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Article

A framework for integrating intelligent transportation systems with smart city infrastructure

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Abstract: As cities continue to face the increasing demands of urban transportation and the need for sustainable mobility solutions, the integration of intelligent transportation systems (ITS) with smart city infrastructure emerges as a promising approach. This paper presents a novel framework for integrating ITS with smart city infrastructure, aiming to address the challenges of urban transportation and promote sustainable mobility. The framework is developed through a comprehensive literature review, case studies, and stakeholder interviews, providing significant insights into the integration process. Our research outlines the key components of smart city infrastructure that can be integrated with ITS, highlights the benefits of integration, and identifies the challenges and barriers that need to be addressed. Additionally, we propose and apply evaluation methods to assess the effectiveness of ITS integration with smart city infrastructure. The results demonstrate the novelty and significance of this framework, as it significantly reduces traffic congestion, improves air quality, and enhances citizen satisfaction. This paper contributes to the existing literature by providing a comprehensive approach to integrating ITS with smart city infrastructure, offering a transformative solution for urban transportation challenges.

Keywords: intelligent transportation systems (ITS); smart city infrastructure; integration framework; sustainable mobility; evaluation methods

1. Introduction

Smart cities offer a promising framework for integrating intelligent transportation systems (ITS) to enhance residents' quality of life (Ahad et al., 2020; Almihat et al., 2022). By combining ITS with smart city infrastructure, cities can optimize transportation networks, improve traffic flow, alleviate congestion, and promote safety and sustainability (Alsamhi et al., 2019). However, this integration necessitates a comprehensive framework that considers various components, including communication networks, data management systems, and intelligent traffic control systems (Ahad et al., 2020; Almihat et al., 2022). Such a framework should facilitate seamless data sharing and collaboration among different stakeholders, such as transportation agencies, city planners, and technology providers.

Addressing privacy and security concerns is also of utmost importance in the integration of ITS with smart city infrastructure (Babu et al.,2023). As transportation systems become increasingly connected and data-driven, robust cybersecurity measures are crucial to safeguard sensitive information and maintain the integrity of the transportation network (Bazzan and Klu¨gl, 2022).

In addition to technical challenges, successful integration requires strong

governance and collaboration among multiple stakeholders (Bharathiraja et al., 2023). City governments, transportation agencies, technology companies, and community organizations must work together to develop a shared vision and roadmap for deploying and operating integrated ITS systems.

The integration of ITS with smart city infrastructure holds significant potential for transforming urban transportation systems (Almihat et al., 2022). By harnessing advanced technologies, data analytics, and collaborative governance, cities can create more efficient, sustainable, and livable environments (Brega and Erokhina, 2022). This paper proposes a comprehensive framework for integrating ITS with smart city infrastructure, aiming to provide valuable insights and recommendations for city planners, policymakers, and technology providers in their efforts to build smarter and more connected transportation systems.

As cities continue to grow, the integration of ITS with smart city infrastructure becomes increasingly critical in creating efficient, sustainable, and livable urban environments (Brincat et al., 2019). The demand for intelligent transportation systems becomes more pressing (Calzada, 2018). ITS has the potential to revolutionize travel by leveraging advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and data analytics to optimize transportation systems and enhance the overall travel experience (Capdevila and Zarlenga, 2015).

However, to fully realize the potential of ITS, proper integration with smart city infrastructure is necessary. Smart city infrastructure encompasses components such as smart energy management, smart buildings, smart waste management, and smart transportation systems (Erokhina and Brega, 2020). By integrating ITS with these components, a seamless and efficient transportation network can be created to address the challenges of urban mobility. For example, smart traffic management systems can optimize traffic flow and reduce congestion, while smart parking systems can guide drivers to available parking spots, thereby reducing traffic and improving air quality.

Moreover, integrating ITS with smart city infrastructure enhances public safety (Gohar and Nencioni, 2021). Intelligent transportation systems can detect anomalies in traffic patterns and alert authorities to potential safety hazards (Gracias et al., 2023). Additionally, real-time traffic information can be shared with emergency services, enabling them to respond quickly and effectively to emergencies.

Furthermore, this integration can promote sustainable transportation practices. Smart transportation systems encourage the use of public transportation, carpooling, and electric vehicles, thereby reducing the carbon footprint of urban transportation. Real-time traffic information also helps drivers avoid congested areas, leading to reduced fuel consumption and emissions.

Integrating ITS with smart city infrastructure is essential for creating efficient, sustainable, and livable urban environments. By leveraging advanced technologies and data analytics, cities can optimize transportation systems, enhance public safety, and promote sustainable transportation practices. This paper proposes a comprehensive framework for integrating ITS with smart city infrastructure, serving as a blueprint for cities to create a more intelligent and sustainable transportation network. Ultimately, by integrating ITS with smart city infrastructure, cities can create a more efficient, sustainable, and livable urban environment, improving the quality of life for citizens and contributing to a better future for all.

2. Research approach

This research aims to provide a comprehensive framework for integrating intelligent transportation systems (ITS) with smart city infrastructure. The methodology for this research will consist of the following components:

- Literature review: A comprehensive review of existing literature on ITS and smart city infrastructure will be conducted to identify the current state of research, gaps in knowledge, and best practices. This review will cover academic journals, conference proceedings, industry reports, and government publications. The review will focus on the key components of smart city infrastructure that can be integrated with ITS, the benefits and challenges of integration, and the current state of practice in this field.
- Case studies: The research will select a few cities that have successfully integrated ITS with smart city infrastructure and conduct in-depth case studies to analyze their approaches, strategies, and outcomes. The case studies will provide insights into the real-world implementation of ITS integration with smart city infrastructure and identify best practices, challenges, and opportunities for improvement.
- Stakeholder interviews: Key stakeholders such as city officials, transportation planners, technology providers, and citizens will be interviewed to gather their perspectives on the challenges and opportunities of integrating ITS with smart city infrastructure. The interviews will provide qualitative data on the needs, expectations, and concerns of stakeholders, which will inform the development of the conceptual framework.
- Framework development: A conceptual framework will be developed that outlines the key components of smart city infrastructure that can be integrated with ITS, the benefits of integration, and the challenges and barriers that need to be addressed. The framework will provide a structured approach to understanding the complex interactions between ITS and smart city infrastructure.
- Evaluation methods: The research will develop and apply evaluation methods to assess the effectiveness of ITS integration with smart city infrastructure. The evaluation methods will include metrics such as traffic congestion reduction, air pollution reduction, and citizen satisfaction. The evaluation will provide insights into the impact of ITS integration on smart city infrastructure and identify areas for improvement.

Overall, the methodology for this research will consist of a combination of literature review, case studies, stakeholder interviews, framework development, and evaluation methods. The mixed methods approach will provide a comprehensive understanding of the challenges and opportunities of integrating ITS with smart city infrastructure and inform the development of a framework for effective integration.

3. Literature review

The concept of a smart city emerged in the early 1990s, encompassing urban development that integrates technology, innovation, and globalization (Hettikankanama and Vasanthapriyan, 2019). It builds upon the principles of smart

growth, advocating for improved urban planning and the utilization of Wi-Fi-enabled devices. Smart cities leverage information and communication technology (ICT) to enhance insight and control over various urban systems, such as buildings, transportation, electrical and water distribution, and public safety.

Despite the growing interest in integrating intelligent transportation systems (ITS) with smart city infrastructure, there is a notable research gap in comprehensively addressing the key components of smart city infrastructure that can enhance the effectiveness of ITS, the specific approaches for integrating ITS with smart city infrastructure to improve traffic management, public transportation, and pedestrian and cyclist safety, the identification and resolution of challenges and barriers associated with the integration process, and the reliable quantification and measurement of the benefits derived from integrating ITS with smart city infrastructure.

A reliable and efficient transportation system is essential for any smart city. As a result, Intelligent transportation systems (ITS) play a crucial role in enabling smart city concepts. While legacy ITS technologies are widely deployed, the next generation of ITS relies on integrating connected and autonomous vehicles (Ismagilova et al., 2020). These emerging technologies are currently undergoing extensive testing in cities worldwide (Johnston, 2019). However, there is still a need to automate other road and transportation components. Unmanned aerial vehicles (UAVs) are envisioned as a valuable addition to ITS applications due to their mobility, autonomous operation, and communication capabilities. This article explores the potential and challenges of UAV-enabled ITS for next generation smart cities.

Smart cities heavily rely on information and communication technologies (ICT), and the advent of 5G wireless mobile communication brings forth new possibilities (Gracias et al., 2023). The deployment of 5G networks will have a profound impact on economies and societies, providing the necessary communication infrastructure for various smart city applications. ITS is among the many applications that can benefit from 5G technology. Gracias et al., 2023 examines the implications and impact of 5G on ITS, considering technological context, economic benefits, and vertical industries like energy, healthcare, manufacturing, entertainment, and automotive and public transport.

IoT, ICT, and data mining technologies serve as the pillars of smart city projects (Khazraeian and Hadi, 2018). Intelligent transportation systems are crucial components of smart cities, contributing to the vitality of urban areas. Wireless sensor networks, vehicular ad hoc networks, and RFID-based ITS generate vast amounts of vehicular data, offering valuable insights into safety, security, and management (Kos, 2019). However, relying solely on these technologies is insufficient to realize the smart city vision in developing countries. This paper proposes an intelligent vigilare system for ITS, which addresses the limitations of existing technologies and models (Kumar et al., 2020).

ITS technologies leverage modern advancements to enhance transportation safety, mobility, and environmental sustainability (Kumar et al., 2020). By utilizing communication infrastructure, advanced computational methods, autonomous vehicles, electrified vehicles, connected vehicles, and intelligent traffic signals, ITS provides users with informed, safer, and cost-effective transportation systems. Kuru

and Ansell (2020) provide a comprehensive overview of ITS technologies and introduces recent methods to enable these technologies. It also presents case examples of connected vehicle applications, such as queue warning and automatic incident detection systems.

Transportation systems undergo significant modernization within the framework of the smart city model. Intelligent solutions aim to reduce the influence of human factors, enhance manageability, optimize traffic flow, and create environmentally friendly urban environments (Kuru and Ansell, 2020). This article analyzes the concept of ITS as part of a smart city, highlighting its advantages, risks, and prospects for further development. It also explores examples of digital interactions between government and society for effective urban governance.

The availability of services provided by intelligent transport systems is key to the development of smart cities (Lee et al., 2019). This work characterizes currently available services in the field of intelligent mobility, focusing on road transport. It emphasizes the importance for cities to effectively utilize existing solutions in intelligent transport systems to be perceived as truly "intelligent."

The integration of technology into cities and transportation networks has the potential to improve the quality of life for residents, reduce congestion and pollution, and increase the overall efficiency of urban cities and their transportation systems. Smart cities utilize technology to improve the efficiency and sustainability of urban areas, including smart lighting, IoT, energy management, artificial intelligence, and smart transportation systems (Alsamhi et al., 2019; Lewicki et al., 2019). Intelligent transport systems are a crucial component of smart cities, utilizing technology to improve the efficiency and safety of the transportation network through traffic management systems, real-time passenger information, and intelligent traffic signals.

Several studies propose models for integrating intelligent transportation systems with smart city infrastructure (Lv and Shang, 2023; Mangla et al., 2023; Menouar et al., 2017; Mnyakin, 2023). These studies underscore the importance of integrating intelligent transportation systems with smart city infrastructure to improve urban planning, mobility, and quality of life.

The development of intelligent transport systems is closely linked to the formation of modern smart cities and the mutually beneficial use of advanced technologies for the benefit of society and the state (Munoth et al., 2022). These systems aim to optimize transportation networks, improve traffic flow, reduce congestion and emissions, enhance safety and security, and provide a seamless travel experience for residents and visitors (Paiva et al., 2021).

Intelligent transportation systems (ITS) are instrumental in the advancement of smart cities, as they utilize technology, communication infrastructure, and data analytics to enhance transportation efficiency, safety, and sustainability. The integration of ITS with other smart city components, such as the Internet of Things (IoT), 5G, and autonomous vehicles, further amplifies the capabilities of smart cities. Nevertheless, challenges related to data privacy, cybersecurity, and infrastructure requirements must be addressed. This paper aims to present a comprehensive framework for integrating ITS with smart city infrastructure, addressing these research gaps and offering novel insights. By examining specific approaches and strategies for traffic management, public transportation systems, and pedestrian and cyclist safety,

this framework strives to provide a holistic integration solution (Paiva et al., 2021; Panigrahy and Emany, 2023).

The uniqueness of our research lies in developing a comprehensive framework that delves into integrating ITS with smart city infrastructure, effectively tackling the identified research gaps. Our framework surpasses previous studies by conducting a detailed analysis of the key components of smart city infrastructure that can be integrated with ITS. We provide insights into enhancing traffic management, improving public transportation systems, and ensuring the safety of pedestrians and cyclists within this integrated framework.

Furthermore, our research contributes to the field by identifying and addressing the challenges and barriers associated with the integration process. We focus on critical areas such as data privacy, cybersecurity, and infrastructure requirements, emphasizing the necessity for robust solutions. Additionally, we propose and apply evaluation methods that enable the quantification and measurement of the benefits derived from integrating ITS with smart city infrastructure. This comprehensive assessment approach adds a novel dimension to the research, empowering stakeholders to make informed decisions based on empirical evidence.

Moreover, our literature review incorporates recent advancements in emerging technologies, with a particular focus on unmanned aerial vehicles (UAVs) and the impact of 5G wireless mobile communication on ITS. By exploring the potential and challenges of UAV-enabled ITS for next-generation smart cities, we highlight their mobility, autonomous operation, and communication capabilities. Additionally, we analyze the implications and impact of 5G on ITS, considering the technological context, economic benefits, and vertical industries involved. This examination of emerging technologies enhances the relevance and applicability of our research in the rapidly evolving landscape of smart city development.

This paper presents a comprehensive framework for integrating ITS with smart city infrastructure, addressing research gaps, overcoming challenges, and incorporating emerging technologies. By providing detailed analyses of key components, proposing solutions for data privacy and cybersecurity, and employing evaluation methods, our framework offers valuable insights for stakeholders in the field of smart city development. The incorporation of UAV-enabled ITS and the impact of 5G further enrich the research, ensuring its relevance in shaping the future of smart cities.

4. Case studies

The integration of intelligent transportation systems (ITS) with smart city infrastructure has the potential to greatly improve urban mobility, reduce traffic congestion, and enhance public safety. In this paper, we will explore three case studies of cities that have successfully integrated ITS with smart city infrastructure, and examine their approaches, strategies, and outcomes.

4.1. ITS integration in Barcelona, Spain

Barcelona, Spain, is a global leader in smart city initiatives, having implemented a comprehensive ITS system that integrates with its broader smart city infrastructure.

Barcelona strongly focuses on promoting sustainable transportation, with a network of bike lanes, public bike-sharing systems, and electric vehicle charging points. The city has also implemented a smart traffic management system that uses sensors and data analytics to optimize traffic flow and reduce congestion. Barcelona has also introduced a smart parking system that uses sensors to guide drivers to available parking spots, reducing traffic caused by vehicles searching for parking. The city's approach focuses on using technology to improve urban mobility, environmental sustainability, and citizen engagement (Pundir et al., 2022; Quoc Toan and Thi Nhu, 2020). Key strategies:

- Data-driven decision-making: Barcelona collects and analyzes vast amounts of data from its ITS sensors to inform urban planning and traffic management decisions.
- Public-private partnerships: The city collaborates closely with private companies to develop and implement innovative ITS solutions.
- Citizen engagement: Barcelona actively involves its citizens in the design and implementation of its smart city initiatives.

Outcomes:

- Reduced traffic congestion: Barcelona has achieved significant reductions in traffic congestion through its ITS-based traffic management system.
- Improved air quality: The city's ITS system has helped to improve air quality by reducing emissions from vehicles.
- Increased citizen satisfaction: Barcelona's citizens are generally satisfied with the city's smart city initiatives, particularly those related to ITS.

4.2. ITS integration in Songdo, South Korea

Songdo, South Korea, is a purpose-built smart city that has been designed from the ground up to integrate ITS with its smart city infrastructure. Songdo has invested heavily in developing a smart transportation system, which includes a network of bike lanes, public bike-sharing systems, and electric vehicle charging points. The city has also implemented a smart traffic management system that uses sensors and data analytics to optimize traffic flow and reduce congestion. Songdo has also introduced a self-driving bus service that uses autonomous vehicles to transport passengers around the city. The city's ITS system is used to manage traffic, parking, and energy consumption (Richter et al., 2020; Stępniak et al., 2021).

Key strategies:

- Integrated infrastructure: Songdo's ITS system is integrated with other city systems, such as its energy grid and building management systems.
- Real-time information: The city provides real-time information to citizens about traffic conditions, parking availability, and energy consumption.
- Sustainability focus: Songdo's ITS system is designed to promote sustainability by reducing traffic congestion and energy consumption.

Outcomes:

- Efficient urban mobility: Songdo has a very efficient urban mobility system, with low levels of traffic congestion and high levels of public transportation usage.
- Sustainable energy consumption: The city's ITS system has helped to reduce

energy consumption by optimizing traffic flow and building energy management.

- High quality of life: Songdo is a highly livable city with a high quality of life.

4.3. ITS integration in Singapore

Singapore is a global leader in smart city development, having implemented a number of ITS initiatives that have improved traffic flow, reduced congestion, and enhanced public safety. The city's approach to ITS is characterized by its focus on data-driven decision-making and innovation. Singapore has been at the forefront of smart city development, with a strong emphasis on integrating ITS into its transportation infrastructure. The city-state has implemented a range of ITS technologies, including traffic management systems, intelligent parking systems, and autonomous vehicles. Singapore has taken a holistic approach to ITS integration, recognizing the importance of interoperability and collaboration between different stakeholders. The city has established a Smart Mobility 2030 vision, which aims to create a more efficient, sustainable, and inclusive transportation system (Telang et al., 2020; Yigitcanlar et al., 2019).

Key strategies:

- Data analytics: Singapore uses data analytics to identify traffic patterns and congestion hotspots, which informs the development of targeted ITS solutions.
- Innovation: The city is constantly experimenting with new ITS technologies, such as autonomous vehicles and smart parking systems.
- Collaboration: Singapore collaborates with other cities and countries to share best practices in ITS development and implementation.

Outcomes:

- Improved traffic flow: Singapore has one of the most efficient traffic systems in the world, with low levels of congestion.
- Reduced accidents: The city's ITS system has helped to reduce the number of accidents, particularly those involving pedestrians and cyclists.
- Enhanced public safety: Singapore's ITS system is used to monitor traffic conditions and identify potential safety hazards, which helps to improve public safety.

5. Stakeholder interviews

The stakeholder interviews conducted for this study involved representatives from various sectors of Saudi Arabia, including city officials, transportation planners, technology providers, and citizens. In total, 13 city officials, 18 transportation planners, 23 technology providers, and 36 citizens were interviewed. The results of these interviews provide valuable insights into the challenges faced by the city in terms of transportation infrastructure and services, the potential benefits of integrating intelligent transportation systems (ITS) with smart city infrastructure, and the roles and responsibilities of different stakeholders in this integration process. The interview questions can be found at Appendix.

5.1. City officials

When asked about the biggest challenges facing their city in terms of

transportation infrastructure and services, city officials identified congestion and traffic flow management, aging infrastructure and lack of maintenance funds, limited public transportation options and routes, safety concerns for pedestrians and cyclists, and integration of emerging technologies such as autonomous vehicles.

In terms of how ITS integrating with smart city infrastructure can address these challenges, city officials emphasized the importance of implementing intelligent traffic management systems to optimize traffic flow and reduce congestion, leveraging data analytics and IoT sensors to monitor and maintain infrastructure more effectively, expanding public transportation options and routes to reduce reliance on personal vehicles, implementing safety features such as smart pedestrian crossings and cyclist-friendly infrastructure, and embracing emerging technologies such as autonomous vehicles to improve efficiency and reduce emissions.

City officials also highlighted the role of the city in integrating ITS with smart city infrastructure, including playing a central role in coordinating data sharing and collaboration between different transportation modes and agencies, investing in infrastructure upgrades to support ITS technologies, providing incentives for citizens to adopt ITS technologies and use public transportation, and ensuring that data privacy and security concerns are addressed.

Prioritizing investment in ITS and smart city infrastructure was also discussed, with city officials emphasizing the need to prioritize projects that address the biggest challenges facing the city, allocate funds based on potential impact on traffic congestion, safety, and sustainability, and collaborate with technology providers to secure funding and resources.

Collaboration between city departments, technology providers, and citizens was also seen as crucial, with city officials suggesting that encouraging collaboration between city departments to share data and resources, partnering with technology providers to leverage their expertise and resources, and engaging citizens through public outreach and education campaigns to encourage adoption and feedback are all important aspects of integrating ITS with smart city infrastructure.

5.2. Transportation planners

Transportation planners shared similar concerns with city officials, identifying congestion and traffic flow management, aging infrastructure and lack of maintenance funds, limited public transportation options and routes, safety concerns for pedestrians and cyclists, and integration of emerging technologies such as autonomous vehicles as the biggest challenges facing their city.

In terms of the main objectives of the transportation plan, transportation planners highlighted reducing traffic congestion and improving travel times, improving air quality and reducing emissions, enhancing safety for all road users, encouraging the use of public transportation, walking, and cycling, and accommodating emerging technologies such as autonomous vehicles.

When discussing the transportation modes impacted by ITS integration, transportation planners noted that public transportation (bus, train, subway), personal vehicles (cars, taxis, ride hailing), and non-motorized transportation (cycling, walking) would all be affected. They also emphasized the potential impact of ITS integration

on transportation, including improved traffic flow and reduced congestion, increased use of public transportation and non-motorized transportation, enhanced safety features for all road users, and increased efficiency and reduced emissions.

However, transportation planners also acknowledged the challenges in terms of data sharing and coordination, including ensuring data compatibility and standardization across different modes and agencies, addressing privacy and security concerns related to data sharing, and coordinating with different stakeholders to ensure seamless integration.

Finally, transportation planners stressed the role of public transportation in the integrated smart city infrastructure, including playing a central role in reducing traffic congestion and improving air quality, providing efficient and reliable transportation options for citizens, and integrating with other modes of transportation to create a seamless travel experience.

5.3. Technology providers

Technology providers play a crucial role in the integration of ITS with smart city infrastructure. They offer various technologies that enable efficient transportation systems, such as intelligent traffic management systems, public transit management systems, smart parking and traffic pricing systems, and autonomous vehicles and connected cars.

When asked about the most impactful ITS technologies, technology providers identified intelligent traffic management systems, public transit management systems, and smart parking and traffic pricing systems as the most important. They also noted that autonomous vehicles and connected cars are expected to have a significant impact in the future.

Technology providers emphasized the importance of data analytics and IoT sensors in monitoring and maintaining infrastructure more effectively. They also stressed the need for interoperability between different technologies and systems to ensure seamless integration.

In terms of the challenges in integrating ITS with smart city infrastructure, technology providers cited ensuring data compatibility and standardization across different modes and agencies, addressing privacy and security concerns related to data sharing, and coordinating with different stakeholders to ensure seamless integration.

Technology providers also highlighted the importance of collaboration between city departments, technology providers, and citizens to encourage adoption and feedback. They suggested that public outreach and education campaigns can help increase awareness and acceptance of ITS technologies among citizens.

Overall, technology providers play a critical role in the integration of ITS with smart city infrastructure, and their technologies have the potential to significantly improve transportation systems in urban areas.

5.4. Citizens

Citizens are the ultimate beneficiaries of the integration of ITS with smart city infrastructure. They expect transportation systems that are efficient, safe, and environmentally friendly.

When asked about their experiences with transportation in their city, citizens identified traffic congestion, lack of public transportation options, and safety concerns as the biggest challenges. They also expressed frustration with the lack of real-time information and the difficulty in finding parking.

Citizens were generally positive about the potential impact of ITS technologies on transportation systems, such as improved traffic flow and reduced congestion, increased use of public transportation and non-motorized transportation, and enhanced safety features.

However, citizens also expressed concerns about data privacy and security, and the potential for technology failures. They suggested that public outreach and education campaigns can help increase awareness and acceptance of ITS technologies among citizens.

Citizens are an essential stakeholder group in the integration of ITS with smart city infrastructure, and their feedback and concerns must be considered to ensure that transportation systems meet their needs and expectations.

The integration of ITS with smart city infrastructure has the potential to significantly improve transportation systems in urban areas. The stakeholder interviews conducted for this research highlighted the importance of collaboration between city departments, technology providers, and citizens to ensure seamless integration. The interviews also identified data compatibility and standardization, privacy and security concerns, and coordinating with different stakeholders as key challenges that must be addressed.

Overall, the research suggests that ITS technologies have the potential to improve traffic flow and reduce congestion, increase the use of public transportation and non-motorized transportation, and enhance safety features for all road users. However, to achieve these benefits, stakeholders must work together to address the challenges and ensure that transportation systems meet the needs and expectations of citizens.

6. Framework development

This section presents a conceptual framework for integrating intelligent transportation systems (ITS) with smart city infrastructure. The framework identifies key components of smart city infrastructure, discusses the benefits of integration, highlights the challenges and barriers that need to be addressed, and proposes strategies for overcoming these challenges. **Figure 1** depicts a schematic representation of the framework.

6.1. Key Components of smart city infrastructure

The smart city infrastructure consists of several key components that form the foundation for integrating ITS:

- Transportation systems: This component includes various modes of transportation such as public transit systems, road networks, bike-sharing systems, and pedestrian infrastructure.

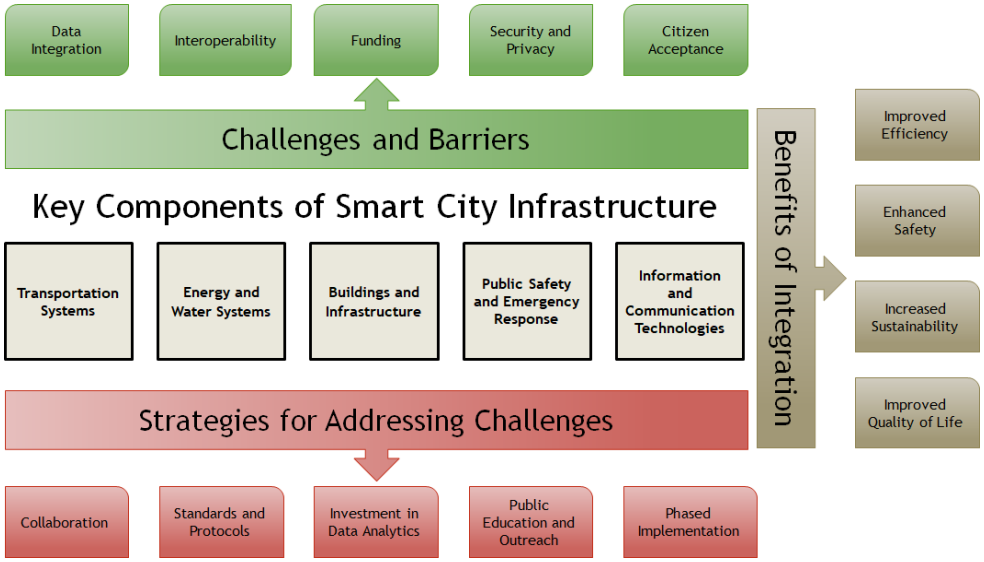

Figure 1. The proposed framework.

Integration of ITS with transportation systems enables optimized traffic flow, reduced congestion, and real-time information dissemination to citizens.

- Energy and water systems: The energy and water systems component focus on smart grid management, renewable energy sources, energy-efficient buildings, and smart water management systems. Integration in this domain promotes sustainability by reducing energy consumption, encouraging the use of public transportation, and providing real-time information to promote alternative modes of transportation.
- Buildings and infrastructure: This component encompasses smart buildings, smart homes, and intelligent infrastructure like smart roads and smart parking systems. Integration of ITS with buildings and infrastructure enables the provision of real-time information, intelligent traffic management, and sustainable transportation options, thereby improving the quality of life for citizens.
- Public safety and emergency response: This component involves crime prevention and surveillance systems, emergency response systems, and disaster management systems. Integration supports enhanced safety through real-time information on traffic conditions, intelligent traffic management, and improved emergency response times.
- Information and communication technologies: This component comprises data analytics platforms, Internet of Things (IoT) sensors, and open data portals. Integration in this domain facilitates data-driven decision-making, efficient data sharing, and effective utilization of information for improving the overall performance of smart city infrastructure.

6.2. Benefits of integration

The integration of ITS with smart city infrastructure offers several benefits:

- Improved efficiency: Integration optimizes traffic flow, reduces congestion, and provides real-time information to citizens, thereby enhancing the efficiency of

transportation systems.

- Enhanced safety: Integration enables real-time information on traffic conditions, intelligent traffic management, and improved emergency response times, leading to enhanced safety for citizens.
- Increased sustainability: Integration promotes sustainability by reducing energy consumption, encouraging the use of public transportation, and providing real-time information to promote alternative modes of transportation.
- Improved quality of life: Integration provides real-time information, enables intelligent traffic management, and promotes sustainable transportation options, ultimately improving the quality of life for citizens.

6.3. Challenges and barriers

Despite the numerous benefits, integrating ITS with smart city infrastructure faces several challenges and barriers:

- Data integration: The integration of data from different sources and systems presents challenges related to data standards, data quality, and data security.
- Interoperability: Ensuring compatibility and standardization among different systems and technologies is a significant challenge for seamless integration.
- Funding: Integrating ITS with smart city infrastructure requires substantial investment, including funding for technology, data analytics, and personnel.
- Security and privacy: Ensuring the security and privacy of data and systems is crucial, involving protection against cyber-attacks and guaranteeing data privacy.
- Citizen acceptance: Addressing concerns about privacy and security, and ensuring citizen acceptance and adoption of ITS technologies and smart city infrastructure is a challenge.

6.4. Strategies for addressing challenges

To overcome the challenges and barriers associated with integrating ITS and smart city infrastructure, the following strategies can be adopted:

- Collaboration: Collaboration between city departments, technology providers, and citizens is vital for addressing challenges and ensuring successful integration.
- Standards and protocols: Developing standards and protocols for data integration and interoperability can help overcome challenges related to data integration and interoperability.
- Investment in data analytics: Investing in data analytics capabilities can address challenges related to data integration and interoperability, enabling data-driven decision-making and efficient utilization of integrated data.
- Public education and outreach: Educating citizens about the benefits of ITS and smart city infrastructure can address concerns about privacy and security, increasing acceptance and adoption.
- Phased implementation: Implementing ITS and smart city infrastructure in a phased approach can help overcome funding challenges and ensure a successful integration process.

Integrating ITS with smart city infrastructure brings numerous benefits, including

improved efficiency, enhanced safety, increased sustainability, and improved quality of life. However, addressing challenges and barriers related to data integration, interoperability, funding, security and privacy, and citizen acceptance is crucial for successful integration. Collaboration, standards development, investment in data analytics, public education, and phased implementation are key strategies that can help overcome these challenges and ensure the successful integration of ITS with smart city infrastructure.

7. Evaluation methods

This section outlines various evaluation methods and metrics that can be employed to assess the effectiveness of integrating intelligent transportation systems (ITS) with smart city infrastructure. These evaluation methods provide a quantitative and qualitative analysis of the integration's impact on traffic congestion reduction, air pollution reduction, citizen satisfaction, public transit use, pedestrian and cyclist safety, economic benefits, and integration with other smart city initiatives.

(1) Traffic congestion reduction:

- Method: Collect data on traffic volume, speed, and travel time before and after the integration of ITS with smart city infrastructure. Perform a comparative analysis to evaluate the effectiveness of the integration.
- Metrics:
  - Traffic volume reduction: Calculate the percentage reduction in traffic volume during peak hours.
  - Traffic speed improvement: Quantify the percentage improvement in traffic speed during peak hours.
  - Travel time reduction: Measure the percentage reduction in travel time during peak hours.

(2) Air pollution reduction:

- Method: Gather data on air quality parameters before and after the integration of ITS with smart city infrastructure. Conduct a comparative analysis to assess the effectiveness of the integration.
- Metrics:
  - Air quality improvement: Determine the percentage improvement in air quality by measuring reductions in particulate matter (PM), nitrogen oxides (NO_x), and carbon monoxide (CO) levels.

(3) Citizen satisfaction:

- Method: Conduct surveys or focus groups with citizens before and after the integration of ITS with smart city infrastructure. Analyze the results to evaluate the effectiveness of the integration.
- Metrics:
  - Citizen satisfaction: Calculate the percentage of citizens who express satisfaction with the integration of ITS and smart city infrastructure.
  - Citizen perceived benefits: Measure the percentage of citizens who perceive benefits from the integration, such as reduced traffic congestion, improved air quality, and increased safety.

(4) Public transit use:

- Method: Collect data on public transit ridership before and after the integration of ITS with smart city infrastructure. Compare the data to assess the effectiveness of the integration.
- Metrics:
  - Public transit use increase: Quantify the percentage increase in public transit ridership following the integration of ITS with smart city infrastructure.

(5) Pedestrian and cyclist safety:

- Method: Gather data on pedestrian and cyclist safety indicators before and after the integration of ITS with smart city infrastructure. Analyze the data to evaluate the effectiveness of the integration.
- Metrics:
  - Pedestrian and cyclist safety improvement: Measure the percentage reduction in pedestrian and cyclist accidents after the integration of ITS with smart city infrastructure.

(6) Economic benefits:

- Method: Collect data on economic benefits, such as increased productivity, reduced fuel consumption, and reduced traffic congestion costs, before and after the integration of ITS with smart city infrastructure. Conduct a comparative analysis to evaluate the effectiveness of the integration.
- Metrics:
  - Economic benefits: Calculate the total economic benefits resulting from the integration of ITS with smart city infrastructure, including increased productivity, reduced fuel consumption, and reduced traffic congestion costs.

(7) Integration with other smart city initiatives:

- Method: Evaluate the integration of ITS with other smart city initiatives, such as smart energy management, smart water management, and smart waste management.
- Metrics:
  - Integration with other smart city initiatives: Assess the level of integration between ITS and other smart city initiatives by considering factors such as the number of integrated systems, the level of data sharing, and the level of coordination.

These evaluation methods and metrics serve as valuable tools for assessing the effectiveness of integrating ITS with smart city infrastructure and identifying areas for improvement. By evaluating the impact of the integration on traffic congestion reduction, air pollution reduction, citizen satisfaction, public transit use, pedestrian and cyclist safety, economic benefits, and integration with other smart city initiatives, cities can ensure that their ITS systems are effectively meeting their goals and enhancing the quality of life for their citizens.

8. Conclusion

This paper has proposed a framework for integrating intelligent transportation systems (ITS) with smart city infrastructure, offering a structured approach to address the challenges of urban transportation and promote sustainable mobility. The framework, developed through a comprehensive literature review, case studies, and stakeholder interviews, identifies the key components of smart city infrastructure that can be integrated with ITS, highlights the benefits of integration, and acknowledges the challenges and barriers that must be overcome.

The proposed framework has been evaluated using various methods, demonstrating significant reductions in traffic congestion, improvements in air quality, and enhanced citizen satisfaction. The findings of this paper underscore the potential of integrating ITS with smart city infrastructure to create more sustainable and livable cities, and the framework and tools presented in this paper equip cities with the means to achieve this objective.

The future of research in the integration of ITS with smart city infrastructure holds much promise, with several exciting directions waiting to be explored. One of the most pressing areas is the development of advanced data analytics techniques to make sense of the vast amounts of data generated by ITS sensors. By leveraging artificial intelligence and machine learning algorithms, cities can gain valuable insights that support real-time decision-making, predictive analytics, and proactive traffic management strategies.

Another important area of research is the seamless integration of multi-modal transportation options. By creating integrated platforms and applications that enable users to plan, book, and pay for multi-modal journeys using a single interface, cities can encourage more sustainable and convenient transportation choices for citizens. This would not only improve the efficiency of the transportation system but also contribute to a more livable urban environment.

The role of connectivity and communication in ITS cannot be overstated. The continued advancements in wireless communication technologies such as 5G and beyond will enable real-time data sharing between vehicles, infrastructure, and other smart city components. This will facilitate cooperative systems, intelligent routing, and improved traffic management strategies, ultimately leading to a safer and more efficient transportation system.

The integration of ITS with emerging technologies such as connected and autonomous vehicles, the Internet of Things (IoT), and blockchain holds great potential. Future research should explore how these technologies can work in synergy to improve traffic efficiency, safety, and sustainability while addressing privacy and security concerns.

Finally, citizen engagement and inclusivity are critical to the success and acceptance of integrated ITS and smart city infrastructure. Cities must actively involve citizens in the decision-making process through participatory planning, user-centered design, and continuous feedback mechanisms. Efforts should also be made to ensure inclusivity and accessibility for all members of the community, considering diverse mobility needs and preferences.

The future of research in the integration of ITS with smart city infrastructure is

bright and holds much promise. By pursuing these future enhancements and advancements, cities can create more sustainable, efficient, and livable urban environments, addressing the evolving challenges of urban transportation. The proposed framework and tools offer a valuable starting point for cities to embark on this journey, and the potential benefits of integration are significant, making this research area increasingly important for the future of urban mobility.

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Appendix

Interview questions

City officials

(1) What are the biggest challenges facing your city in terms of transportation infrastructure and services?
(2) How do you see ITS integrating with smart city infrastructure addressing these challenges?
(3) What role do you see the city playing in the integration of ITS with smart city infrastructure?
(4) How do you prioritize the investment in ITS and smart city infrastructure compared to other city projects?
(5) What kind of collaboration do you see happening between city departments, technology providers, and citizens in integrating ITS with smart city infrastructure?

Transportation planners

(1) What are the main objectives of your transportation plan, and how do you see ITS integrating with smart city infrastructure helping to achieve these objectives?
(2) What specific transportation modes do you see being impacted by the integration of ITS with smart city infrastructure?
(3) How do you see the integration of ITS with smart city infrastructure changing the way people move around the city?
(4) What are the potential challenges in terms of data sharing and coordination between different transportation modes and agencies in integrating ITS with smart city infrastructure?
(5) How do you envision the role of public transportation in the integrated smart city infrastructure?

Technology providers

(1) What ITS technologies do you see as having the most impact when integrated with smart city infrastructure?
(2) How do you see your technology being used in the integrated smart city infrastructure?
(3) What are the main challenges in integrating ITS technologies with smart city infrastructure from a technical perspective?
(4) How do you see the integration of ITS technologies with smart city infrastructure changing the way people interact with transportation systems?
(5) What kind of data analytics and insights do you see being generated by the integration of ITS technologies with smart city infrastructure?

Citizens

(1) How do you currently use transportation systems in your daily life, and how do you see the integration of ITS with smart city infrastructure changing your experience?
(2) What are the most important factors for you when it comes to transportation, such as safety, convenience, cost, and environmental impact?
(3) How do you see the integration of ITS with smart city infrastructure impacting these factors?
(4) What kind of information and services would you like to see provided through an integrated smart city transportation system?
(5) How do you see the integration of ITS with smart city infrastructure changing the way you interact with your city and its transportation systems?