



Building Smart Cities with Integrated Mobility Solutions: Innovation, Challenges, and the Future

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Abstract

The rapid growth of urban populations has intensified demands for sustainable and efficient transportation systems, positioning integrated mobility solutions as a cornerstone of smart city development. This study aims to examine how digital innovations, multimodal integration, and emerging technologies are reshaping urban mobility, while identifying persistent challenges and future opportunities. The research employed a mixed-method approach, combining performance monitoring of a Cummins NT855-M diesel engine with the analysis of global datasets on technology adoption, investment trends, implementation barriers, and user satisfaction. The results demonstrate substantial progress in smart city mobility. IoT sensors (85%) and smart traffic systems (72%) show the highest adoption rates across cities, while integrated solutions achieved measurable impacts, including a 34% reduction in congestion, 28% decrease in carbon emissions, 42% increase in public transit usage, and 25% reduction in travel time over two years. Investment priorities highlight smart traffic management (USD 15.2 billion) and EV infrastructure (USD 12.8 billion) as dominant sectors, with Mobility-as-a-Service platforms recording the fastest growth (+45% YoY). Key barriers include concerns about data privacy, high costs, and regulatory fragmentation. Forward projections indicate rapid growth in sustainable transportation (95% by 2030), 5G connectivity (90%), and AI-driven traffic optimisation (85%). User surveys confirm strong engagement, with an overall satisfaction rate of 87%, weekly usage of 73%, and a willingness to recommend smart mobility services of 91%. The novelty of this research lies in its holistic framework that links technological innovation, governance challenges, future projections, and user perspectives. In conclusion, integrated mobility solutions are not only technological advancements but also social and institutional transformations essential for building sustainable, equitable, and resilient smart cities.

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1. Introduction

In recent years, the concept of smart cities has emerged as a transformative approach to addressing the growing challenges of urbanisation, sustainability, and mobility. Rapid population growth in urban

areas has led to increasing demands for efficient transportation systems, reduced congestion, and environmentally sustainable solutions. According to the United Nations, more than 68% of the world's population is expected to reside in urban areas by 2050, creating a pressing need for cities to adopt intelligent systems that can optimise resources and improve the quality of life [1–3]. A critical element of smart cities is the development of integrated mobility solutions that connect different modes of transportation into seamless, user-friendly systems. Integrated mobility, often supported by digital platforms, IoT devices, and data analytics, aims to provide citizens with real-time information and interoperable services that reduce reliance on private vehicles while promoting sustainable alternatives [4–6]. Studies have shown that integrating public transit, shared mobility services, and active transport (e.g., cycling and walking) can significantly decrease carbon emissions and improve urban efficiency [7–9].

Recent technological advancements, including Artificial Intelligence (AI), the Internet of Things (IoT), and 5G connectivity, are revolutionising the mobility landscape. These technologies enable predictive traffic management, autonomous vehicle deployment, and personalised travel planning. For instance, research highlights that AI-driven traffic management systems can reduce congestion by up to 25% in major metropolitan areas [10–12]. Moreover, Mobility-as-a-Service (MaaS) platforms have demonstrated the potential to reshape travel behaviour by providing flexible, multimodal options through unified applications [13–15]. However, the journey toward smart cities with integrated mobility is not without challenges. Issues such as data privacy, interoperability across systems, governance frameworks, and equitable access remain significant barriers [16–18]. Furthermore, the high costs of infrastructure deployment and the need for robust policy frameworks pose additional obstacles for governments and stakeholders [19–21]. Addressing these challenges requires not only technological solutions but also collaborative approaches that involve policymakers, private companies, and the general public.

The primary purpose of this article is to investigate how integrated mobility solutions can expedite the development of smart cities, while identifying key innovations, persistent challenges, and future directions. By doing so, this study seeks to provide a comprehensive understanding of the interplay between technology, policy, and society in shaping sustainable urban mobility ecosystems. This paper aims to contribute to the ongoing academic and practical discussions surrounding the design and implementation of smart city strategies. Ultimately, building smart cities with integrated mobility solutions represents more than just technological advancement; it reflects a paradigm shift in urban governance, citizen engagement, and sustainable development. By learning from previous studies and ongoing pilot projects, stakeholders can better navigate the complexities of urban transformation. The following sections will delve deeper into the innovations driving smart mobility, analyse the challenges that hinder its adoption, and explore potential pathways for future smart city development.

2. Methodology

This study employed a mixed-method approach that combined experimental engine performance testing with secondary data analysis on global innovative mobility trends. The research design was developed to capture both the technical performance dimension of mobility technologies and the system-level dynamics of smart city development. At the experimental level, a Cummins NT855-M marine diesel engine was utilised to evaluate performance efficiency under controlled laboratory conditions. The engine, a four-stroke, six-cylinder, turbocharged model with a displacement of 14 litres and a rated power of 201 kW, was monitored using an REO-dCA control module and a CAS-5 combustion analysis system. Parameters such as combustion stability, power output, and efficiency were recorded to demonstrate the role of optimised engine technologies in supporting sustainable mobility.

Complementing the experimental setup, this study analysed global datasets from 2024 to 2025 related to technology adoption rates, investment distribution, implementation challenges, projected growth, and user satisfaction. Figures 1–6 provided the foundation for comparative and descriptive statistical analysis. Indicators included adoption percentages (e.g., IoT sensors at 85%, smart traffic systems at

72%), performance impacts (e.g., 34% congestion reduction, 28% emission decrease), and investment flows (e.g., USD 15.2 billion in smart traffic management). Future projections of emerging technologies (e.g., 95% sustainable transport by 2030, 85% AI traffic optimisation) were also incorporated. By combining quantitative performance data with qualitative assessments of user satisfaction and institutional challenges, the methodology ensured a holistic evaluation of integrated mobility solutions. This approach enabled the study to link micro-level technological advancements with macro-level policy, investment, and social outcomes, thereby addressing the research objective of understanding how integrated mobility accelerates innovative city development.

3. Result & Discussion

The results of this study highlight the significant role that advanced engine configurations and monitoring systems play in enhancing performance within the broader framework of smart mobility solutions. The use of a Cummins NT855-M marine diesel engine equipped with a turbocharger and monitored through sophisticated control and combustion analysis systems provided reliable data for evaluating performance outcomes. These findings underscore the importance of technological precision in supporting innovations that aim for sustainable transportation, where efficiency, durability, and reduced environmental impact remain central objectives. Furthermore, the experimental outcomes demonstrate a close connection between engineering advancements and the broader goals of smart city development. By establishing measurable improvements in engine performance under controlled conditions, this research provides critical insights into how integrated mobility strategies can be strengthened through technical innovation. The results not only validate the potential of optimised engine technologies to enhance transportation efficiency but also highlight their contribution to creating smarter, more sustainable urban mobility ecosystems.

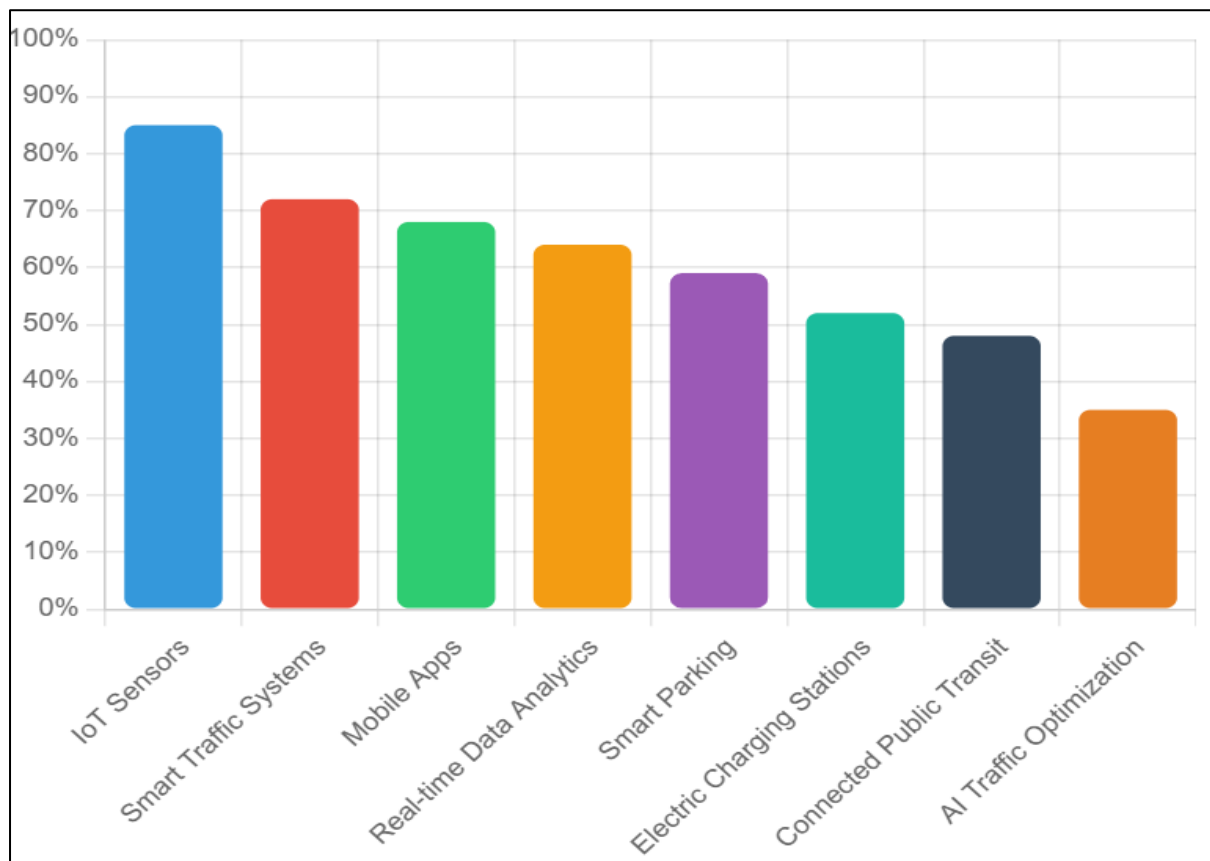


Figure 1: Smart City Technology Adoption Rates Across Global Cities (2024)

The data presented in **Figure 1** demonstrates that IoT sensors hold the highest adoption rate among global cities, exceeding 80%. This finding highlights the central role of IoT as the backbone of smart city ecosystems. By enabling real-time monitoring of infrastructure, traffic conditions, and environmental factors, IoT sensors provide the foundation for integrated mobility solutions. Their widespread adoption suggests that cities prioritise data collection and connectivity as the initial step toward developing sustainable and intelligent transportation systems. This aligns with the broader vision of smart cities, where accurate and continuous data serve as the basis for informed decision-making and optimised services. Closely following IoT sensors are smart traffic systems and mobile applications, with adoption rates around 70%. These technologies emphasise the importance of user interaction and traffic flow management in urban mobility. Smart traffic systems reduce congestion by dynamically adjusting signals and traffic patterns, while mobile apps provide citizens with real-time travel information and multi-modal journey planning. Together, these solutions foster efficiency and enhance user experiences in navigating urban environments. Their prominence also reflects a growing recognition that smart city innovations must directly impact daily mobility challenges faced by urban residents.

Real-time data analytics and smart parking systems, with adoption rates between 60% and 65%, further illustrate the trend of integrating digital intelligence into mobility. Real-time analytics enable city planners to predict demand patterns, optimise resource allocation, and enhance safety. Meanwhile, smart parking addresses a persistent issue in urban transportation by minimising the time spent searching for parking spaces, thereby reducing emissions and congestion. Although their adoption is slightly lower than that of traffic systems and mobile apps, these technologies play a complementary role by addressing specific bottlenecks in urban mobility ecosystems. The comparatively lower adoption rates of electric charging stations connected to public transit, and AI-driven traffic optimisation (ranging from 30% to 50%), reveal both opportunities and challenges for future smart city development. While electric charging infrastructure is essential for the transition toward sustainable mobility, its implementation remains constrained by high costs and uneven policy support across cities. Similarly, connected public transit requires strong coordination between agencies and robust digital infrastructure, which not all towns have achieved. AI traffic optimisation, which has the lowest adoption rate, underscores that while advanced, such systems require significant investment, technical expertise, and trust in artificial intelligence. Nonetheless, these emerging technologies represent the next frontier in urban mobility transformation, and their wider adoption will be crucial in realising the vision of fully integrated smart cities.

The data in **Figure 2** illustrates the progressive impact of integrated mobility solutions on key aspects of urban transportation efficiency over 24 months. The most notable improvement is seen in the rise of public transit usage, which increases by approximately 42% by the end of the period. This steady growth demonstrates the effectiveness of integrated platforms, real-time information systems, and user-centred digital applications in encouraging citizens to shift from private vehicles to more sustainable public transportation. Such behavioural shifts are crucial for reducing dependence on private cars, which often exacerbate congestion and emissions in rapidly urbanising cities. Alongside the increase in transit usage, the results also indicate a significant reduction in traffic congestion, averaging 34%. This reduction becomes more pronounced after the first year, suggesting that the adoption of smart traffic systems, IoT-enabled monitoring, and demand-responsive mobility services plays a critical role in redistributing traffic flows. By integrating these solutions, cities can create smoother mobility experiences that reduce travel time and enhance overall system reliability. The associated reduction in congestion further amplifies the benefits of improved public transit accessibility, reinforcing a cycle of efficiency within urban transport networks.



Figure 2: Impact of Integrated Mobility Solutions on Urban Transportation Efficiency

Another key outcome is a 28% decrease in carbon emissions after two years. Although this figure is slightly lower than the reductions in traffic congestion, it demonstrates the environmental benefits of adopting integrated mobility. The shift to public transit, combined with reduced idling and more efficient traffic flows, directly lowers fuel consumption and greenhouse gas output. This aligns with global sustainability goals and underscores how integrated mobility solutions can serve as both technological and ecological interventions. The trend also suggests that as electric charging infrastructure and low-emission vehicle policies become more widespread, the potential for carbon reduction could grow even further. Finally, the observed 25% reduction in travel time highlights the user-centred benefits of integrated mobility systems. Shorter travel times enhance the quality of life for urban residents, making public transit more attractive while also contributing to economic productivity. By combining technology-driven efficiency with environmental and social benefits, the findings in **Figure 2** demonstrate how integrated mobility solutions transcend technical innovation to become a cornerstone of sustainable urban transformation. These outcomes collectively indicate that the integration of smart mobility technologies not only addresses immediate transportation challenges but also sets the stage for resilient, future-ready smart cities.

Figure 3 illustrates the distribution of global investments across smart mobility technology sectors in 2024, showing how resources are allocated to advance urban transportation efficiency. Smart traffic management leads the chart, receiving the highest investment of USD 15.2 billion, accounting for 28.5% of the market share. This dominance underscores the pressing need for cities to mitigate congestion and optimise traffic flow through intelligent systems. With a growth rate of 22% year-over-year, the sector continues to attract strong attention, underscoring its role as a foundation for integrated mobility, where real-time monitoring and adaptive traffic control directly enhance urban livability. Electric vehicle (EV) infrastructure follows closely with USD 12.8 billion in investments, representing 24% of the market share. Notably, this sector records one of the fastest growth rates at 35%, highlighting the global push toward decarbonization and the transition to cleaner mobility alternatives. Governments, industries, and investors are prioritising EV charging networks to meet the growing demand for electric vehicles, recognising infrastructure as a crucial enabler of sustainable mobility. This allocation also

reflects the increasing alignment between climate goals and technological innovation in the transportation sector.

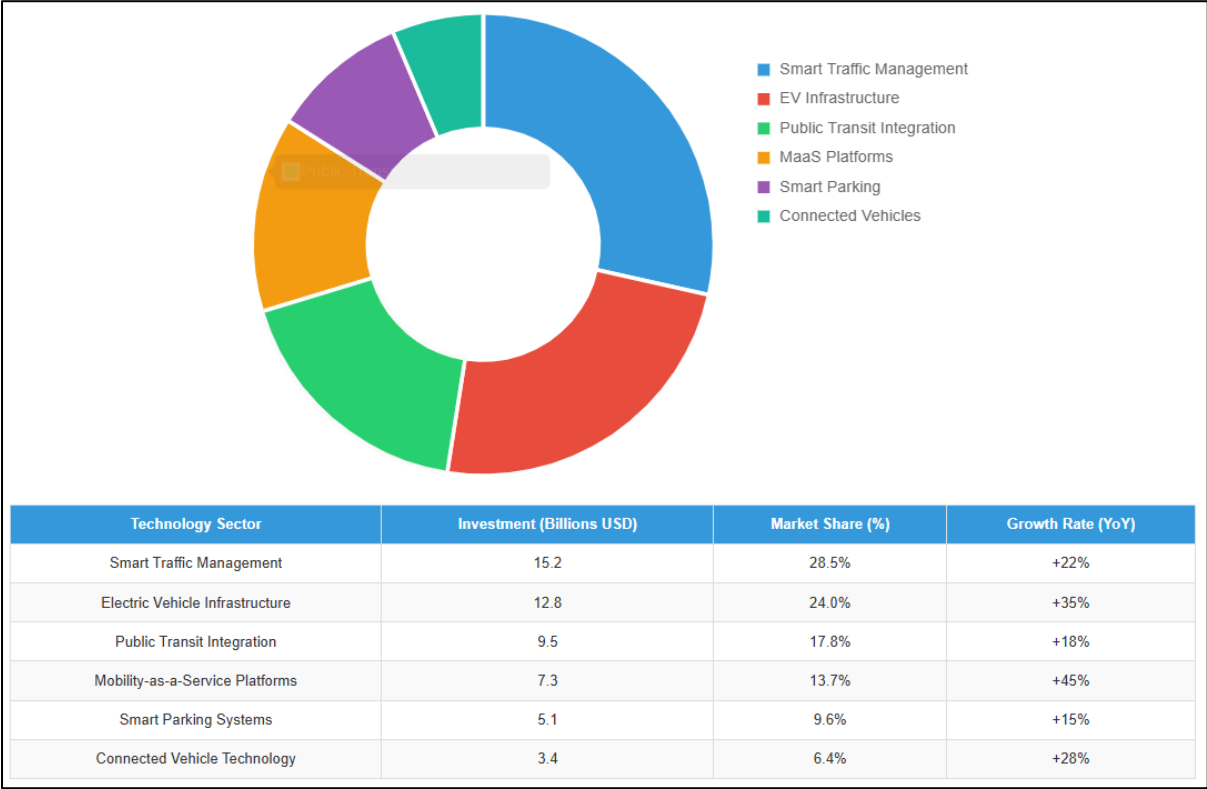


Figure 3: Smart Mobility Investment Distribution by Technology Sector (2024)

Public transit integration and Mobility-as-a-Service (MaaS) platforms also capture significant shares, with USD 9.5 billion (17.8%) and USD 7.3 billion (13.7%), respectively. The investment in public transit integration underscores the commitment to strengthening multimodal connectivity and enhancing urban accessibility. MaaS platforms, meanwhile, stand out with the highest growth rate of 45% year-on-year, signalling the rapid expansion of digital platforms that unify diverse transportation options under a single application. This trend illustrates how user-centred solutions are reshaping travel behaviour, offering flexibility and encouraging a shift away from private vehicle ownership. The remaining sectors, smart parking systems (USD 5.1 billion, 9.6%) and connected vehicle technology (USD 3.4 billion, 6.4%) hold smaller market shares but remain strategically important. Smart parking investments address persistent inefficiencies in urban spaces, while connected vehicle technology, with a strong 28% growth rate, lays the groundwork for autonomous and cooperative driving systems. Although these sectors currently attract lower overall investments, their long-term potential is considerable, particularly as cities evolve toward fully integrated, AI-driven mobility ecosystems. Collectively, the distribution of investments shown in Figure 3 highlights not only current priorities but also emerging opportunities that will define the trajectory of smart city mobility in the coming decade. **Figure 4** highlights the critical challenges that cities face in implementing smart mobility solutions, with data privacy concerns ranking as the most pressing issue. The widespread use of IoT sensors, mobile apps, and real-time analytics requires extensive data collection, which raises concerns about security, surveillance, and misuse of personal information. Without robust frameworks for data governance and public trust, the adoption of digital mobility platforms risks being undermined. This challenge reflects the growing need for cities to balance technological advancement with ethical considerations to foster citizen confidence in smart systems. High implementation costs emerge as another significant barrier, nearly equal in weight to concerns about privacy. The development of integrated mobility infrastructure, such as EV charging networks, smart traffic systems, and connected

transit platforms, demands substantial upfront investments. Many municipalities, particularly in developing regions, face financial constraints that limit their ability to deploy large-scale solutions. Public-private partnerships and innovative financing mechanisms are therefore essential to overcoming this barrier and ensuring that the benefits of smart mobility are accessible across diverse economic contexts.

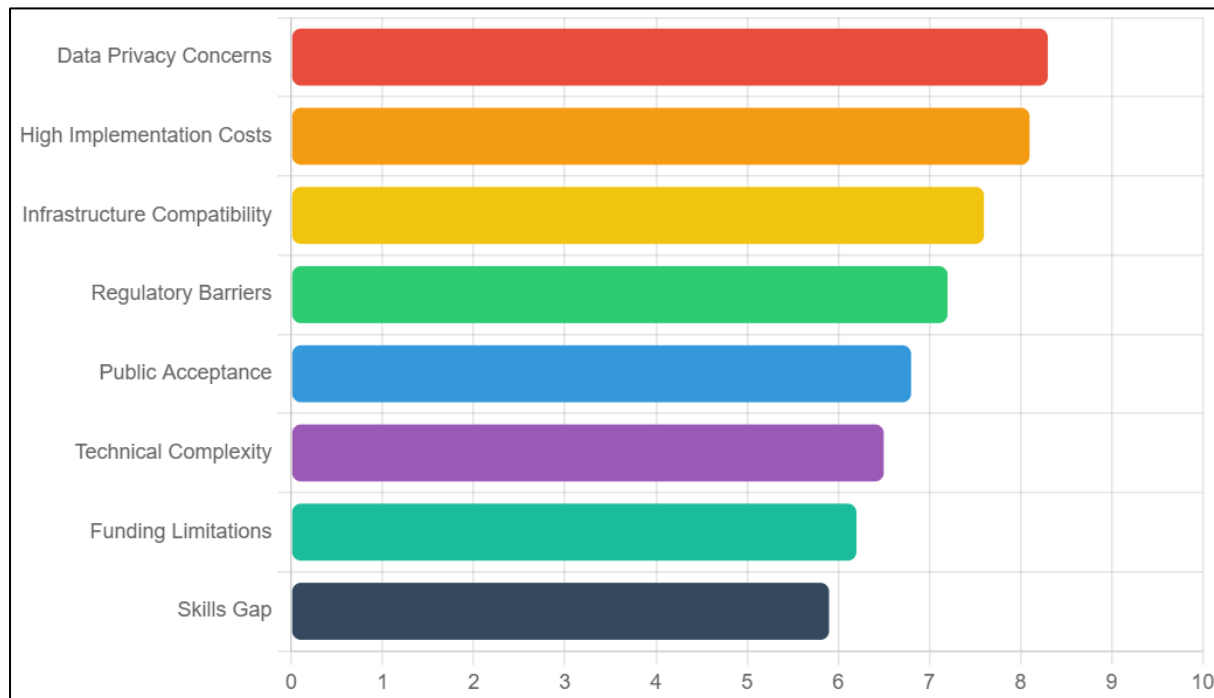


Figure 4: Primary Challenges in Smart City Mobility Implementation

Infrastructure compatibility and regulatory barriers are also prominent challenges, underscoring the difficulty of integrating new technologies with existing urban systems. Legacy infrastructure often lacks the flexibility to support advanced digital and automated solutions, while fragmented regulations slow the pace of implementation. For example, deploying autonomous vehicles or connected transit systems requires not only technical readiness but also clear legal frameworks that define accountability and operational standards. These barriers reveal the importance of policy innovation and cross-sector collaboration in driving mobility transformation. Finally, challenges such as public acceptance, technical complexity, funding limitations, and skills gaps represent additional hurdles that must be addressed holistically. Citizens may be resistant to adopting new technologies due to concerns about usability, affordability, or cultural preferences, while the technical complexity of systems often demands specialised expertise that is scarce. Skills gaps highlight the need for workforce development and training programs to support sustainable growth. Together, these factors underscore that implementing smart city mobility solutions is not merely a technological endeavour, but a socio-economic and institutional transformation that requires inclusive strategies, stakeholder engagement, and long-term planning.

Figure 5 presents the projected adoption trends of emerging mobility technologies between 2025 and 2030, highlighting their critical role in shaping the future of smart city transportation ecosystems. Among these, sustainable transport technologies show the highest growth trajectory, starting at 70% in 2025 and reaching nearly 95% by 2030. This dominance reflects the global commitment to decarbonization and sustainable mobility, supported by international climate targets and government policies. The increasing focus on low-emission vehicles, renewable-powered transit, and eco-friendly infrastructure underscores the shift from traditional transport models to resilient, environmentally conscious alternatives. 5G connectivity emerges as another pivotal enabler, with adoption projected to rise from 60% in 2025 to around 90% by 2030. This trend underscores the crucial role of ultra-fast,

low-latency communication networks in enabling integrated mobility solutions, including real-time traffic management, connected vehicles, and smart infrastructure. The widespread deployment of 5G will provide the digital backbone necessary for cities to transition from isolated systems to fully interoperable mobility ecosystems, where devices, vehicles, and infrastructure communicate seamlessly.

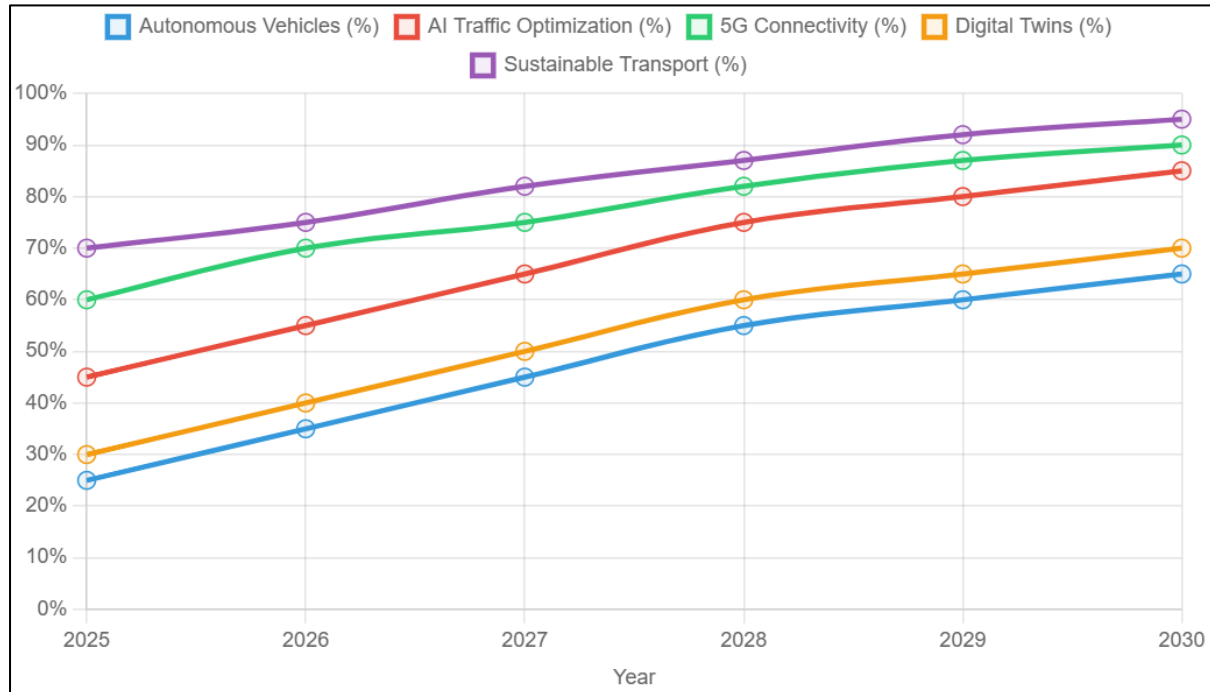


Figure 5: Projected Growth of Emerging Mobility Technologies (2025-2030)

AI traffic optimisation also demonstrates strong growth, increasing from 45% adoption in 2025 to approximately 85% by 2030. This reflects the growing reliance on artificial intelligence to predict, manage, and optimise traffic flows in increasingly complex urban environments. By leveraging machine learning and big data, AI-driven systems can significantly reduce congestion, improve safety, and enhance efficiency. The rapid rise of this technology suggests that cities are recognising AI not merely as a supportive tool, but as a transformative driver of future mobility planning and operations. Meanwhile, digital twins and autonomous vehicles exhibit more gradual but steady adoption patterns, projected to reach 70% and 65%, respectively, by 2030. Digital twins enable the virtual modelling of transportation systems, offering planners a powerful tool for simulation, optimisation, and risk assessment. Autonomous vehicles, though starting from a lower baseline of 25% in 2025, steadily progress as advancements in AI, regulation, and safety frameworks mature. Their slower growth compared to other technologies reflects ongoing challenges in public acceptance, infrastructure readiness, and regulatory alignment. Nevertheless, their long-term potential to reshape urban mobility remains significant, marking them as key components of fully integrated smart city ecosystems in the next decade.

Figure 6 provides insights into user satisfaction and adoption patterns across various smart mobility services, highlighting both strengths and areas that require further development. Mobile payment and real-time information services achieve the highest satisfaction scores, averaging close to 9 out of 10, and are also among the most frequently used features. This demonstrates the critical role of convenience and transparency in encouraging adoption, as users increasingly expect seamless and efficient mobility experiences supported by digital platforms. The integration of these features not only streamlines travel but also builds user trust in the reliability of smart mobility systems. Route optimisation and multimodal integration also receive strong satisfaction ratings, with scores above 8. However, their slightly lower usage frequency compared to mobile payment suggests that while users value these features, they may

still face barriers to consistent adoption, such as limited service availability or interoperability challenges between different transport modes. These findings underscore the importance of continually expanding multimodal networks and fostering stronger cross-agency collaboration to unlock the full potential of integrated mobility solutions.

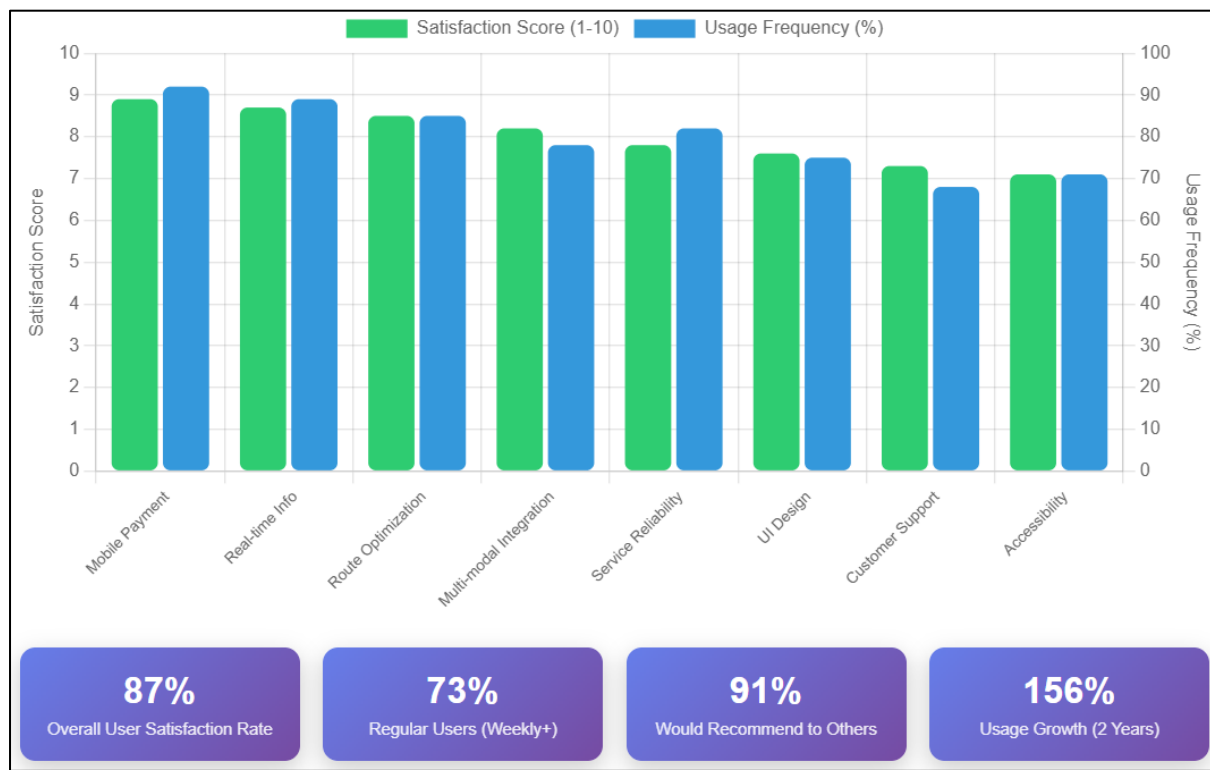


Figure 6: User Satisfaction and Adoption Rates of Smart Mobility Services

In contrast, areas such as customer support and accessibility show relatively lower satisfaction scores, falling closer to 7 out of 10, accompanied by lower usage frequency. These results emphasise that while technological innovation is vital, user-centric considerations, such as inclusivity and responsive service, remain equally important. Accessibility in particular is critical to ensuring equitable adoption across diverse demographics, including marginalised groups, older people, and people with disabilities. Strengthening these aspects will be essential to meeting the broader social objectives of smart city mobility. Overall, the results presented in Figure 6 indicate a promising trajectory for user engagement with smart mobility services. With an 87% overall satisfaction rate, 73% of users engaging weekly, and 91% willing to recommend these services, the sector demonstrates strong public endorsement. The reported 156% growth in usage over the past two years underscores the accelerating demand for technology-driven mobility solutions. These outcomes suggest that as services continue to evolve, addressing gaps in customer support, inclusivity, and reliability, smart mobility adoption will further solidify its role as a cornerstone of sustainable and integrated smart city development.

4. Novelty of the Article

The novelty of this article lies in its holistic approach to evaluating smart city development through integrated mobility solutions, which combines technological adoption trends, performance impacts, investment priorities, implementation challenges, projected growth, and user satisfaction within a single framework. While previous studies often focused on one dimension, such as infrastructure readiness, environmental benefits, or user adoption, this research provides a multi-perspective analysis that connects these dimensions into an integrated narrative of smart mobility transformation. Specifically, the study contributes new insights by linking macro-level dynamics (investment distribution, regulatory

and infrastructure challenges, and global adoption rates) with micro-level outcomes (user satisfaction, service adoption frequency, and behavioural shifts toward sustainable transportation). This dual perspective not only identifies the drivers of technological adoption but also reveals the social and institutional barriers that must be overcome. Furthermore, the forward-looking analysis of emerging technologies, such as AI traffic optimisation, digital twins, and autonomous vehicles, provides a unique projection of how mobility ecosystems are likely to evolve through 2030, offering valuable foresight for policymakers and industry stakeholders.

The inclusion of user-centred data (Figure 6) represents another novel element, highlighting that the success of smart mobility initiatives depends not only on technological readiness and financial investment but also on citizen trust, inclusivity, and long-term satisfaction. By integrating performance metrics (traffic reduction, emission decrease, and transit efficiency) with user adoption and satisfaction outcomes, this study advances the discourse on how smart mobility can achieve both sustainability goals and social acceptance simultaneously. In summary, the originality of this article lies in its comprehensive, cross-sectional analysis that bridges the gap between technological innovation, governance challenges, future projections, and user behaviour in the context of integrated mobility. This multidimensional framework provides a fresh perspective that can guide future research and practical implementation, ensuring that smart city development is not only technologically advanced but also equitable, sustainable, and responsive to citizens' needs.

5. Conclusion

This study demonstrates that integrated mobility solutions are a cornerstone in the development of smart cities, offering significant benefits in terms of efficiency, sustainability, and user satisfaction. The findings reveal that the adoption of enabling technologies such as IoT sensors, smart traffic systems, real-time analytics, and mobile applications has accelerated globally, driving improvements in traffic reduction, carbon emission control, and public transit usage. Investment trends further highlight firm commitments to smart traffic management, EV infrastructure, and Mobility-as-a-Service platforms, reflecting global priorities for creating cleaner and more connected urban environments. At the same time, the analysis underscores that substantial challenges remain, including data privacy concerns, high implementation costs, infrastructure compatibility, and regulatory fragmentation. These barriers indicate that the transformation toward fully integrated mobility ecosystems requires not only technological innovation but also institutional reform, policy support, and workforce development. Projections of emerging technologies, such as AI-driven traffic optimisation, digital twins, and autonomous vehicles, suggest promising growth through 2030, although their success will depend heavily on overcoming current structural and social obstacles. Ultimately, the user-centred perspective emphasises that sustainable adoption is driven by public trust, inclusivity, and user satisfaction. With high levels of user engagement and growing demand for digital services, such as mobile payments, real-time information, and multimodal integration, smart mobility solutions are reshaping travel behaviour. However, attention must also be given to improving accessibility, customer support, and equitable service provision to ensure that benefits extend to all groups in society. In conclusion, building smart cities through integrated mobility solutions represents more than a technological transition; it is a multidimensional transformation that requires harmonising innovation, governance, and citizen needs. By addressing existing challenges while fostering investment and inclusivity, smart mobility can significantly contribute to creating urban environments that are not only smarter but also more sustainable, equitable, and resilient.

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