

A Systematic Review of GIS Evolution in Transportation Planning: Towards AI Integration

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Abstract

Previous reviews have examined specific facets of Geographic Information Systems (GIS) in transportation planning, such as transit-focused applications and open source geospatial tools. However, this study offers the first systematic, PRISMA-guided longitudinal evaluation of GIS integration in transportation planning, spanning thematic domains, data models, methodologies, and outcomes from 2004 to 2024. This study addresses this gap through a longitudinal analysis of GIS-based transportation research from 2004 to 2024, adhering to PRISMA guidelines. By conducting a mixed-methods analysis of 241 peer-reviewed articles, this study delineates major trends, such as increased emphasis on sustainability, equity, stakeholder involvement, and the incorporation of advanced technologies. Prominent domains include land use–transportation coordination, accessibility, artificial intelligence, real-time monitoring, and policy evaluation. Expanded data sources, such as real-time sensor feeds and 3D models, alongside sophisticated modeling techniques, enable evidence-based, multifaceted decision-making. However, challenges like data limitations, ethical concerns, and the need for specialized expertise persist, particularly in developing regions. Future geospatial innovations should prioritize the responsible adoption of emerging technologies, inclusive capacity building, and environmental justice to foster equitable and efficient transportation systems. This review highlights GIS’s evolution from a supplementary tool to a cornerstone of data-driven, sustainable urban mobility planning, offering insights for researchers, practitioners, and policymakers to advance transportation strategies that align with equity and sustainability goals.

Keywords: GIS; transportation planning; land use integration; sustainable mobility; environmental justice; data analytics; emerging technologies



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1. Introduction

The landscape of transportation planning is undergoing a paradigm shift with the integration of cutting-edge technologies and analytical methodologies. Over the past few decades, GIS have emerged as invaluable tools in this transformation [1–3]. As GIS capabilities have expanded alongside emerging data sources and methodologies, the application of GIS in transportation planning has undergone substantial evolution [4,5].

GIS methods facilitate the effective handling of extensive datasets and the modeling of urban spatial patterns, integrating ecosystem services derived from natural systems [6,7]. While earlier reviews, such as GIS applications in transit planning [8] and open source geospatial tools [9], have offered valuable perspectives on specific GIS for transportation (GIS-T) applications, this study provides a comprehensive, longitudinal synthesis spanning multiple dimensions. Despite significant advancements, a systematic review analyzing focus areas, data models, methods, and outcomes in GIS-transportation planning is absent. This review aims to fill this gap by providing a holistic longitudinal analysis of GIS-transportation planning scholarship and practice.

The integration of GIS into transportation planning began to gain momentum in the late 20th century, particularly during the 1990s, with the widespread adoption of ArcGIS software [10,11]. The foundational work by Miller and Shaw [12], provided a critical framework for GIS-T, focusing on network analysis, spatial data management, and transportation modeling. Similarly, Thill [13] emphasized the role of GIS in enhancing transportation research through spatial analysis techniques. In the early 21st century, the GIS-T field underwent significant transformation, propelled by advancements in data acquisition, storage, processing, and communication technologies [9]. Despite these developments, their [12,13] works remains a key reference, highlighting the need for an updated framework that incorporates emerging technologies such as artificial intelligence, the Internet of Things, and real-time data analytics, as explored in this review [14].

This systematic review investigates key domains, data types, methods, and findings in GIS-transportation planning research from 2004 to 2024, a period marked by significant GIS adoption following ArcGIS 9.0's release [11]. The aim is to elucidate evolving priorities and capabilities shaping GIS integration in transportation planning. Specifically, this review addresses four objectives:

1. Examine evolving thematic domains and subdomains to identify trends in research focus.
2. Analyze motivations and goals to uncover priorities driving GIS-transportation studies.
3. Assess developments in data types and sources to highlight expanding capabilities.
4. Synthesize methods and findings to demonstrate analytical advances and contributions.

Addressing these four objectives facilitates a multidimensional perspective across critical facets, enabling a comprehensive investigation of the trajectory of GIS-transportation research over the past 20 years. The insights gained inform contemporary emerging directions and growth areas within this rapidly developing field at the intersection of GIS, spatial analysis, and transportation planning.

To achieve the stated objectives, this review employs a rigorous systematic methodology aligned with PRISMA guidelines for conducting literature reviews. This encompasses a structured search process, applying inclusion/exclusion criteria, and extracting/analyzing information from the identified articles. The analytical framework focuses on examining developments across key parameters: domains and subdomains, objectives, data models, methods, and findings. By tracking these facets over time, the quantitative and qualitative assessment reveals impactful shifts and trends in the evolution of GIS-transportation planning scholarship.

This study yields insights into the changing role of geospatial analytics in transportation planning, leading to discussions around emerging technologies, policy directions, and future outlooks for this critical field. This review's transparent, reproducible systematic methodology and multidimensional analytical lens offers a useful foundation for elucidating meaningful developments in GIS-transportation integration to inform contemporary research and practice.

Prior reviews have examined specific dimensions of GIS in transportation planning, such as transit-focused applications [8] or open source geospatial tools [9], but none

have comprehensively traced the evolution of GIS across thematic domains, data models, methodologies, and outcomes over an extended timeframe. For example, Sutton [8] concentrated on GIS in transit planning, and Lovelace [9] highlighted open source tools, yet neither offered a broad, longitudinal perspective. This study fills this gap through a PRISMA-guided analysis of 241 peer-reviewed articles spanning 2004 to 2024, exploring trends in sustainability, equity, and advanced technology integration to guide future GIS-T research and practice.

2. Methodology

This study adopts a systematic methodology based on PRISMA guidelines to investigate trends in GIS-based transportation planning research. A thorough literature search was conducted in February 2025 using the Web of Science database, chosen for its extensive collection of high-impact, peer-reviewed journals in GIS and transportation planning, as well as its reliable indexing and citation tracking features. Keywords such as “GIS”, “transportation planning”, “urban mobility”, “land use”, and “geographic information systems” were combined with Boolean operators to form the search strategy (Table 1).

Table 1. Components of search formula.

Item	Sub-Item	Details
Keywords	Main keywords	GIS, transportation planning, urban mobility, geographic information systems
	Supplemented keywords	Land use, mobility, transportation geography, spatial analysis, network analysis, transport modeling, smart cities, sustainability, equity
Operators		“OR”, “AND”
Time period		February 2004–February 2024
Language		English
Document type (included)		Journal paper
Document type (excluded)		Excluded document types include conference proceedings, non-peer-reviewed articles, book chapters, government or consulting reports, preliminary papers, and theses/dissertations
Inclusion criteria		Articles employing GIS techniques/analysis for urban transportation planning
Exclusion criteria		Studies focused solely on rural or regional transportation planning, studies not substantially involving GIS
		Non-English studies were omitted from the evaluation process
Date of search		Sunday, 16 February 2025

The search yielded over 700 records, which were evaluated against predefined inclusion and exclusion criteria. Studies were included if they applied GIS techniques to urban transportation planning. Articles focusing solely on regional or rural transportation planning or those with minimal GIS analysis were excluded. Non-English publications were also excluded due to resource limitations and the need for uniform analysis by English-speaking reviewers, though this may introduce bias, particularly in developing regions where local-language studies might capture context-specific GIS-T applications.

Following the screening, 241 articles were chosen for in-depth review. These articles cover a diverse range of geographical contexts, offering insights into global developments. They were published over a span of 20 years, from 2004 to 2024.

Two independent reviewers conducted a thorough review of the full texts of these articles, resolving any disagreements through discussion. Pertinent information was extracted, encompassing details about the studies’ locations, objectives, methodologies, data sources, findings, and other relevant parameters.

This study employs a multidimensional framework to systematically examine trends in GIS-transportation planning research from 2004 to 2024, following PRISMA guidelines, as illustrated in Figure 1. The comprehensive search and selection process (Figure 1) identified 241 eligible studies from an initial pool of 741 records, providing a robust foundation for trend analysis across multiple dimensions. The analytical framework facilitates the systematic examination of developments across key facets including thematic domains, subdomains, research objectives, methodological approaches, data models, and empirical findings. Tracking domains and subdomains reveal shifting priorities and focus areas in applying GIS-based techniques to transportation planning challenges. Analyzing research objectives provides perspective on evolving goals and motivations driving scholarly inquiry in this field. Assessing methodological approaches and data models highlights analytical and technological advances enabling new capabilities in geospatial transportation analysis. Synthesizing key findings across the 241 included studies illustrates the collective contributions and outcomes of two decades of research. By taking a holistic approach across these critical dimensions, the pattern analysis yields rich, nuanced insights into the trajectory of GIS-transportation scholarship. The systematic review methodology, detailed in the PRISMA flow diagram (Figure 1), and documented in the PRISMA 2020 Checklist [15], ensures comprehensive coverage while the multidimensional analytical framework elucidates changing research needs, emerging technological opportunities, and overall disciplinary progression. Quantitative techniques help summarize statistical trends in this evolution, while qualitative synthesis provides contextual understanding of methodological transitions. Ultimately, this multidimensional framework, applied to the systematically selected corpus of 241 studies, enables a comprehensive vantage point to thoroughly investigate advances in integrating GIS and transportation planning over the past twenty years.

By systematically reviewing these 241 articles through a rigorous process, this study establishes a foundation for a comprehensive analysis in line with PRISMA guidelines. The methodology ensures transparency, reproducibility, and a thorough perspective on the advancements in GIS-based transportation planning research between 2004 and 2024. The insights gained from this analysis inform future directions and growth areas within this field.

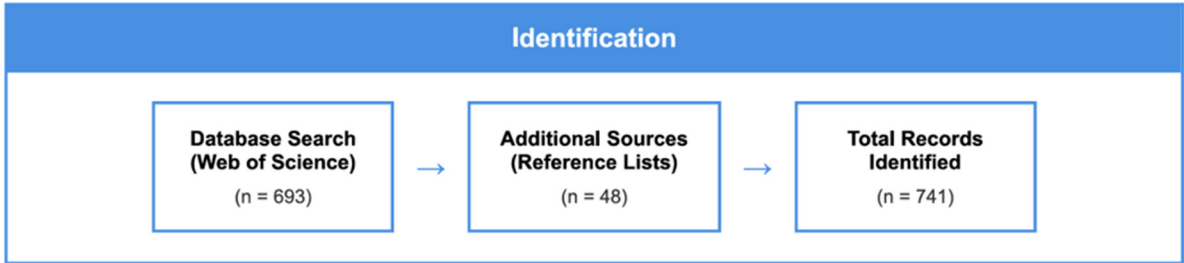


Figure 1. Cont.

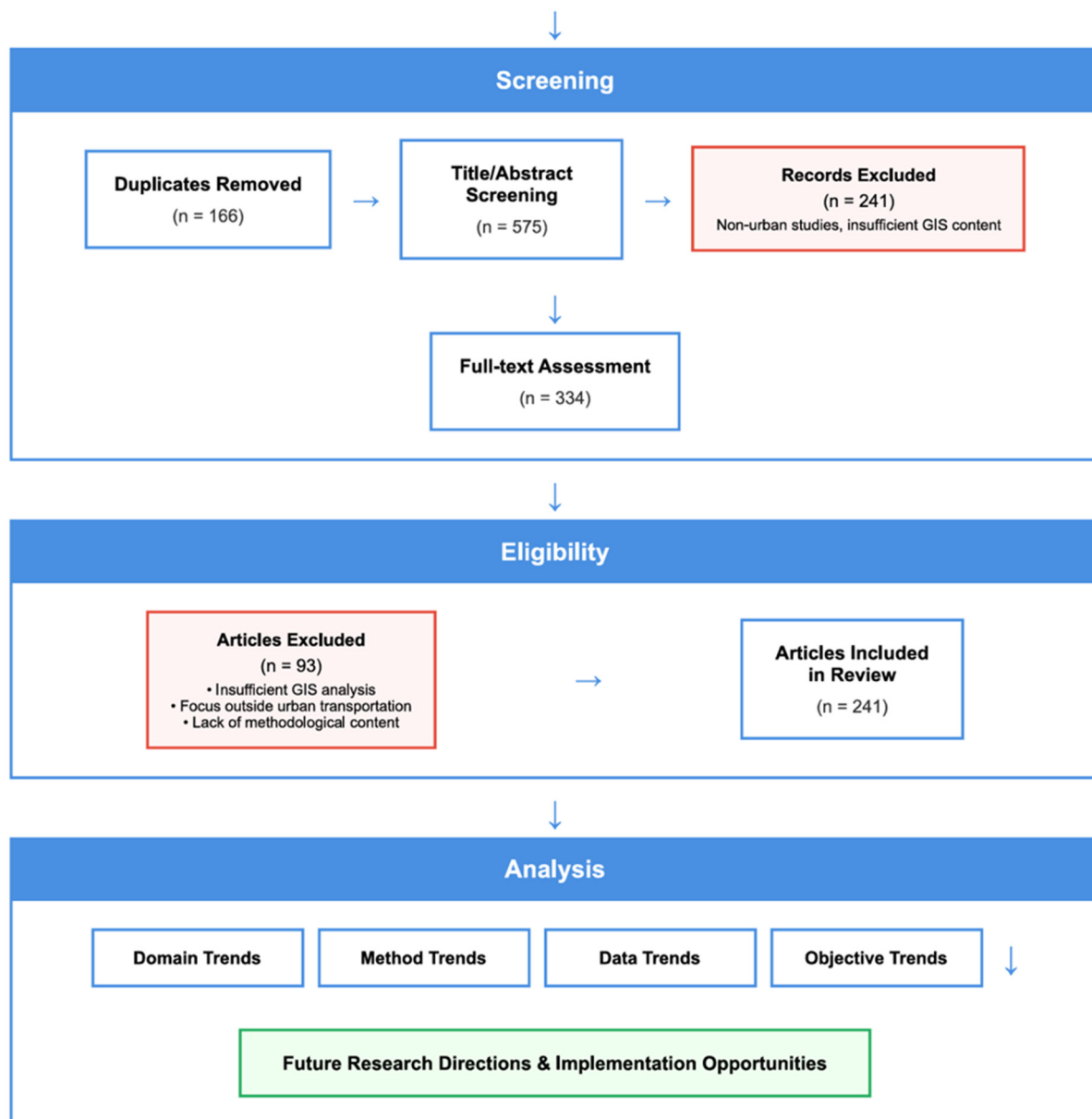


Figure 1. PRISMA flow diagram of the study selection process.

3. Trend Analysis

3.1. Trends in Research Domains

Over the past 20 years, research in GIS for transportation (GIS-T) has evolved from fundamental spatial analysis to encompass a wide range of domains, highlighting priorities such as sustainability, equity, and technological advancements (Table 2). The most prevalent domain, land use–transportation integration, accounts for 30% of studies and focuses on coordinating urban planning with transportation networks. Subdomains, such as environmental impact assessment, have become increasingly prominent [16–18]. As shown in Table 2, land use and transportation integration was the most frequently occurring domain, with geographic equity analysis, environmental impact assessment, and public participation and stakeholder engagement as the top subdomains [1,17,18]. Transit planning and analysis and geographic equity analysis were also frequent domains [8,19]. While the absolute frequencies vary, land use and transportation integration occurred about three times as often as transit planning and analysis, the second most common domain. Geographic equity analysis occurred nearly twice as frequently as the third most common

domain, public participation and stakeholder engagement [1]. The data show land use and transportation integration is the predominant focus area, with equity and environmental considerations as common sub-topics [20–22]. Transit planning is also addressed regularly [8], while public engagement and emergency response planning occur less frequently [18,23]. This indicates an emphasis on integrating transportation infrastructure with land use through an equity lens, while also working to expand public transit access.

Table 2. Summary of major domains and subdomains and key focus trends in GIS-transportation research.

Domain	Estimated Frequency (% of Studies)	Subdomains	Key Focus	Temporal Trends (2004–2024)	References
Land Use–Transportation Integration	30% (~72)	Land use–transportation integration, environmental impact assessment	Aligning spatial planning with transport networks	Consistently dominant, increasing focus	[16]
Geographic Equity Analysis	15% (~36)	Accessibility, social inclusion	Ensuring equitable access	Growing post-2010	[1,24]
Transit Planning and Analysis	10% (~24)	Transit network optimization	Enhancing public transit efficiency	Steady, with multimodal focus	[8,19]
Public Participation	7.5% (~18)	Community involvement	Inclusive decision-making	Increasing with participatory GIS	[25]
Sustainability	5.4% (~13)	Environmental impact assessment	Mitigating ecological footprint	Rising focus on environmental metrics	[22]
Non-Motorized Planning	5.4% (~13)	Active transportation planning	Enhancing walkability and bikeability	Growing with urban health trends	[26]
Intelligent Transportation Systems	5.4% (~13)	ITS adoption	Real-time traffic management	Emerging post-2015	[27]
Peri-Urban Structure Plans	5.4% (~13)	Peri-urban mobility planning	Connectivity in transitional areas	Emerging recently	[28]
Multi-Criteria Decision Analysis	5.4% (~13)	Decision support systems	Optimizing infrastructure choices	Increasing with complex projects	[29]
Technological Advancements	5.4% (~13)	Network optimization	Leveraging AI and IoT	Rapid growth	[30]
Emergency Response Planning	5.4% (~13)	Disaster mobility planning	Supporting crisis scenarios	Increasing with resilience focus	[31]

As illustrated in Table 2 and Figure 2, the prominence of land use–transportation integration underscores its vital role in sustainable urban planning, with emerging domains such as intelligent transportation systems and peri-urban planning gaining momentum after 2015 [27,28]. Scholars increasingly acknowledge the interconnectedness of land use and transportation, prioritizing coordinated strategies to foster sustainable and efficient mobility systems. This focus is evident in subdomains, where land use–transportation integration remains a consistent priority. More recently, domains such as peri-urban

structure plans and intelligent transportation systems (ITS) have gained prominence, accompanied by advanced methodologies like graph neural networks (GNNs) for traffic assignment [32–34], reflecting their growing significance in GIS-based transportation planning. ITS adoption is also apparent in subdomains, demonstrating the evolving role of GIS in transportation operations and infrastructure enabled by new technologies. Another major domain is geographic equity analysis, which has gained more attention as studies assess spatial disparities in access to examine the equity implications of transportation policies [1,24]. Related subdomains around justice, accessibility, and social inclusion have also arisen [23,35]. Public participation and stakeholder engagement have become integral domains as well, to foster inclusive planning processes [23]. This aligns with subdomains focused on community involvement in decision-making [25,36,37]. Sustainability-related domains are increasingly prominent, using GIS to evaluate and mitigate transportation’s environmental footprints [22,36]. Similarly, subdomains on environmental impact assessment have emerged [29,38]. Active transportation and non-motorized planning remain enduring domains and subdomains, reflecting goals to create walkable and bikeable urban environments [26]. Finally, the incorporation of network optimization, real-time monitoring, and traffic management demonstrates the growing role of technological advancements in enhancing system efficiency and mobility [27].

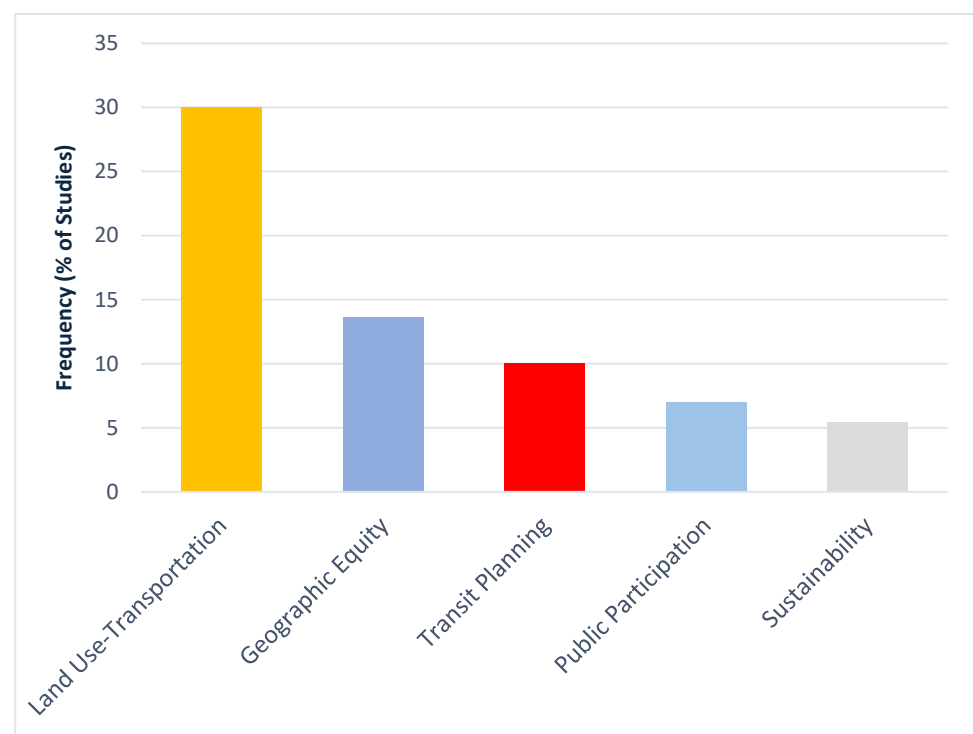


Figure 2. GIS-transportation research domain (2004–2024).

Table 2 provides a summary of major domain and subdomain trends and key focus areas.

3.2. Trends in Research Objectives

The research objectives involving GIS-based transportation planning have evolved considerably over the past two decades. In the early years, many studies focused on technical aspects of GIS and transportation planning including developing foundational GIS databases, systems, and models to support transportation analysis and planning. For instance, objectives included creating GIS databases of transport infrastructure [39], developing travel demand forecasting models [40], and optimizing routing and facility location

problems [41]. Additionally, some initial research explored web-based GIS applications for engaging stakeholders in transportation planning [42]. However, the scope was limited primarily to technical GIS capabilities for core transportation analysis [39].

From the mid-2010s, objectives expanded to address land use interactions, urban growth, and traffic management, moving beyond isolated transportation issues [43]. For example, studies aimed to model land use impacts on transport demand and congestion patterns [17]. The objectives also shifted towards multimodal network analysis, instead of just roads, to incorporate transit, cycling and walking [8–19].

Recently, emerging technologies have increasingly driven GIS-based transportation research objectives. For instance, studies have focused on integrating intelligent transportation systems, AI, and machine learning to enable real-time monitoring, dynamic predictions, and optimized operations [30]. Furthermore, social equity considerations came into focus, with objectives around accessibility and spatial disparity analysis [23,24]. Resilience also grew as a priority, using GIS to support disaster management and climate adaptation [31].

In recent years, comprehensive policy and scenario assessments have emerged as key objectives, supported by advanced GIS modeling [6]. Data-driven planning objectives are also increasing, leveraging big data sources to gain multidimensional insights through spatial analysis techniques like machine learning [44]. Immersive technologies have entered the fray as well, with studies aiming to develop VR and computer vision systems for transportation planning and modeling. These trends are summarized in Figure 3, which provides an overview of the key shifts in research objectives related to GIS in transportation planning between 2004 and 2024.

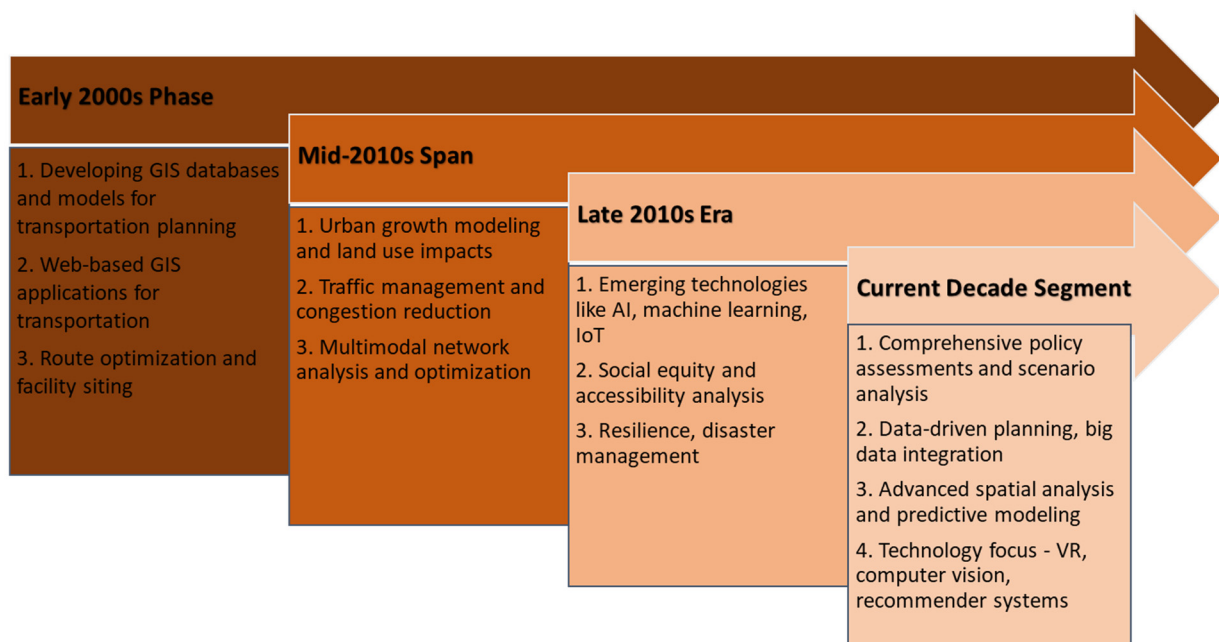


Figure 3. Shifting priorities in GIS-transportation planning research objectives (2004–2024).

GIS-transportation research objectives have substantially expanded over the past 20 years, from a narrow technical focus to encompassing diverse emerging priorities around sustainability, equity, engagement, technology integration, and data-driven policy assessments. As urban transportation challenges evolve, GIS-based planning is increasingly valued for its ability to provide holistic evidence to guide decisions through integrated spatial analysis. The progression of research objectives reflects this growing multifaceted role of GIS in enabling comprehensive, collaborative, and technologically integrated transportation planning.

3.3. Trends in Methodological Approaches and Models

Over the past 20 years, the methods and models used in GIS-transportation planning research have undergone significant evolution, transitioning from basic spatial analysis techniques towards more advanced, multifaceted approaches. While fundamental methods like network and accessibility analysis have remained core tools for evaluating transportation infrastructure and flows [45], the integration of new techniques has expanded the scope and capabilities of GIS-transportation. In particular, geographic equity analysis has become more widely adopted to ensure equitable community access [1,24], and public participation methods now enable collaborative stakeholder engagement in planning decisions [25]. Concurrent technological advances have also allowed the incorporation of data-driven techniques like machine learning and visualization to provide enhanced dynamic insights for analysis and monitoring [46,47]. Traditional models such as travel demand forecasting models remain in use [48], but newer approaches, including end-to-end heterogeneous graph neural networks for traffic assignment [32] and graph neural networks for seismic retrofit planning with a focus on equity [49], are increasingly adopted. These developments highlight a GIS’s capacity to tackle intricate network dynamics and promote fairness in transportation planning [23]. The proliferation of these innovative new methods and models highlights the growing complexity of urban transportation challenges, and the need for integrated solutions that leverage advanced GIS capabilities to address contemporary priorities [50]. Overall, GIS-transportation has transitioned from limited siloed techniques to more collaborative, technologically integrated, and equity-focused approaches that provide a multifaceted systems perspective to tackle evolving transportation needs. Table 3 summarizes the evolution of methods and models used in GIS-transportation planning research between 2004 and 2024.

Table 3. Evolution of methods used in GIS-transportation planning research (2004–2024).

Year	Key Methods	Key Models	References
Early 2000s Phase	Network analysis, route optimization, spatial analysis	Network optimization models, travel demand forecasting models, land use–transportation integration models	[25,51]
Mid-2010s Span	Land use–transportation integration, geographic equity analysis, non-motorized planning, public participation	Geographic equity analysis, travel demand forecasting, transit evaluation models	[52,53]
Late 2010s Era	ITS, MCDA, tracking analysis, real-time data, remote sensing	Geographic equity analysis, remote sensing, spatial econometrics, machine learning	[16,17,28,30]
Current Decade Segment	Machine learning/AI, big data, IoT, data visualization, modeling, VR/AR	Virtual reality, digital twin models, deep learning, travel demand forecasting	[8,23,37]

3.4. Data Trends

Over time, GIS-transportation research has seen substantial data expansion. Early studies used basic road networks, traffic, land use, and census data. Recent studies utilize diverse, dynamic, and multidimensional data, such as real-time sensor feeds and 3D models, compared to earlier static datasets [47]. This evolution allows for advanced

analysis of transportation's intricate interplay. It aligns with the evidence-based planning, technology utilization, and contextual understanding of transportation in human–environment systems.

The types of data have diversified to include 3D models, satellite imagery, street-level imagery, accident data, transit network data, GPS trajectories, air quality data, mobile phone signals, remote sensing data, and many more [8,24,28,36,43,44,54–59]. These new sources provide multidimensional perspectives. The nature of data has also evolved from static spatial attributes to dynamic, real-time data from sensors, surveys, and mobile devices [30]. This enables a more accurate and up-to-date analysis of evolving transportation systems [27].

Moreover, the complexity of data has increased substantially. Advanced analysis techniques are applied, integrating complex datasets—travel demand modeling, multi-criteria analysis, location-allocation models, road accident analytical models, and environmental impact assessment [42,45,48,60–63]. These approaches leverage data diversity for deeper insights into interactions between transportation and land use. Big data has also expanded possibilities, with large-scale data from satellites, street imagery, crowdsourcing, and social media supplementing traditional data [55].

Importantly, non-spatial data have been increasingly incorporated, like socioeconomics [1], noise [61], climate [56], and demographic data [51]. This provides a more holistic context beyond pure location-based factors. Public participation data from surveys and interactive platforms are also integrated to engage communities [60]. And sustainability data, such as emissions and energy use, allow for analyzing environmental impacts [36,56]. This evolution of data is summarized in Figure 4, which outlines the key changes in data sources utilized for GIS-based transportation planning over time.



Figure 4. Progression of data sources in GIS-based transportation planning.

3.5. Synthesis of Findings

This study identifies both commonalities and variations in the GIS-T literature, contributing to both theoretical and practical advancements. Recurring themes include a focus on land use–transportation integration and geographic equity analysis, with research consistently emphasizing coordinated urban planning and equitable access to transportation [15,24]. However, methodological differences are evident: developed regions often utilize advanced techniques such as AI-driven modeling [17], while developing regions rely on conventional spatial analysis due to limited data availability [50]. On a theoretical level,

GIS-T has enhanced spatial theory by incorporating human–environment interactions, particularly in studies addressing sustainability [6]. Practically, the findings guide equitable infrastructure development, such as optimizing transit networks [19], and inform policy measures to promote sustainable mobility [22]. These insights underscore the importance of customizing GIS-T approaches to balance technological innovation with the realities of regional data constraints.

4. Challenges and Limitations

A GIS provides substantial advantages for transportation planning, including its capacity to synthesize diverse data sources, such as real-time sensor data and 3D models, and to facilitate evidence-based decisions through spatial analysis techniques like network optimization and equity evaluations [8,24,64]. These features support nuanced insights into urban mobility systems, improving planning efficiency and promoting inclusivity. However, challenges persist, including algorithmic biases, such as the modifiable areal unit problem, which can skew spatial analyses and worsen inequities when biased training data are employed [65,66]. Furthermore, GIS's reliance on high-quality data restricts its use in developing regions, and its computational demands may limit adoption without specialized skills. Addressing these issues requires transparent model development, diverse training datasets, and periodic bias audits to promote fair outcomes.

To tackle data scarcity in developing countries, approaches include utilizing open source platforms like OpenStreetMap to augment incomplete datasets, encouraging international data-sharing partnerships, and employing cost-effective, crowdsourced data collection methods, such as mobile applications and community surveys. Capacity-building initiatives can also equip local planners with skills to develop and manage GIS datasets, fostering self-reliance and strengthening local expertise [2].

The reliance on Web of Science as the sole database may have excluded relevant studies from other sources, such as Scopus or regional journals, potentially overlooking interdisciplinary or context-specific GIS-T applications. This focus was necessary to ensure a manageable, high-quality dataset for this review, but future research could expand to additional databases for greater comprehensiveness.

Excluding non-English studies may have underrepresented GIS-T research from developing regions, where local-language publications often offer valuable context-specific insights. This limitation suggests the need for future reviews to include multilingual sources, possibly through translation tools or international collaborations, to achieve a more inclusive global perspective, particularly in data- and resource-constrained regions.

Ethical and privacy concerns surrounding personal data, such as mobile phone records or social media content, remain critical in GIS-T applications. Responsible practices involve implementing stringent data anonymization to safeguard user identities, obtaining informed consent for data collection, and establishing transparent data governance frameworks inspired by GDPR principles. Regular ethical audits of GIS-T projects can further detect and address risks, ensuring adherence to privacy standards and building public confidence [37,66].

Bureaucratic impediments, fragmented governance structures, and inadequate institutional support present obstacles to the seamless integration of new tools into practical applications. Overcoming challenges related to securing funding, aligning various agencies, and updating existing workflows proves to be complex. Often, the adoption of innovative pilot projects precedes wider implementation [31,52].

While the advancement of modeling techniques introduces novel capabilities, inherent uncertainties persist. It is crucial to recognize that no single method can fully capture the intricate dynamics of urban environments. Limitations regarding predictive validity,

potential overfitting, and the interpretability of results should be carefully considered when employing “black box” models [64,65].

Lastly, ongoing assessment of equity and sustainability implications is imperative. The development and utilization of high-tech tools possess the potential to inadvertently exacerbate existing disparities. Therefore, it is paramount to prioritize principles of justice, inclusivity, and environmental objectives throughout their development and application [21].

5. Integrating AI in GIS-Based Transportation Planning

The incorporation of artificial intelligence (AI) into GIS is a significant development reshaping transportation planning. Notable applications include machine learning for traffic demand forecasting, as shown by Kim et al. (2023) [17], who employed explainable AI (XAI) to assess the impact of urban growth on transportation in Seoul. Computer vision, applied to street-level imagery, supports real-time traffic monitoring [55], while natural language processing (NLP) enables the analysis of public feedback from geosocial media to enhance participatory planning [60]. These advancements strengthen GIS-T’s capacity to deliver dynamic, evidence-based insights. Graph neural networks, utilized in traffic assignment [32] and seismic retrofit planning with an equity focus [49], illustrate AI’s potential to improve GIS-T by addressing complex network interactions and promoting transportation equity. Nonetheless, challenges such as a lack of transparency, potential biases, and ethical concerns remain, requiring interpretable models, thorough validation, and robust policy frameworks [66]. Looking ahead, promising directions include the development of hybrid AI-GIS models for real-time scenario analysis, the use of XAI to enhance model transparency, and the creation of AI-driven digital twins to simulate intricate urban mobility systems, incorporating real-time IoT data for dynamic policy assessment [30].

6. Outlook and Directions

6.1. Future Outlook

Moving forward, GIS-based transportation planning should embrace a multifaceted systems approach that harnesses emerging technologies while centering equity and sustainability. Incorporating multilingual reviews using translation tools or international collaborations can enhance inclusivity, particularly in developing regions where the non-English literature is prevalent. Key opportunities include the following:

Adopting artificial intelligence and machine learning responsibly to enable data-driven predictive modeling and dynamic insights from diverse transportation data sources [3]. This includes developing hybrid AI-GIS models for real-time scenario analysis, leveraging explainable AI (XAI) to enhance transparency, and creating AI-driven digital twins to simulate urban mobility systems, integrating IoT data for dynamic policy evaluation [17,30,66].

Fostering open geospatial data ecosystems and tools that engage diverse stakeholders in collaborative innovation [37]. Developing bias mitigation algorithms and improving data quality standards can further address GIS limitations, ensuring robust and equitable applications. But strong data protections, ethical oversight, and digital accessibility measures are needed to prevent disparate impacts.

Using immersive visualization technologies like AR/VR to increase understanding of complex transportation interactions and engage communities in participatory planning [53]. Yet, potential barriers to access must be proactively addressed.

Simulating and optimizing the transition to sustainable mobility modes through geospatial analysis of infrastructure, travel behavior, and environmental factors [20,22,54]. This can inform investments and policies to accelerate decarbonization.

Incorporating resilience considerations and climate adaptation strategies into transportation plans using spatial modeling capabilities [31]. This is imperative to mitigate intensifying climate risks.

Realizing geospatial innovation's potential depends on effective governance, human-centered design, inclusive capacity building, and integrating justice into technological advancements [52,53].

6.2. Technology Interactions

GIS integration with emerging technologies brings new capabilities but also oversight needs:

- Combining geospatial analytics with AI and big data infrastructure can enable more sophisticated dynamic modeling [3]. But biases and limitations must be evaluated.
- Leveraging IoT sensors and real-time data analytics to support intelligent transportation systems requires strong cybersecurity and data protections [27].
- Immersive visualization technologies require thoughtful UX design and accessibility considerations to broaden access [53].
- Cloud computing facilitates scalable geospatial analysis but should adhere to location data and privacy regulations [64].

Overall, holistic impact assessment and human-centered design are essential when connecting GIS across technologies to ensure ethical, socially responsible innovation. By prioritizing ethical integration and inclusive design, GIS–technology interactions can drive transformative advancements in transportation planning.

7. Policy Implications

Based on two decades of GIS-based transportation research, this study underscores the importance of targeted policy measures to promote equitable and sustainable urban mobility. The following practical recommendations, derived from this review's findings, offer guidance for policymakers:

- I. Develop Open Data Portals: Support and sustain open geospatial data platforms, such as OpenStreetMap, to enhance data access, particularly in developing regions where limited data availability constrains GIS-T applications [2].
- II. Enforce Ethical Standards: Implement GDPR-inspired regulations for GIS-T projects involving personal data, mandating transparency reports and informed consent to address ethical issues [66,67].
- III. Promote Workforce Development: Establish interdisciplinary training programs to build GIS-T expertise among planners, addressing technical skill shortages in resource-limited regions [17].
- IV. Fund Pilot Initiatives: Allocate resources for pilot projects to test innovative GIS-T tools, such as AI-driven traffic models, to facilitate adoption and overcome bureaucratic obstacles [31,68].
- V. Incorporate Equity Assessments: Mandate the inclusion of equity evaluations in GIS-T projects to address spatial disparities in transportation access, aligning with trends in geographic equity analysis [24].
- VI. Invest in Sustainable Infrastructure: Leverage GIS-based analysis to direct funding toward low-carbon transportation options, such as sharing bikes, electric buses and bike lanes, to advance sustainability objectives [22,69].

By integrating governance, collaboration, and technological advancements with equity and sustainability priorities, policymakers can harness GIS to foster transformative, inclusive, and environmentally responsible transportation systems.

This systematic review was conducted and reported in accordance with PRISMA 2020 guidelines [70].

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