

Smart Mobility as a Key Enabler of Smart Cities: Technologies, Governance, and Sustainability Challenges

Nouhaila Belmajdoub

Agronomic and Veterinary Institute of Hassan II
Rabat, Morocco
email: n.belmajdoub@iav.ac.ma

Kenza Ait El Kadi

Agronomic and Veterinary Institute of Hassan II
Rabat, Morocco
email: k.aitelkadi@iav.ac.ma

Abstract— Rapid and continuous urbanization is placing increasing pressure on urban transport systems, infrastructures, and city energy systems. In response to these challenges, the concept of the Smart City has emerged as a strategic framework aimed at improving urban efficiency through the integration of digital technologies and sustainable energy solutions. Among its various components, Smart Mobility occupies a central position, as it directly conditions access to services, economic performance, and environmental sustainability. This paper provides a literature review with an analysis of Smart mobility as a structuring lever of the smart city. It demonstrates that smart mobility goes well beyond the mere technological modernization of transport systems, constituting a genuine data infrastructure able to transform urban management from a reactive approach to a predictive and integrated one. The study highlights the essential role of Geographic Information Systems (GIS), geospatial intelligence, intelligent transport systems, and digital twins in optimizing mobility flows, reducing gas emissions, and improving the safety and reliability of travel. However, these technological advances are accompanied by significant challenges. Issues related to data governance, privacy protection, territorial equity, and social inclusion limit the effectiveness of purely technology-driven approaches. The analysis also draws attention to the persistent tension between traffic optimization and genuine sustainability, particularly with regard to the energy footprint of digital infrastructures. Overall, smart mobility emerges as a fundamental component of the smart city, provided it is conceived as a comprehensive form of urban intelligence in which technical, social, and environmental dimensions are inseparable. Its success ultimately depends on the ability to reconcile technological innovation, spatial justice, and long-term sustainability.

Keywords- *Smart City; Smart Mobility; Geographic Information Systems; Intelligent Transportation Systems; Digital Twins.*

I. INTRODUCTION

Urbanisation worldwide has reached historic levels, with more than 55 % of the population living in urban areas, a share expected to rise to 68 % by 2050 according to the United Nations Department of Economic and Social Affairs [14]. This demographic concentration creates strong pressure on infrastructure networks, air quality, and social cohesion. In response, the Smart City concept has become the dominant framework for modern urban management. Built on the massive integration of Information and Communication Technologies (ICT), a smart city aims to optimise resource use in order to ensure economic growth and environmental sustainability [1].

The Smart City rests on six fundamental pillars: economy, citizens, governance, environment, lifestyle, and mobility and it is mobility that forms the true circulatory system of the city [4]. Smart Mobility does not simply mean vehicle electrification; it is a digital intelligence layer that overlays the physical space. Through geospatial intelligence, Geographic Information Systems (GIS), and digital twins, every movement is turned into usable data, allowing a shift from reactive to predictive territory management [11].

The main challenge of smart mobility lies in its ability to reduce negative externalities. By synchronising flows in real time, it promises a major time saving for users, a significant reduction in CO₂ emissions, and increased efficiency of existing infrastructure without requiring costly extensions [7]. However, the academic literature highlights blind spots, especially regarding personal data protection and the social inclusion of marginalized populations [2].

This study is based on a qualitative review of existing literature on smart mobility and smart cities, without primary data or empirical case studies. As a result, the analysis reflects published concepts and theoretical perspectives, which may overlook emerging practices. In addition, the selection of sources is limited by database coverage and language constraints. Finally, the study does not empirically assess the actual sustainability impacts of smart mobility initiatives, highlighting the need for future research to evaluate their effects on energy efficiency and greenhouse-gas emissions.

The rest of the paper is organized as follows. Section III presents the concept of smart city, with a focus on smart mobility, and reviews prior research and recent advances in intelligent cities and urban mobility systems. And also provides a definition and examines the central role of smart mobility, its technical foundations (with special attention to GIS and geospatial intelligence), and its importance in urban transformation, highlighting contributions to efficiency, sustainability, and resilience, as well as the concept of Mobility-as-a-Service (MaaS) in urban development. Section IV integrates the main findings from the literature and offers a critical analysis of strengths, gaps, and emerging trends.

II. SMART MOBILITY AS A STRATEGIC PILLAR OF THE SMART CITY

A. Smart city and smart mobility: conceptual background

A smart city is not just a city equipped with Wi-Fi cameras and various gadgets; it is a comprehensive concept that aims to improve citizens quality of life, environmental sustainability, and public-service efficiency through the combined use of ICT and Artificial Intelligence (AI).

The smart city is portrayed as an urban ecosystem that employs ICT to enhance urban-service quality and lower costs. It rests on six interconnected dimensions [4]. The smart city is also described as an urban system where information technologies act as a lever to improve service efficiency [1]. The “Smart Mobility” dimension goes beyond installing sensors; it includes multimodal mobility, Intelligent Transportation Systems (ITS), and sustainable logistics, thereby creating a genuine travel ecosystem that serves the entire city.

B. Definition and Central Role of Smart Mobility

First, the smart city is based on six dimensions as illustrated in Figure 1; Economy, Citizens, Governance, Environment, Lifestyle and Mobility, so Smart Mobility functions as the physical and digital connector [12]. Without smooth mobility, the other pillars (such as the economy or lifestyle) collapse under urban congestion. A city cannot claim to be “Smart” if its transport flows are inefficient [2], because mobility determines access to all other urban resources. By ensuring fluid movement, it creates the necessary foundation for the proper functioning of the other pillars; otherwise, road congestion threatens economic competitiveness, quality of life, and environmental sustainability [2].

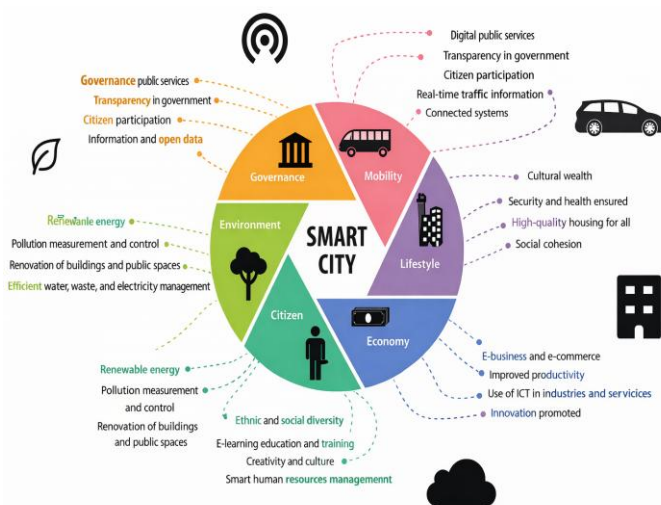


Figure 1. The six pillars of a Smart City [13].

The work of Albino et al. [1] shows that smart mobility is not limited to optimizing physical flows; it also includes digital platforms that can collect, analyse, and deliver real-time data from sensors, GIS, and mobile apps. This

“big-data” approach enables reference models that anticipate travel needs, cut travel times, and improve energy efficiency [5].

Figure 2 illustrates how these digital infrastructures such as GIS, IoT (Internet of Things) sensors, real-time data streams, ITS, digital twins and MaaS are woven together with the physical connectors (roads, public transport, bike lanes, pedestrians, electric vehicles) to form an integrated Smart Mobility ecosystem.

Moreover, sustainable-mobility initiatives especially in medium-sized northern cities demonstrate how combining multimodal infrastructure (public transport, shared bikes, autonomous vehicles) with incentive policies reduces CO₂ emissions while strengthening social inclusion [6]. Studies by Biyik et al. [3] and by Pribyl et al. [7] underline that the uptake of these solutions depends heavily on user perception, the availability of reliable services, and transparent governance.

In sum, smart mobility acts as the physical and digital “connector” of the smart city; it determines access to services, urban resilience, and a metropolis’s ability to become an attractive, sustainable hub.

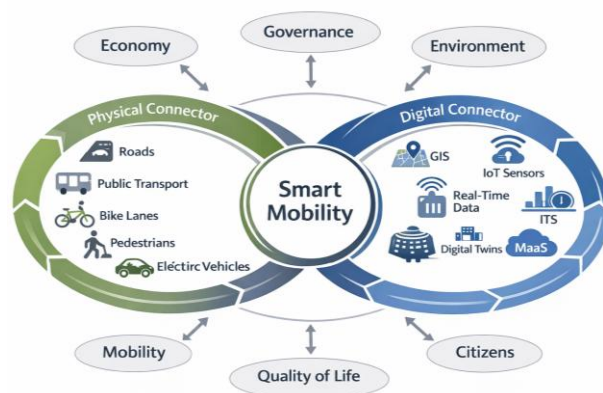


Figure 2. Smart Mobility in a Smart City.

C. Maintaining the Integrity of the Specifications

The proper functioning of smart mobility depends on a dense technical infrastructure, with GIS and geospatial intelligence forming its cognitive core. By aggregating massive real time, geo located data streams, GIS can model travel supply and demand with fine spatial and temporal precision, enabling dynamic decisions such as traffic signal adjustments, public vehicle reallocation, or congestion forecasting [5].

However, this approach mainly emphasizes a technico-operational view of mobility, giving limited attention to territorial inequalities and social dynamics that shape actual network use.

ITS converts these data into concrete actions by linking infrastructure (sensors, lights, signs) with users [7]. Dynamic signalling, automated intersection control, and real time information services illustrate how ITS improves overall flow while enhancing safety. Although these tools boost the

efficiency of the smart mobility network, their performance is often evaluated with city wide average indicators, which can mask spatial disparities between well served central neighborhoods and less favoured peripheral areas.

Digital twins are among the newest and most powerful contributions to Smart City. By creating a dynamic virtual replica of a city that is continuously fed by IoT sensors, they provide simulations where mobility scenarios (e.g., road works, accidents, new traffic directions) can be tested before real deployment [5]. This approach lets planners assess impacts on traffic flow, CO₂ emissions, and the resilience of the urban transport network without disrupting daily traffic. As a result, digital twins support more predictive and data-driven approaches to urban transport management.

To achieve these capabilities, however, digital twins rely on advanced digital infrastructures, including extensive sensor networks, high-capacity data transmission systems, and integrated data platforms. In cities where digital infrastructure remains uneven, these technological and financial requirements may limit the deployment and effectiveness of digital twin technologies for real-time urban management [5], [11]. Furthermore, their integration with ITS depends on reliable data flows and interoperable urban platforms, which remain significant challenges for many cities undergoing digital transformation [7], [8].

Furthermore, Yigitcanlar et al. [8] highlight that integrating these technologies must be paired with transparent governance and citizen participation to ensure acceptance and service equity. Savastano & al. [9] also stress the need for a continuous evaluation framework to measure the true “smart-ness” of mobility solutions and steer policies toward greater sustainability. Yet, the literature still struggles to offer fully integrated frameworks that combine fine-grained spatial analysis, multicriteria evaluation, and citizen participation, leaving a gap between technological innovation and territorial equity.

D. The Importance of Smart Mobility in Urban Transformation

GIS and sensor technologies constitute a technological foundation for making urban mobility genuinely sustainable. By combining spatial data with real-time flow information, they deliver three major benefits:

- Time optimization: Synchronizing traffic signals and providing dynamic routing shorten trips and waiting times, easing congestion and increasing user productivity [2].
- Energy efficiency and emission reduction: Fewer unnecessary stops lower greenhouse-gas emissions, aligning the city with a sustainability-first goal and the four pillars of smart mobility: technological, economic, social, and governance. This also reduces negative externalities and supports the transition to MaaS as a sustainability lever [6], [8].

- Safety and reliability: Better visibility of traffic flows enables effective actions, reduces vehicle conflicts, decreases accident numbers, and makes public-transport schedules more predictable, thereby strengthening user confidence [7].

By bringing together these effects, the technologies enable the emergence of MaaS, where dynamic planning, energy savings, and safety act as a single lever to transform the city into a resilient, inclusive system with a low carbon footprint [1], [5].

Figure 3 visualises this framework, placing Smart Mobility at the centre and linking the Technological, Economic, Social and Governance pillars to the shared outcomes of time optimisation, energy efficiency and safety.

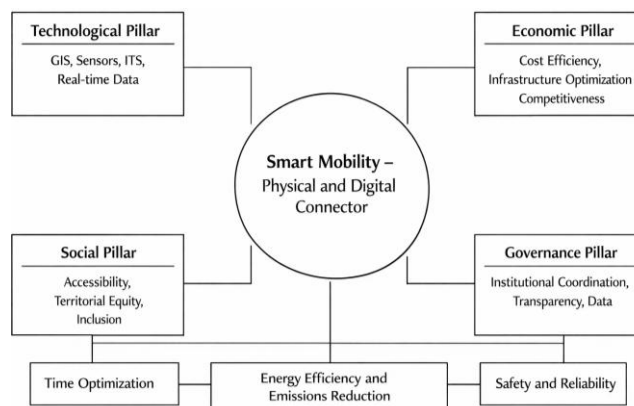


Figure 3. Smart Mobility as a physical and digital connector within the Smart City.

E. Smart Mobility and MaaS in Urban Development

MaaS refers to a digital platform that integrates heterogeneous transport options: public transit, shared mobility, bike-sharing, and on-demand ride-hailing into a single user-centric service providing real-time routing, booking, and payment [2], [8]. By leveraging GIS and sensor networks, MaaS transforms spatial temporal mobility data into actionable services, enabling dynamic multimodal trip planning that adapts to congestion, incidents, and changing travel conditions [7].

The main benefits of MaaS align with the core pillars of smart mobility. First, time optimization is achieved through integrated traffic management and adaptive routing, reducing travel time and minimizing waiting periods [3], [7]. Second, energy efficiency and emission reduction result from fewer unnecessary trips and a greater modal shift toward low-carbon transportation options, positioning MaaS as an important lever for sustainable urban mobility [6], [8]. Third, safety and reliability are enhanced through continuous traffic monitoring and improved coordination between different transportation modes [7].

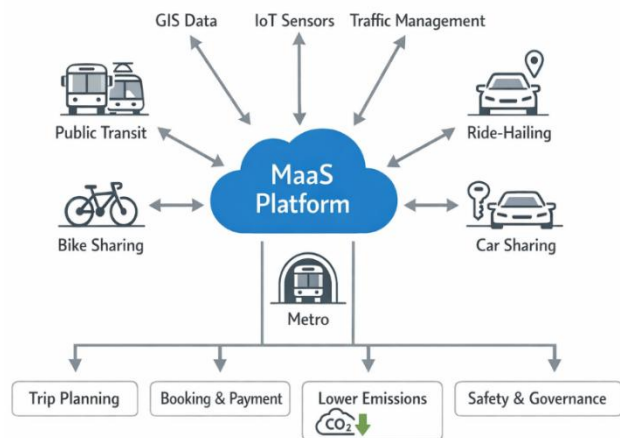


Figure 4. Integrated MaaS Platform for Multimodal Urban Transportation.

Figure 4 visualizes the integrated MaaS ecosystem: a central “MaaS Platform” cloud links eight mobility services such as public transit, metro, bike-sharing, ride-hailing, car-sharing, IoT sensors, traffic-management, and GIS data and feeds into four benefit blocks (trip planning, booking payment, reduced CO₂ emissions, and safety/governance). The figure also underscores how a single digital hub orchestrates diverse transport modes, turning real-time data into seamless, multimodal journeys for citizens.

Beyond these operational benefits, MaaS also supports governance and social equity by enabling data-driven mobility planning and providing digital platforms that improve accessibility to urban services [9]. However, the increasing reliance on mobility data requires transparent governance frameworks and robust data-privacy policies to mitigate potential surveillance risks. Successful implementation therefore depends on collaboration between city authorities, mobility providers, and citizens, ensuring that MaaS platforms remain interoperable, affordable, and responsive to local mobility needs [3], [8].

III. SYNTHESIS AND DISCUSSION

Smart Mobility operates continuously and adaptively; it captures the city’s real-time state, identifies needs through geospatial intelligence, and then adjusts mobility flows to optimize efficiency. It is no longer just a transport service but an intelligent layer that makes the urban environment predictable and resilient. As researchers such as Benevolo et al. [2] note, the goal is to create a “seamless city” where movement is no longer an obstacle to daily activity.

Current solutions often rely on centralized data platforms. This creates technological dependence, raises privacy-violation risks, and can exacerbate inequalities if the data do not equally reflect the usage patterns of the most vulnerable neighborhoods. Implementing a federated model where data are processed locally without distinction between center and periphery and where learning algorithms are

aggregated without transferring raw information can strengthen system resilience and facilitate citizen participation in flow governance. Alternatively, a pilot Smart Mobility program could be launched in a midsize city, then compared on congestion, CO₂ emissions, user satisfaction, and territorial equity indicators against a centralized scenario. This would allow analysis of how decentralized governance influences public trust and long-term sustainability.

In the literature, two clear strands can be distinguished: the “systems” approaches and the “user-oriented” approaches. Pribyl et al. [7] argue that cyber-physical infrastructure (V2X) can improve efficiency, reduce congestion, and ease traffic flow. By contrast, Yigitcanlar et al. [8] claim that this view is incomplete unless environmental sustainability is placed at the core of design as a primary constraint. Where Pribyl treats technology as a direct solution, Yigitcanlar suggests a more suitable answer by introducing “Smart and Sustainable Mobility,” noting that smooth traffic is meaningless if it simply induces a larger overall vehicle volume.

Regarding adoption, a comparison of Biyik et al. [3] with Müller-Eie and Kosmidis [6] reveals fundamental differences. Biyik adopts a methodology focused on the individual psychology of users, while Müller-Eie emphasizes urban design and municipal planning. Müller-Eie’s method appears more effective for public policymakers because it demonstrates that physical infrastructure (connected bike lanes, pedestrian zones) is a more powerful lever than mere technological or psychological incentives.

Finally, the debate over data governance pits Lim et al. [5] against Savastano et al. [9]. Lim proposes a reference model that centralizes big-data to optimize services, a method that prioritizes overall network performance. In contrast, Savastano adopts a far more critical stance that aligns with current democratic concerns: he argues that a city’s intelligence should be measured by its ability to remain resilient and inclusive without relying on massive surveillance. This clash highlights that Savastano’s approach, although less “optimizing” on paper, offers a more sustainable solution for urban social cohesion by avoiding the algorithmic biases inherent in the centralized models advocated by Lim.

IV. CONCLUSION AND FUTURE WORK

Smart mobility should no longer be seen merely as a transport service but as the core data infrastructure that truly makes a city “Smart” [1]. Its concrete contribution to urban performance relies on the integration of geospatial intelligence and GIS. These tools transform static territorial management into dynamic, predictive management, helping to reduce congestion and CO₂ emissions through ITS [8]. The MaaS model merges public and private offerings into a single interface, encouraging a shift away from private-vehicle use [2].

In the literature, two clear currents are distinguished; the “systems” approaches, which rely on cyber-physical infrastructure (V2X) to ease traffic, and the “user-oriented” approaches, which place environmental sustainability in the

heart of design. The former treats technology as a direct solution, while the latter stresses that improving traffic flow must not encourage an increase in vehicle numbers.

On the adoption front, studies contrast an individual-psychology perspective of the user with an approach focused on urban design and municipal planning. The latter demonstrates that physical infrastructure such as connected bike lanes and pedestrian zones serves as a more powerful lever than purely technological or behavioral incentives.

Finally, the debate over data governance pits a centralized model, optimized for network performance, against a critical vision that prioritizes resilience and inclusion without massive surveillance. This contrast highlights the need for governance frameworks that supports urban social cohesion.

Future research could further explore how these technological, spatial, and governance dimensions can be effectively integrated in real urban contexts. In particular, empirical studies and case-based analyses would help assess the actual sustainability impacts of Smart Mobility solutions and evaluate how emerging tools such as digital twins or MaaS platforms can contribute to more resilient and inclusive urban mobility systems.

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