works (KKR), officially adopts ITS as a collaborative national priority, with a focus on integration. Its goals aim for seamless mobility, reduced congestion, improved safety, optimised commercial vehicle operations, and strong inter-agency cooperation, marking a shift to interoperable, data-driven mobility governance.

Geospatial transport and mobility refers to an integrated framework of geographical data, technology, and analytical methodologies for understanding, modelling, and optimising the movement of people and products across physical and digital transportation networks. Transport is defined as the spatial flow of movement along mapped infrastructures such as roads, railways, air corridors, and active-mobility routes. In contrast, mobility expands on this concept by emphasising accessibility, efficiency, safety, and equity in reaching destinations within spatial and temporal constraints. Geospatial technologies provide critical spatial intelligence by connecting location, movement, and decision-making, enabling transportation systems to adapt efficiently to increased travel demand, environmental concerns, and limited resources.

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Geospatial innovations (geoinnovation) offer ITS with the "spatial intelligence data or layer" that it needs to flourish in the contemporary environment. Geospatial main technologies such as GNSS positioning, RS, LiDAR-derived 3D mapping, and location-based services (LBS) support the entire ITS pipeline, from sensing and situational awareness to prediction, optimisation, and targeted interventions. Geospatial intelligence, when integrated with big data platforms, IoT sensor networks, and AI analytics, may accomplish tasks such as identifying and alleviating traffic jams, mapping incidents and hazards, changing routes on the fly, providing travellers with information, and monitoring compliance for freight and commercial vehicles. Malaysian ITS initiatives have shown that integrated data centres and federated data sources (such as highway operators, local authorities, and public transport operators) are needed for "smart mobility" to work, showing that "smart mobility" is not only a technological upgrade, but also a challenge for institutions and data governance.

The integration of geospatial technologies with ITS in contemporary transportation systems enables data-driven connectivity, automation, and real-time operational awareness (Dovis et al., 2020; Khoramshahi et al., 2025; Li & Qiao, 2025). These capabilities enable transport authorities to assess traffic dynamics, infrastructure performance, safety hazards, and environmental implications within a single geographic framework. Beyond technological applications, geospatial transport systems also address governance and ethical concerns, such as data protection, security, interoperability, and equitable access. These elements are becoming more important for creating inclusive, trustworthy, and sustainable mobility ecosystems, establishing geospatial intelligence as a strategic basis for transportation policy, planning, and long-term mobility development (Butler et al., 2020; Noh, 2024).

The study objectives are to (i) delineate the principal geospatial functions relevant to transport and mobility applications; (ii) qualitatively investigate how geoinnovation fosters intelligent transport and smart mobility (Butler et al., 2020; Noh, 2024; Tenzer et al., 2023). This review would provide a comprehensive understanding of the field by integrating end-to-end geospatial pipelines, from sensing to decision-making. It connects international best practices with Malaysia's practical experiences, offering valuable insights for researchers, practitioners, and policymakers. Geospatial innovation is not merely a technological advance, but a key part of creating innovative, sustainable, and resilient mobility futures.

2.0 Literature Review

Cities worldwide are facing mounting challenges in meeting the growing demands for safe, efficient, and sustainable transport and innovative mobility. Increasing travel demand, climate pressures, and constrained resources have created an urgent need for transportation systems that are not only operationally efficient but also resilient and equitable. From a geospatial perspective, transport refers to the spatial movement of people and goods across mapped networks, while mobility reflects accessibility and the efficiency of that movement. The integration of geospatial data and analytics within ITS has therefore emerged as a transformative approach for improving decision-making, safety, and service delivery through intelligent, data-driven connectivity and automation (Dovis et al., 2020; Li & Qiao, 2025).

Over the past decade, geospatial technologies have revolutionised the design, monitoring, and management of transportation systems. The convergence of GIS, GNSS, GeoAI, and Mobility-as-a-Service (MaaS) represents one of the most significant paradigm shifts in modern mobility management (İnce, 2025; Li & Qiao, 2025). These technologies provide real-time insights for planning, navigation, and infrastructure optimisation while enabling data integration across diverse transport networks. GIS supports spatial visualisation, network mapping, and multi-layered analysis of environmental and socio-economic data (Tayi et al., 2024), while GNSS ensures high-precision positioning for route optimisation and fleet tracking (Dovis et al., 2020). Complementing these, Mobile Mapping Systems (MMS) and remote sensing (RS) deliver high-resolution, time-stamped spatial data crucial for modelling road conditions, hazards, and urban dynamics (Khoramshahi et al., 2025).

Despite these advancements, several research and practical gaps remain. Much of the global scholarship focuses on technical performance or single-technology solutions, often overlooking integration across sensing, data management, analytics, and operational service layers in a geospatial perspective. The growing scale and velocity of geospatial data have introduced new computational challenges in indexing, fusion, and retrieval. At the same time, model generalisation across urban contexts remains limited, as algorithms trained in one city often perform poorly in another due to differences in land use, sensing density, and demand patterns (Tenzer et al., 2023). Moreover, governance and ethical dimensions such as data privacy, security, and equitable access are increasingly critical for ensuring trusted and inclusive smart mobility (Butler et al., 2020; Noh, 2024).

Within this global transformation, Malaysia provides a compelling case for observing geospatial innovation in action. Applications such as GeoAI-driven base-map routing generation (Jaafar et al., 2024), spatial-human perception analysis of the LRT3 project (Abdullah et al., 2024), and GIS-based natural disaster detour modelling (Abdul Rasam et al., 2023) exemplify localised yet globally relevant solutions. Further examples include active-mobility cartography for cycling networks (Mustapha et al., 2023; Billy et al., 2025), road accessibility studies in gated communities (Adnan et al., 2023), and participatory GIS initiatives linking mobility to public health (Jalil & Rasam, 2024). The Malaysian Intelligent Transport System Blueprint 2019–2023 has also been developed by the Ministry of Works (2019) to guide the deployment, integration, and collaboration of ITS across Malaysia.

Given the rapid expansion of literature across ITS, GeoAI, and smart-city mobility from 2015 to 2025, a narrative synthesis is both timely and necessary. Fragmented research has created conceptual overlaps that require consolidation and comparative evaluation (İnce, 2025; Zaroujtaghi et al., 2025). Emerging frontiers, such as Urban Air Mobility (UAM), cooperative vehicle-to-everything (C-V2X), and digital twins, are transitioning from conceptual models to practical deployment, demanding comprehensive assessment (Lee & Cho, 2025; Wang et al., 2025). However, no existing review systematically examines how geospatial innovation enhances intelligent transport and mobility, particularly in Malaysia's evolving transport landscape, from an empirical spatial perspective (Jaafar et al., 2024; Mustapha et al., 2023).

3.0 Methodology: Narrative Search Strategy

This narrative review employed a qualitative synthesis approach to explore the intersection of geospatial technologies, ITS, and mobility solutions. Relevant literature was retrieved from major academic databases, including Scopus AI, Web of Science, and ProQuest, covering the period 2015 to 2025, officially provided by UiTM. The search utilised a combination of key terms, including "geospatial technologies," "intelligent transportation systems," "mobility solutions," "urban transportation," and "geoinnovations." The selection criteria focused on peer-reviewed journals and proceedings articles published in English, emphasising studies with direct relevance to geospatial innovations and their applications in intelligent transport and mobility contexts. The collected literature was then reviewed to identify key themes, conceptual developments, and emerging research directions within the domain, as stated in the objectives, namely principal geospatial functions and geoinnovation applications in ITSMS.

4.0 Findings and Discussion

4.1 Key Functions of Geospatial Innovations in Transport and Mobility Systems

Geospatial technologies form the foundation of modern intelligent transport and mobility systems by integrating spatial data acquisition, processing, and analytics to enhance decision-making and optimise transportation and mobility performance. These technologies include GIS, GNSS, RS, Light Detection and Ranging (LiDAR), and others, each serving specific roles in spatial data management (Gupta & Bhatnagar, 2024) as shown in Fig. 1. GIS enables real-time spatial visualisation and analysis, supporting urban planning, environmental monitoring, and transportation management, while GNSS delivers high-precision positioning crucial for automated navigation, fleet monitoring, and autonomous driving. GeoAI (such as RS, LiDAR, UAV, AI) techniques facilitate large-scale mapping of road networks, land-use patterns, and infrastructure dynamics, offering a continuous flow of data for transport analytics and planning (Lu et al., 2022). Collectively, these components enable dynamic, data-driven decision-making and predictive modelling for mobility systems.

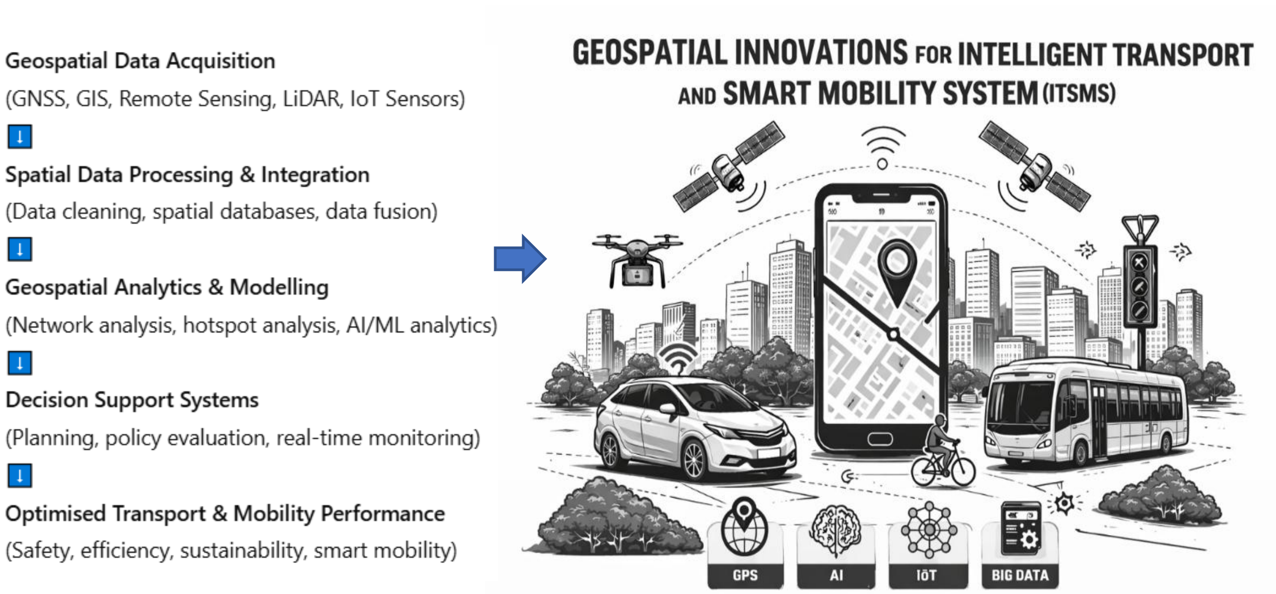

Fig. 1: Geospatial Innovations in Intelligent Transport and Mobility Systems Revolutions

The integration of AI and Machine Learning (ML) with geospatial data or GeoAI has further transformed transport analytics by converting spatial datasets into actionable intelligence. GeoAI supports functions such as mode detection, traffic forecasting, connectivity assessment, and risk prediction, advancing the precision of transportation models (Li & Qiao, 2025). Moreover, AI-based predictive algorithms help optimise congestion control, route planning, and scheduling in public transportation systems. Similarly, the incorporation of GNSS-RTN technology allows continuous, centimetre-level location tracking for automated navigation and intelligent routing. These innovations make transportation systems not only more efficient but also more adaptive to real-time conditions.

Recent advancements in MMS have revolutionised spatial data collection and three-dimensional modelling for transport networks. MMS combines GNSS, LiDAR, and imaging sensors to generate high-resolution, georeferenced road models, which are essential for asset management and safety monitoring (Khoramshahi et al., 2025). Additionally, GIS-based simulation models have enhanced urban traffic visualisation and infrastructure planning, evolving from basic cartographic mapping to advanced ITS applications such as LBS, Advanced Driver Assistance Systems (ADAS), and autonomous vehicle control. Sustainable mobility initiatives have also benefited from these technologies through the integration of electric vehicles (EVs), MaaS, and shared mobility platforms, all of which rely on geospatial analytics for network optimisation (Cui et al., 2025; Butler et al., 2020). In essence, the convergence of geospatial technology with AI and automation is redefining transport systems as intelligent, adaptive, and sustainable networks.

4.2 Geoinnovation for Intelligent Transport and Smart Mobility Systems

From a geospatial perspective, transport refers to the spatial flows of people and goods, while mobility encompasses accessibility, ease of movement, and socio-economic factors that influence travel. ITS leverages geospatial, information, and communication technologies to integrate these dimensions into innovative, responsive mobility ecosystems. ITS incorporates subsystems such as Advanced Traveler Information Systems (ATIS), Advanced Traffic Management Systems (ATMS), ADAS, and Advanced Fleet Management Systems (AFMS), all aimed at enhancing safety, efficiency, and sustainability (Avcı & Koca, 2024; Wang et al., 2025; Cordoș et al., 2025). These systems enable adaptive cruise control, automated routing, collision avoidance, and multimodal integration, facilitating coordinated, safer travel decisions across networks.

Geospatial technologies also play a pivotal role in the development and operation of smart mobility. GIS supports the construction of detailed spatial models for route optimisation, traffic monitoring, and emergency management. Meanwhile, MMS and RS technologies support asset maintenance and infrastructure mapping through continuous spatial updates. Web-based GIS and crowdsourced data are emerging as cost-effective tools for real-time feedback and participatory mobility planning (Avcı & Koca, 2024). Moreover, geospatial approaches underpin resilience and sustainability efforts by identifying transport accessibility gaps, supporting hazard mapping, and aiding disaster evacuation planning. The integration of these technologies in ITS enhances data-driven governance and ensures that transport infrastructure evolves in tandem with urbanisation trends and sustainability imperatives.

4.3 GeoAI for Smart-City Mobility Initiatives

The enhancement of smart mobility initiatives such as ITS through geospatial innovation occurs through two primary mechanisms: technological integration and empirical validation. Technological integration involves merging geospatial analytics with AI, IoT, and big data systems to produce intelligent, adaptive transport solutions. Connected vehicles, smart sensors, and real-time communication networks generate vast geospatial data streams. When processed through AI-based predictive analytics, these datasets enable real-time traffic forecasting, adaptive signal control, and personalised travel services (Mai et al., 2025). For example, route optimisation tools integrated with GIS and IoT technologies allow logistics operators to reduce fuel consumption and emissions while improving delivery efficiency. Similarly, AI-assisted ITS applications optimise public transport scheduling and prioritise routes during emergencies.

Empirical case studies confirm that cities utilising GIS-enabled ITS have experienced measurable improvements in congestion mitigation, safety enhancement, and travel-time reliability. Real-time data analytics within urban control centres enable adaptive signal coordination and congestion forecasting, leading to more efficient traffic flow (Wu et al., 2025). Furthermore, integrating mobile mapping and participatory GIS enhances community involvement in transport design, aligning infrastructure development with user needs. Through these advancements, geospatial innovation emerges as a critical driver of more innovative, more equitable, and sustainable mobility ecosystems that respond dynamically to user demand, environmental change, and policy priorities.

GeoAI advances smart-city mobility projects by using AI and geospatial data to create intelligent, adaptable, and real-time transportation solutions. GeoAI enables traffic prediction, route optimisation, micromobility management, and safety improvement by analysing large amounts of spatial data from IoT sensors, GNSS, and mobile mapping systems. These skills help make urban transportation systems more sustainable, user-centric, and data-driven.

4.4 Case Snapshots

Globally, smart cities use GIS and ITS technologies to improve multimodal mobility, traffic control, and public transportation efficiency. Platforms like Singapore's LTA DataMall and Helsinki's MaaS use real-time geospatial data to optimise routes and reduce congestion. Malaysia's ITS Blueprint, adaptive traffic lights, and ATMS programs all demonstrate similar advances in data-driven traffic management (KKR, 2019). Developed cities use C-ITS, V2X, and MaaS to improve network performance. In contrast, Poland's AI- and IoT-enabled systems, as well as South Korea's UAM mapping, demonstrate geospatial innovations that improve accessibility and sustainability worldwide.

Geospatial technologies in Malaysia support transport and mobility planning by integrating infrastructure, risk, and user behaviour. GeoAI speeds up base-map updates and asset detection for the smart built environment, resulting in better network inventory for planning and operations (Jaafar et al., 2024). Spatial perception study surrounding LRT3 identifies local environmental problems and informs equitable mitigation near stations (Abdullah et al., 2024). For resilience, multi-criteria and least-/spatial-cost path models identify flood detours and critical route continuity (Abdul Rasam et al., 2023) and map transmission-suitability corridors to regulate movement during disease outbreaks (Jalil & Rasam, 2024).

Aside from that, landslide susceptibility, combined with network mapping, enables preventive rerouting in hilly corridors (Abdul Rasam et al., 2023). Active-mobility cartography informs the design of bike infrastructure and park routes (Mustapha et al., 2023; Billy et al., 2025). Neighbourhood studies link road accessibility and safety in gated versus non-gated neighbourhoods to design standards (Adnan et al., 2023), whereas proximity assessments near schools' link traffic exposure to operational decisions and safer curb management. Finally, participatory GIS connects lifestyles and health, emphasising people-centered mobility measures alongside engineering performance (Adnan et al., 2023; Abdul Rasam et al., 2023).

Despite significant advancements, geospatial applications in transportation face ongoing data, technological, and ethical issues. High-velocity, varied urban traffic data place a burden on spatial indexing, storage, and retrieval systems, limiting their real-time performance. Data interoperability remains problematic due to differences in formats, spatial resolutions, and domain shifts, which impede cross-city model transferability. AI-driven analytics and unsecured service layers pose ethical and privacy problems. Furthermore, discrepancies in accessibility exist for marginalised groups and rural locations (Tayi et al., 2024; Noh, 2024). To overcome these limits, researchers need standardised data frameworks, privacy-preserving geospatial analytics, and equity-first mobility regulations (Butler et al., 2020).

5.0 Conclusion

This review demonstrates that geospatial innovations have become integral to the development of intelligent, equitable, and sustainable transport and mobility systems. By synthesising a decade of global and Malaysian evidence, the study highlights how GIS, GeoAI, GNSS, and related Geo-IoT integration enhances real-time traffic management, accessibility, and hazard resilience. These technologies enable informed decision-making and support automation, electrification, and Mobility-as-a-Service (MaaS) models. Despite challenges in data heterogeneity, privacy, and model generalisation, geospatial frameworks continue to evolve as enablers of connected, safe, and efficient mobility ecosystems. In Malaysia, their application across natural disaster routing, cycling infrastructure, and smart-city operations demonstrates substantial practical value. Moving forward, equitable geospatial data governance and cross-city benchmarking are essential to sustain trust and scalability. Ultimately, geospatial innovation is not only a technological evolution but also a strategic pathway toward inclusive, resilient, and intelligent transport and smart mobility futures that align with global sustainability and digital-transformation goals.

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Paper Contribution to the Related Field of Study

This review advances the field of intelligent transportation by synthesising how geospatial innovations strengthen intelligent transport and smart mobility systems (ITSMS). It highlights significant geospatial components, including spatial decision-support systems that improve real-time monitoring, prediction, and adaptive transport operations; integrated GIS-based data management; GeoAI-enabled analytics; and accurate GNSS positioning. Furthermore, the study emphasises data privacy, equitable access, and ethical governance as key elements of geospatial decision-making. This work supports national ITS agendas, low-carbon initiatives, and evidence-based planning for resilient and inclusive mobility futures in Malaysia by framing geospatial innovation as a policy-relevant foundation for green mobility and sustainable transportation.

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