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Review

Exploring Smart Mobility Potential in Kinshasa (DR-Congo) as a Contribution to Mastering Traffic Congestion and Improving Road Safety: A Comprehensive Feasibility Assessment

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Abstract: The urban landscape of Kinshasa, Democratic Republic of Congo, faces significant mobility challenges, primarily stemming from rapid urbanization, overpopulation, and outdated infrastructure. These challenges necessitate the exploration of modern smart mobility concepts to improve traffic flow, road safety, and sustainability. This study investigates the potential of solutions such as Mobility-as-a-Service, car sharing, micro-mobility, Vehicle-as-a-Service, and electric vehicles in addressing these challenges. Through a comparative analysis of global implementations, this research identifies key success factors and barriers that inform the feasibility of integrating these solutions into Kinshasa's unique socio-political and infrastructural context. The study presents a conceptual framework, supported by stakeholder analysis, for adapting these solutions locally. A detailed feasibility analysis considers technological, economic, social, environmental, and regulatory factors, offering a clear roadmap for implementation. Drawing on lessons from cities facing similar urban mobility challenges, the paper concludes with actionable recommendations and insights for policymakers and urban planners in Kinshasa. This research not only highlights the viability of smart mobility solutions in Kinshasa but also contributes to the broader discourse on sustainable urban development in rapidly growing cities. While smart mobility studies have largely focused on cities with developed infrastructure, there is a gap in understanding how these solutions apply to cities like Kinshasa with different infrastructural and socio-political contexts. Previous research has often overlooked the challenges of integrating smart mobility in rapidly urbanizing cities with underdeveloped transportation systems and financial constraints. This study fills that gap by offering a feasibility analysis tailored to Kinshasa, assessing smart mobility solutions for its traffic congestion and road safety issues. The smart mobility solutions studied—Mobility-as-a-Service (MaaS), car sharing, electric vehicles (EVs), and micro-mobility—were chosen for their ability to address Kinshasa's key mobility challenges. MaaS reduces reliance on private vehicles, easing congestion and improving public transport. Car sharing offers affordable alternatives to vehicle ownership, essential in a city with income inequality. EVs align with sustainability goals by reducing emissions, while micro-mobility (bikes and e-scooters) improves last-mile connectivity, addressing public transit gaps. These solutions are adaptable to Kinshasa's context and offer scalable, sustainable improvements for urban mobility.

Keywords: smart mobility; Kinshasa; mobility as a service; car sharing; micro-mobility; vehicle as a service; electric vehicles; feasibility analysis; urban mobility systems

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1. Introduction

This paper investigates the potential for implementing smart mobility solutions in Kinshasa to alleviate severe traffic congestion and improve road safety. It begins by analyzing the current mobility challenges in Kinshasa, such as congestion, pollution, and inadequate public transportation, detailed in the Section on the city's background and mobility issues.

This study offers a thorough literature review of global smart mobility concepts, emphasizing Mobility-as-a-Service (MaaS), car sharing, micro-mobility, Vehicle-as-a-Service (VaaS), and electric vehicles (EVs). These insights are detailed in the literature review Section. Following this review, the study proposes a conceptual framework for integrating these solutions into Kinshasa's existing infrastructure, customized to local conditions, as elaborated in the conceptual framework Section.

A thorough feasibility analysis follows, evaluating technological, economic, social, cultural, environmental, regulatory, and legal aspects. This is covered in the methodology and feasibility analysis Section. The paper also examines successful smart mobility implementations in other cities, extracting lessons that can be adapted for Kinshasa, detailed in the case studies Section.

While numerical validation is often used to quantify the impact of smart mobility solutions, it is important to recognize that in the case of Kinshasa, specific quantitative data may not yet be available or applicable. The city's infrastructure is still in a developmental phase, and smart mobility solutions have not been implemented on a scale that would allow for meaningful numerical validation. As a result, this study adopts a qualitative and conceptual approach, emphasizing feasibility through comparative case studies and expert insights. However, the study does examine data, learned lessons, and real-world experiences from other cities, such as Curitiba, Singapore, and many more, where sustainable mobility systems have been implemented, providing relevant benchmarks and lessons that Kinshasa can apply. These case studies offer indirect but valuable validation, allowing Kinshasa's policymakers and planners to draw insights on potential outcomes without the need for direct numerical data at this stage.

The study concludes with strategic recommendations for implementing smart mobility solutions in Kinshasa, including policy adjustments and infrastructure investments. It also outlines future research directions to further investigate these solutions in rapidly urbanizing cities, as detailed in the recommendations and future research Section.

The paper addresses several research questions: What are Kinshasa's main mobility challenges? How have other cities successfully implemented smart mobility solutions? What are the essential elements of a conceptual framework for Kinshasa? What is the feasibility of implementing various smart mobility solutions in Kinshasa? What strategic recommendations can ensure successful implementation? These questions are explored throughout the sections on background and context, literature review, conceptual framework, feasibility analysis, and recommendations.

(A) Overpopulation and its main impacts

Current global demographic trends show a substantial increase in urban populations, with forecasts predicting that the world's urban population will hit 6.3 billion by 2050, marking a 75% rise from today [1,2]. This growth is driven by migration, natural population increases, and urbanization, which are causing a shift toward more urban living [3–5]. As cities become more crowded, this overpopulation affects urban mobility, leading to issues like congestion, longer travel times, traffic jams, safety concerns, and environmental pollution [6].

Overpopulation has a major impact on urban transport systems, creating a range of complex issues. It puts extra strain on infrastructure, leading to problems like overcrowded public transport, longer travel times, heavy traffic, and increased pollution [5,7]. As more people move to suburbs, new residential areas pop up along transport routes, which adds even more pressure to these systems [8]. With cities growing denser, there is a growing need for effective and sustainable transport solutions. This means we need to develop strategies to improve public transport routes, explore new technologies, and upgrade road infrastructure and signage [9]. To tackle these challenges, we need a comprehensive approach that looks at how population growth, infrastructure, and environmental impact all connect. In today's digital age, smart mobility is becoming an essential part of sustainable urban development.

Smart mobility encompasses various essential components that play a vital role in enhancing urban transportation networks. These elements include integrating technology to boost efficiency and sustainability [10], offering real-time traffic monitoring and management [11], encouraging multi-modal transportation planning to enhance access to services [12], and adopting innovative transportation methods like electric cars [13] and urban bicycles. These measures help cut down greenhouse gas emissions and air pollution, leading to better air quality and healthier residents. Additionally, smart mobility enhances traffic safety by using advanced traffic monitoring systems and quick response mechanisms to reduce accidents and collisions, ultimately improving the quality of life for all city dwellers [14].

A study on smart mobility in urban areas [12] found that there is a noticeable gap in attention to smart mobility in developing countries, where rapid urbanization is driving a growing need for efficient transportation solutions. Implementing smart mobility solutions is vital for driving economic growth and development in low-income areas. These solutions address transportation challenges and improve access to crucial services [10,15].

(B) Background and context of Kinshasa's current mobility challenges

Kinshasa, the rapidly expanding capital city of the Democratic Republic of Congo, is on track to become Africa's largest megacity by 2030 [16]. However, it faces numerous mobility challenges exacerbated by rapid urbanization and population growth. The city's overpopulation intensifies the strain on its transportation infrastructure, leading to congestion, pollution, and inadequate public transit systems. These issues hinder efficient movement within the city, impacting the daily lives of millions of residents and stalling the city's development [17]. Addressing these multifaceted problems is critical to improving Kinshasa's mobility landscape and overall development trajectory.

To understand the nature of these problems the key basic characteristics of the twenty most populous cities globally, including Kinshasa, were collected. These data are presented in Table 1.

According to the data provided in Table 1, Kinshasa has the highest persons-per-car ratio from the world's twenty most populated cities. This indicates low car ownership relative to population size, which means that existing vehicles are overcrowded, and more people rely on alternative and shared transportation modes. The dense population and insufficient modern public transport options, such as a metro system, present major transportation challenges. Implementing a metro system could offer a high-capacity, efficient alternative to road transport, greatly alleviating traffic congestion. The absence of such a system means that residents have fewer alternatives to navigate within the city, exacerbating road congestion.

The public transport system in Kinshasa is underdeveloped and unreliable [18]. The current transport options are inadequate for the growing population. Many residents have to depend on overcrowded and poorly maintained vehicles, which raises the risk of accidents and diminishes the overall efficiency of the transport system [19].

The transport system is primarily characterized by its informality. It includes various modes such as buses, minibuses, motorcycles, and taxis. Many of these modes operate without regulation, leading to a chaotic and unpredictable environment, including for example "taxi pirates"—unlicensed taxi drivers who fill the gap left by insufficient formal transport services. The dynamic nature of this system adds a layer of complexity and uncertainty for both passengers and drivers.

Table 1. Characteristics of twenty world's most populated megacities.

City	Country	Population (2024)	Density (People/km^2)	Number of Cars	Metro System	Cars per 1000 People
Kinshasa	DR Congo	14,342,000	14,391	1,500,000	No	104.59
Cairo	Egypt	20,901,000	19,376	2,220,000	Yes	106.22
New York City	USA	18,804,000	10,430	2,000,000	Yes	106.36
Tokyo	Japan	37,393,000	6363	4,547,000	Yes	121.60
Lagos	Nigeria	14,368,000	6871	1,800,000	No	125.28
Shanghai	China	27,058,000	3854	3,620,000	Yes	133.79
Osaka	Japan	19,165,000	12,200	2,620,000	Yes	136.71
Dhaka	Bangladesh	21,006,000	29,346	2,900,000	Yes	138.06
Chongqing	China	15,872,000	382	2,600,000	Yes	163.81
Manila	Philippines	13,923,000	18,000	2,300,000	Yes	165.19
Mumbai	India	20,411,000	20,482	3,400,000	Yes	166.58
Kolkata	India	14,850,000	24,000	2,500,000	Yes	168.35
Tianjin	China	13,580,000	1135	2,700,000	Yes	198.82
Buenos Aires	Argentina	15,154,000	14,469	3,200,000	Yes	211.17
Karachi	Pakistan	16,094,000	4421	3,600,000	No	223.69
Mexico City	Mexico	21,782,000	6000	5,500,000	Yes	252.50
Istanbul	Turkey	15,190,000	2848	4,000,000	Yes	263.33
Beijing	China	20,463,000	1326	5,972,000	Yes	291.84
Delhi	India	30,291,000	11,297	11,400,000	Yes	376.35
São Paulo	Brazil	22,043,000	7398	8,500,000	Yes	385.61

This system emerged historically as a response to inadequate urban planning during the colonial era, which did not provide sufficient means for residents to navigate the city. Over the decades, the informal sector has grown substantially, largely due to the government's inability to provide comprehensive public transport solutions. The result is a highly fragmented and unreliable transport network that struggles with regulation and safety issues [17,19].

Kinshasa faces traffic congestion management challenges due to chaotic driver behavior, inadequate road infrastructure, and limited funds for road maintenance and expansion [17]. With a population density of 14,391 people per square kilometer, it is evident that a large number of people are living in a confined area. Rapid urbanization and a lack of adequate transport infrastructure are leading to significant congestion on the roads, especially during peak hours, as many people need to travel within a limited space [18]. This congestion significantly delays travel times and impacts economic productivity. Major routes, such as Lumumba Boulevard, which connects the city center to the international airport, are chronically congested due to the lack of secondary roads and the poor condition of existing infrastructure.

Regular flooding further exacerbates these issues, causing decreased travel speeds, delays, and rerouting that disrupt public transit services. The diminished accessibility to jobs is leading to significant economic burdens for local commuters [20]. This aspect is closely related to the inadequate traffic management and absence of safety regulations that are contributing to the chaotic state of its public transport system. The city's roads are plagued by potholes, and the behavior of drivers is often unpredictable and unsafe. This situation is compounded by the lack of investment in traffic management infrastructure and systems, which leads to frequent traffic accidents and unsafe road conditions.

Another problematic area is the environmental impact of current transport solutions. On the one hand, it is a noise pollution. Traffic noise is a major issue in Kinshasa, with noise levels ranging from 73 to 79 dB along major roads. The high level of noise pollution causes significant annoyance and sleep disturbance among residents. A notable percentage of people are highly annoyed or experience sleep disturbances due to traffic noise, especially in areas with heavy traffic. Additionally, the transport system in its current state is a major contributor to air pollution. The significant presence of outdated and poorly maintained vehicles releases a considerable amount of pollutants, exacerbating health problems within the community. Furthermore, the discharge of untreated wastewater into the Congo River from transport and other activities has led to severe environmental degradation, impacting water quality and public health [21].

Given these above-described significant challenges, overpopulation, in particular, exacerbates the mobility-related issues and challenges. Overpopulation presents a critical challenge for Kinshasa's mobility infrastructure. With the city's population expected to reach over 20 million by 2030, the already-strained transportation system is under immense pressure. Rapid population growth has led to increased demand for transport services, outpacing the city's ability to develop adequate public transportation and road infrastructure. As more residents rely on personal vehicles and informal transit systems, Kinshasa's streets are frequently congested, leading to longer travel times, increased pollution, and a higher rate of road accidents. The overburdening of existing infrastructure also results in frequent breakdowns, worsened road safety conditions, and reduced accessibility, particularly for low-income communities. These impacts make it clear that conventional mobility solutions are no longer sufficient, and innovative approaches, such as smart mobility concepts, must be explored to accommodate the city's growing population and future transportation needs.

Overall, in a nutshell, Kinshasa's mobility challenges are largely driven by rapid urbanization, poor infrastructure development, and a severe lack of reliable public transportation options. Roads such as the "Lumumba Boulevard", a major artery connecting key areas of the city, experience chronic congestion, with travel delays that can extend for hours during peak times. The absence of mass transit systems, such as metro or tram networks, forces residents to depend on personal vehicles or informal, overcrowded taxi services, further contributing to the traffic burden. Additionally, the city's road conditions are often poor, with potholes and insufficient maintenance exacerbating travel inefficiencies. Compounding these issues, Kinshasa suffers from a lack of proper traffic management systems and frequent flooding, which regularly disrupts transportation flow. These problems are not just logistical but also significantly impact the quality of life for residents and the economic productivity of the city. As a result, addressing these mobility challenges through innovative, sustainable, and scalable solutions is essential for Kinshasa's future.

(C) Rationale for Introducing Modern Smart Mobility Concepts in Kinshasa

The need to transform Kinshasa's mobility landscape is driven not only by existing challenges in mobility but also by the necessity to adapt to the changing demands of a modern urban environment. Embracing modern smart mobility concepts can revolutionize Kinshasa's transportation systems, leading to improved transport efficiency, sustainability, equity, economic growth, and a better quality of life for its residents.

In light of Kinshasa's significant mobility challenges, traditional transportation approaches have proven insufficient to address the city's rapidly evolving needs. The absence of effective public transit systems, combined with over-reliance on informal transport modes and personal vehicles, has led to chronic congestion, accidents, and environmental degradation. Smart mobility solutions, such as MaaS, EVs, and car-sharing systems, provide a pathway to resolving these issues. These innovative approaches leverage advanced technologies to improve traffic management, reduce reliance on private vehicles, and offer environmentally friendly alternatives. By incorporating real-time data, automated systems, and intelligent transportation networks, these solutions enable efficient, scalable, and sustainable urban transport. Additionally, lessons from global cities facing similar challenges demonstrate that smart mobility can dramatically improve urban flow, reduce pollution, and increase access to transportation for underserved populations. As Kinshasa looks to the future, embracing smart mobility offers a transformative opportunity to modernize its transportation infrastructure and create a more livable, sustainable urban environment.

In terms of efficiency, smart mobility improves travel routes, shortens wait times, and reduces congestion by utilizing real-time data and cutting-edge technologies [22,23]. Traffic jams and air pollution remain major issues, particularly in large cities, and this situation is unsustainable in the long run. Urban transport systems worldwide face challenges such as pollution and inefficient resource use, which often hinder economic growth. Simply constructing more roads will not solve these problems; there is a need to integrate urban infrastructure through smart connectivity [24]. As a key component of a smart city, smart mobility has the potential to decrease traffic congestion, shorten commuting times, and reduce road accidents, while also allowing passengers to tailor their travel experiences. Indeed, developing smart mobility solutions is one of the top challenges for major cities globally. This involves a series of strategic actions supported by advanced technologies [25]. To provide a comprehensive view of smart mobility, the various elements and dimensions are explored. Additionally, the trends, opportunities, and challenges associated with smart mobility are discussed. This paper emphasizes four key components of smart mobility: intelligent transport systems, open data, big data analytics, and citizen engagement. These interconnected elements are essential for the effective deployment of smart mobility initiatives [15]. By enhancing the movement of people and goods, smart mobility boosts overall efficiency in transportation networks and smoothens urban operations.

As previously noted, Kinshasa is dealing with major environmental issues such as air pollution and carbon emissions. To address these challenges and improve sustainability, adopting a smart mobility strategy could be key. This approach would include integrating EVs, offering micro-mobility options like electric scooters, and expanding shared transportation services [26]. By embracing these eco-friendly solutions, Kinshasa can move toward a greener city and a healthier living environment for its residents.

Smart mobility makes transportation more accessible to everyone, ensuring that people from all income levels and locations can enjoy convenient and affordable travel options [27]. By connecting urban centers with more remote areas, these initiatives foster inclusivity and strengthen social ties [28].

A well-functioning transportation system catalyzes economic activity and prosperity [29]. Embracing smart mobility solutions can attract investment, create employment opportunities in emerging sectors such as EV infrastructure and mobility services, and stimulate overall economic growth through enhanced urban connectivity and efficiency [30].

2. Literature Review

The motivation for this research arises from the pressing urban mobility challenges faced by Kinshasa, including rapid population growth, inadequate infrastructure, and poor traffic management systems. Kinshasa's population growth has outpaced the development of transportation infrastructure, leading to chronic congestion, long commuting times, and unsafe travel conditions. These issues not only affect the quality of life for residents but also hinder economic development. By investigating smart mobility solutions, this research aims to provide innovative and data-driven strategies to alleviate these problems and offer sustainable solutions for Kinshasa's urban transportation network.

2.1. Review of Existing Literature on Smart Mobility Concepts

Smart mobility encompasses a variety of strategies and technologies designed to improve transportation systems. The exploration of smart mobility concepts within existing literature and their implementation globally reveals a multifaceted landscape of innovative strategies, technological advancements, and policy frameworks aimed at revolutionizing urban transportation systems worldwide. Lessons learned from leading cities worldwide can be valuable markers, providing insights into effective technological strategies and best practices for improving urban mobility and quality of life. As Kinshasa advances its transportation improvements, it can draw valuable insights from cities globally. By merging technological advancements with a user-centric approach, enhancing infrastructure, and formulating supportive policies, the city can establish a blueprint for sustainable urban mobility [31]. This holistic strategy addresses present transportation challenges while also paving the way for future resilience, inclusivity, and environmental conservation in urban development.

This literature review highlights three main areas: technological innovations and integration, user-centric approaches and behavior change, and data-driven decision-making. For each of these areas, the primary approach is explained, and case study descriptions are included.

2.1.1. Technological Innovations and Integration in Smart Mobility

The backbone of smart mobility is technological innovations [23,27]. They involve the application of novel information technologies to achieve efficient transportation, offering transformative solutions to address urban transportation challenges. These technologies cover everything from real-time data analysis to sensor networks. They combine innovations like IoT, AI, and big data analytics to improve traffic management, cut down on emissions, and make the overall user experience better [23]. They empower cities to implement efficient traffic management strategies, predictive maintenance protocols, and personalized transportation services tailored to individual needs. Several studies highlight the potential of these technologies to transform urban mobility by making transportation systems more efficient and responsive to real-time conditions [32–34].

Even with their advantages, integrating these technologies comes with major hurdles, such as high costs, the necessity for considerable infrastructure investments, and concerns about data privacy and security. There is also ongoing debate about the environmental impact of EVs, especially regarding battery production and disposal [34].

Case studies from leading smart cities such as Amsterdam and Seoul provide compelling examples of successful technological integration in urban mobility. In various cities, implementing smart traffic lights, adaptive signal control systems, and dynamic route optimization algorithms has resulted in significant benefits. By using data-driven insights and advanced algorithms, these technologies have successfully improved traffic flow, reduced congestion in key areas, and cut down on commute times for travelers [35].

For example, Amsterdam's advanced system of smart traffic lights changes signal timings in real time according to traffic flow, pedestrian activity, and environmental factors. This dynamic control mechanism enhances intersection efficiency, reduces unnecessary stops, and improves overall traffic fluidity within the city. Similarly, Seoul's implementation of adaptive signal control systems intelligently prioritizes high-volume traffic corridors, synchronizing signal timings to accommodate fluctuating demand and minimize delays [36]. Dynamic route optimization algorithms enable commuters to navigate urban landscapes more efficiently, considering factors such as traffic conditions, road closures, and alternative modes of transportation. By providing real-time navigation guidance, these technologies empower users to make informed travel decisions, thereby reducing congestion on congested routes and enhancing overall mobility experiences.

Integrating technological innovations into smart mobility marks a major shift in how we plan and manage urban transportation [37]. By leveraging data analytics, sensor networks, and smart algorithms, cities can develop transportation systems that are more resilient, efficient, and sustainable, adapting to the changing needs of their residents.

Even in towns like Kinshasa, with very underdeveloped and primitive infrastructure, these technological insights can serve as guiding lights. Kinshasa, with its unique set of challenges stemming from rapid urbanization, limited resources, and infrastructural constraints, can learn valuable lessons from the experiences of more developed cities in implementing smart mobility solutions. By learning from experiences and good practices elsewhere, Kinshasa can begin to lay the groundwork for implementing similar solutions, adapting them to suit its unique context and infrastructure limitations. Strategies like using real-time data analytics for traffic management, setting up sensor networks to monitor road conditions, and offering personalized transportation services can all be customized to meet Kinshasa's unique needs and challenges. Additionally, partnering with global experts, tech companies, and international organizations can help with knowledge transfer and capacity building in smart mobility solutions. Kinshasa stands to gain from collaborative efforts that emphasize knowledge exchange, pilot projects, and skill development among local stakeholders, encouraging a culture of innovation and sustainability in urban transportation planning.

2.1.2. User-Centric Approaches and Behavior Change in Smart Mobility

User-focused strategies in smart mobility aim to grasp and shape user behavior to boost the use of eco-friendly transportation options. This means involving users in creating and refining mobility solutions and applying behavioral science to foster a shift toward more sustainable practices. Getting a handle on user behavior is crucial for designing effective and sustainable transportation solutions that cater to the needs and preferences of city dwellers [38].

Studies have found that including end-users in the co-creation of smart mobility solutions can significantly boost acceptance and ensure the solutions better meet user needs [39]. This method not only helps in crafting more effective solutions but also acts as a risk management tool by identifying potential behavioral changes and obstacles early on. This is crucial for the success of smart mobility projects, as behavioral change plays a key role. Research highlights that factors such as social influences, personal innovativeness, and user engagement are major drivers of new technology adoption [40]. Effective strategies to enhance user engagement and promote behavior change include participatory sensing, mobile social networks, and customized communication.

Cities like Copenhagen can serve as exemplary models in promoting user-centric approaches to smart mobility. Copenhagen, famous for its cycling culture, has led initiatives that not only improve infrastructure but also actively promote changes in citizen behavior. The city's substantial investments in dedicated bike lanes, expansive bike-sharing schemes, and cycling incentives have significantly transformed commuting habits, decreasing car dependence and cultivating a culture of active transportation [22]. Copenhagen's success largely stems from its use of behavioral nudges to promote sustainable transportation. The city has cleverly positioned bike racks, introduced traffic-calming measures, and provided financial incentives like tax breaks for cyclists. These strategies have successfully encouraged people to choose cycling over more conventional forms of transport. These nudges subtly influence user behavior, making cycling an attractive and convenient choice for daily commutes and recreational activities. Moreover, Copenhagen's emphasis on user experience extends beyond infrastructure enhancements to encompass holistic support systems for cyclists. From providing amenities like secure bike parking and changing facilities to offering educational programs on cycling safety and maintenance, the city ensures that users feel empowered and supported in adopting sustainable mobility behaviors [41].

Combining Copenhagen's user-focused strategies with cutting-edge tech innovations in smart mobility can greatly enhance urban transportation. By using real-time data, sensor networks, and personalized services, cities can better meet their residents' diverse needs and preferences. Kinshasa, in particular, can gain useful insights from Copenhagen's comprehensive approach, which emphasizes accessibility, safety, and education to encourage sustainable transportation for everyone, regardless of their socio-economic status. Kinshasa can take inspiration from Copenhagen's investment in cycling infrastructure and active mobility promotion. While Copenhagen has well-developed cycling facilities and behavior-changing initiatives, Kinshasa can adapt these core principles—focusing on sustainable transport modes and community engagement—to its own unique urban environment. By implementing similar behavior nudges suited to its local context, Kinshasa can promote sustainable travel choices and alleviate congestion, even with fewer resources. Through this adaptation, Kinshasa can harness the benefits of Copenhagen's strategies, tailored to its specific challenges and opportunities.

2.1.3. Data-Driven Decision-Making in Smart Mobility

Data-driven decision-making harnesses big data analytics to refine and enhance transportation planning and operations. With the surge in urban data from diverse sources like sensors, social media, and mobile devices, cities gain crucial insights into mobility patterns and user behaviors. These data-driven strategies can boost transportation system efficiency, optimize service design, and enable real-time decision-making. By leveraging this wealth of information, cities can improve traffic flow, decrease congestion, and elevate overall transportation efficiency [42].

While utilizing data for decision-making can lead to significant benefits, it also introduces issues related to maintaining data quality, ensuring proper integration, and safeguarding privacy. Ensuring the dependability and precision of data is crucial, as is addressing ethical and privacy issues, to successfully deploy smart mobility solutions [43].

Data-driven decision-making plays a pivotal role in smart mobility by leveraging vast amounts of data generated from various sources such as sensors, GPS devices, and mobile applications. These data provide real-time insights into traffic patterns, commuter behaviors, and transportation inefficiencies. By harnessing these data, city planners and policymakers can make informed decisions about infrastructure improvements, optimize traffic management, and introduce adaptive solutions based on real-time needs. Furthermore, the integration of predictive analytics helps forecast future mobility trends, ensuring that transport solutions evolve alongside the city's growth. In the context of Kinshasa, where transportation data may be scarce, adopting a data-driven approach allows for targeted interventions that address the city's most critical mobility issues.

3. Conceptual Framework

3.1. Overview of Key Smart Mobility Concepts

Smart mobility covers a variety of innovative transportation solutions designed to improve the elements mentioned earlier. Key concepts in this field include MaaS, car-sharing services, micro-mobility options, VaaS, and EVs. All these advancements leverage technology to optimize traffic management, reduce emissions, and improve user experiences, thereby transforming urban transportation landscapes globally [44]. In the following text, the basic characteristics of each concept are described together with its main advantages and challenges.

3.1.1. Concept of "Mobility-as-a-Service"

MaaS marks a significant change toward a mobility ecosystem that is more efficient, sustainable, and focused on the needs of users [45]. It integrates various transportation modes, including buses, trains, taxis, car-sharing, bike-sharing, and micro-mobility options, into a cohesive ecosystem where various modes of transportation converge within a unified digital platform (see Figure 1). MaaS platforms offer personalized travel options, reducing dependency on private vehicles, enhancing user experience, and providing data-driven insights to optimize urban mobility [46].

Key features include a focus on user needs, integration of multiple transportation modes (public transit, ride-sharing, bike-sharing, taxis), a unified digital interface, and flexible payment structures like subscription-based plans or pay-as-you-go models.

At its core, MaaS eliminates the need for individual vehicle ownership, allowing users to effortlessly plan, book, and pay for diverse mobility options through a single interface [47,48]. Traditionally, transportation planning involved disjointed processes with separate payments and fragmented experiences. MaaS, however, streamlines this by offering integrated access to services, enhancing convenience and efficiency. Benefits of MaaS encompass time savings, cost efficiency, environmental sustainability, and the promotion of smart city development [45,49]. This strategy supports urban sustainability objectives by optimizing resource use, lowering carbon emissions, and improving mobility access for every resident.

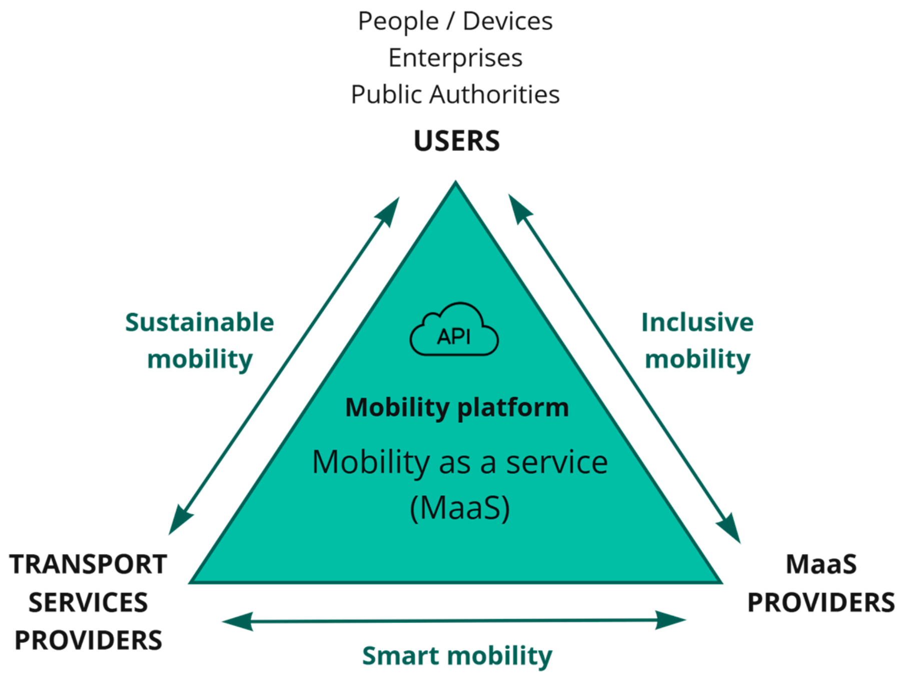

Figure 1. A simplified representation of the Mobility-as-a-Service concept.

Successfully implementing MaaS comes with its own set of challenges. Developing a user-friendly platform that integrates multiple transportation options—like public transit, ride-sharing, bike-sharing, and car rentals—necessitates significant coordination and technological progress [50]. It is essential to ensure that different service providers' systems can work together smoothly, but this can be challenging. Issues with data sharing and privacy must also be addressed, as the success of this service relies on real-time information exchange between multiple entities. Achieving a balance between affordability for users and profitability for service providers is a key challenge in creating a sustainable business model [51]. Updating regulatory and legal frameworks to support this innovative transportation approach can be both complex and politically delicate. To encourage widespread public adoption, it is essential to invest in comprehensive marketing and educational initiatives. These efforts should highlight the advantages and user-friendliness of MaaS, ensuring the system is accessible and inclusive for all individuals.

3.1.2. Concept of "Car Sharing"

Car sharing is a transport model that is gaining traction globally. It offers individuals the opportunity to rent or share vehicles for short periods, typically by the hour. At its core, car sharing represents a departure from traditional car ownership, emphasizing shared access, community collaboration, and environmental sustainability (see Figure 2).

Car-sharing services offer a wide selection of vehicles to meet different needs and preferences, from budget-friendly options to luxury models. Unlike traditional car rentals, these services are available 24/7 and can be easily accessed via user-friendly apps or online platforms. Charges are based on usage, considering both the time the vehicle is used and the distance traveled.

The primary benefit of car sharing is its cost-effectiveness, which frequently makes it more economical than owning a personal vehicle. Additionally, it provides unmatched convenience, with cars readily available near users' locations [52].

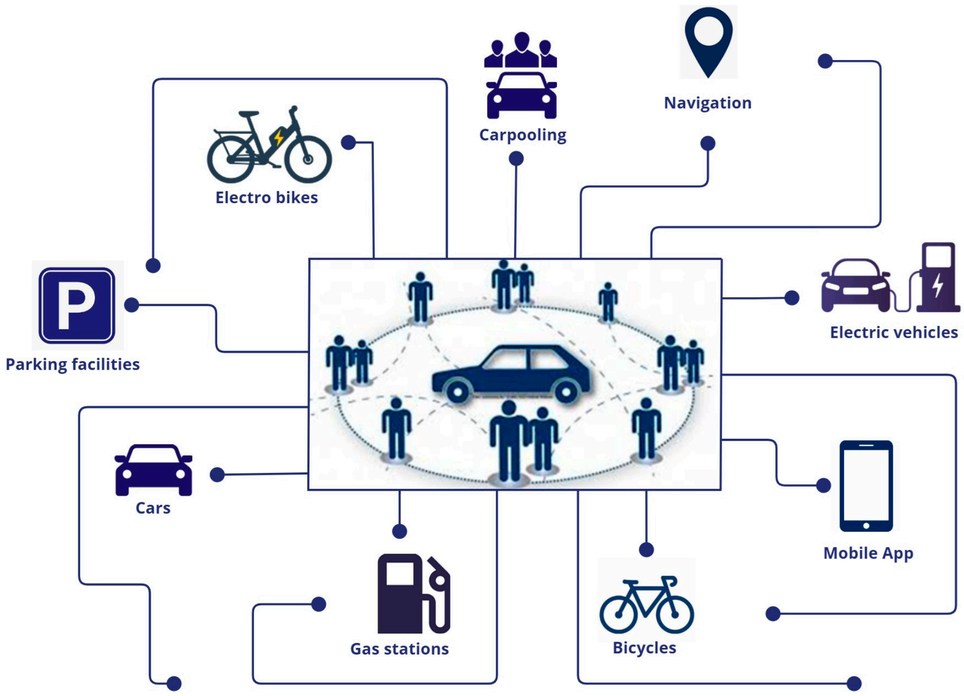

Figure 2. A simplified representation of the car-sharing concept.

Additionally, car sharing benefits the environment by encouraging resource sharing and decreasing the need for private car ownership. With fewer cars on the road, there are lower emissions and a move toward more sustainable urban mobility practices [53].

Implementing car-sharing concepts into the existing transportation system also presents several challenges. One of the primary issues is the need for adequate infrastructure, including designated parking spaces and vehicle maintenance facilities, which can be costly and difficult to integrate into densely populated urban areas. Additionally, there are logistical challenges related to ensuring vehicle availability and distribution to meet user demand, particularly during peak hours. Another significant problem can be the potential resistance from traditional taxi services and private car owners, who may view car sharing as a threat to their livelihoods. Addressing regulatory and legal barriers is essential since car-sharing services must adhere to local transportation laws and regulations. Moreover, to increase user engagement, it is essential to deploy effective marketing tactics and create intuitive technology platforms that provide a smooth and hassle-free experience. Car-sharing services can differ widely in terms of availability and conditions, influenced greatly by the specific region and the service provider involved [54]. Factors such as vehicle selection, pricing structures, accessibility, reservation processes, and usage policies may differ. Additionally, local regulations and infrastructure play important roles in shaping the feasibility and practicality of car sharing in different regions, underscoring the importance of understanding the local context before diving into this mobility solution [55].

3.1.3. Concept of "Electric Vehicles"

An EV is a mode of transportation powered either completely or partially by electricity, providing a cleaner alternative to conventional internal combustion engines that depend on fossil fuels such as gasoline or diesel. EVs are powered by electric motors and vary based on their electricity sources and levels of reliance on electric power. They can be categorized into four main types:

(a) Battery Electric Vehicles (BEVs) rely entirely on electricity stored in rechargeable battery packs and must be plugged into an external power source to recharge. Models like the Tesla Model S and the Nissan Leaf are prime examples of BEVs (situation in 2024).

(b) Plug-in Hybrid Electric Vehicles (PHEVs) blend an electric motor with an internal combustion engine. These vehicles can be recharged using an external power source and are capable of operating purely on electric energy for a specific range before the internal combustion engine activates. Examples of such vehicles are the Chevrolet Volt and the Toyota Prius Prime (situation in 2024).

(c) Hybrid Electric Vehicles (HEVs) integrate an electric motor with an internal combustion engine. However, unlike PHEVs, HEVs lack the ability to recharge their batteries from an external power source. Instead, HEVs rely on regenerative braking and the internal combustion engine to maintain battery power. Instead, the battery is charged through regenerative braking and the internal combustion engine. The Toyota Prius and Honda Insight are widely recognized HEVs (situation in 2024).

(d) Fuel Cell Electric Vehicles (FCEVs) generate electricity on-board through a chemical reaction between hydrogen and oxygen in a fuel cell. FCEVs emit only water vapor and heat as byproducts, with the Toyota Mirai and Hyundai Nexo being prime examples (situation in 2024).

EVs have several crucial components: the electric motor (1) transforms electrical energy into mechanical energy to drive the vehicle, while the battery pack (2) stores this electrical energy. The charging port (3) enables the vehicle to link with an external power source for recharging. The power electronics controller (4) manages the allocation of electrical energy between the motor and the battery. Lastly, the thermal system (5) ensures that the battery, electric motor, and other parts operate within their ideal temperature range.

EVs come with multiple benefits (see Figure 3). For starters, they generate zero tailpipe emissions, which greatly helps cut down air pollution and greenhouse gas emissions. They also boast greater energy efficiency compared to internal combustion engines, converting a higher percentage of battery energy into movement. Moreover, EVs generally offer cost savings over traditional gasoline-powered cars in two key areas: fuel and maintenance. They also offer remarkable performance features, such as immediate torque for rapid acceleration and a smoother overall driving experience. By expanding the use of electric buses and taxis and building a strong charging network, we can speed up EV adoption, enhance air quality, and support sustainable urban transport [56].

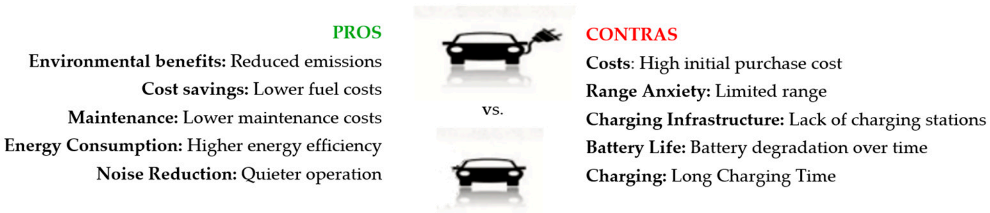

Figure 3. Electric vehicle characteristics compared to traditional combustion vehicles.

Integrating EVs into the current transportation system comes with several challenges [34]. A key technical hurdle is ensuring compatibility with local power grids and having sufficient capacity to handle the increasing demand. To avoid putting undue stress on the system and to sidestep expensive upgrades, it is crucial to carefully plan and manage EV charging activities. Another major issue is cost. EVs tend to be more expensive than traditional combustion engines, and electric buses need specific charging infrastructure, such as fast-charging stations at each route endpoint, which involves significant installation and maintenance expenses. Range anxiety—the worry about limited driving range and the availability of charging stations—is a notable concern [57]. Furthermore, while recharging an EV usually requires more time compared to refueling a traditional gasoline car, ongoing improvements in fast-charging technology are mitigating this issue. The high cost of battery production and concerns about battery lifespan and degradation also pose challenges. These factors make the shift to EVs a complex and costly endeavor.

3.1.4. Concept of "Micro-Mobility"

Micro-mobility encompasses small, lightweight transportation options ideal for short trips within cities. These vehicles are perfect for covering the "last mile" of a journey, offering a range of personal mobility solutions that align with the latest technological advancements and changing preferences. This category includes both electric and non-electric two-wheeled vehicles, each designed to meet the specific needs and preferences of various users. See Figure 4.

Figure 4. The most common 1- and 2-wheeled micro-mobility vehicles.

Scooters, bikes, e-bikes, e-scooters, e-unibikes, and hoverboards are changing how people navigate urban spaces, offering versatile, eco-friendly alternatives for both commuting and leisure. Electric bikes blend traditional cycling with motorized assistance, making it easier to tackle longer commutes and varied terrains, while e-scooters have become iconic in cities due to their compact design and clean energy, perfect for quick, short-distance trips. Scooters, in their traditional, non-motorized form, still serve as a simple and lightweight means of urban transportation. E-unibikes, with their futuristic single-wheel design, offer an agile and exciting way to traverse city streets, while hoverboards, although requiring balance and skill, provide a fun and efficient solution for short-range urban mobility. Traditional bicycles, though not motorized, remain a cornerstone of urban mobility, offering eco-friendly, healthy transportation for short-to-medium distances. Neighborhood Electric Vehicles (NEVs), while four-wheeled, also play a role in localized urban travel, promoting energy efficiency and emissions reduction in neighborhoods and small communities [58].

This diverse array of vehicles highlights the evolving landscape of urban mobility, emphasizing sustainability, reducing congestion, and offering tailored solutions for varied urban transportation needs. Micro-mobility options provide convenient and eco-friendly last-mile connectivity solutions [59]. These options help reduce traffic congestion in densely populated areas and promote sustainable urban transportation alternatives. As technology continues to progress and environmental consciousness grows, it can expect further innovations in both electric and non-electric personal mobility [60].

Implementing the micro-mobility concept, which includes small-scale, lightweight transportation options, into existing transport systems presents several challenges [61]. Cities need to adapt infrastructure with dedicated lanes and parking to safely accommodate these vehicles. Without proper infrastructure, micro-mobility can lead to increased accidents and pedestrian conflicts [62]. Additionally, integrating micro-mobility with existing public transport networks requires seamless connections and convenient access points, which can be difficult to achieve in already congested urban areas. Another challenge is regulatory oversight, including establishing safety standards, and usage rules, and managing the proliferation of vehicles. Effective regulation must balance encouraging innovation while ensuring public safety and minimizing urban clutter. Public acceptance is also crucial, involving concerns about reliability, safety, and the potential for theft or vandalism. Environmental benefits depend on sustainable lifecycle management of vehicles. Ensuring equitable access to micro-mobility options for all residents, including underserved communities, is also vital. Addressing these challenges requires coordinated planning, investment, regulation, public engagement, and sustainability.

3.1.5. Concept of "Vehicle-as-a-Service"

The VaaS concept represents a shift away from traditional vehicle ownership and transportation models. VaaS revolutionizes mobility by offering access to vehicles through subscriptions or on-demand services instead of ownership [63]. Users can conveniently rent vehicles via websites or mobile apps, emphasizing flexibility, convenience, and usage-based payment (see Figure 5). Usually, they pay a flat monthly fee for vehicle access. When transportation is needed, they simply request a vehicle via smartphone. A vehicle promptly arrives at their location, ready for use within the subscription terms.

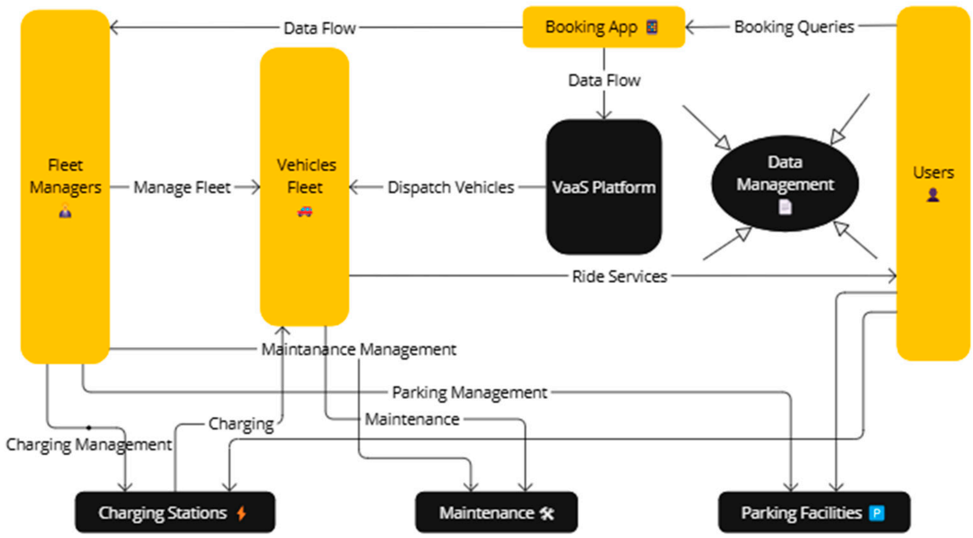

Figure 5. Schematic overview of a Vehicle-as-a-Service concept.

The main advantages of this concept can be described as follows:

(a) Subscription-Based Access: VaaS offers a flexible subscription or pay-per-use system, giving people or companies the chance to use vehicles when they need them instead of having to buy them. This strategy aligns with the growing market preference for access rather than ownership.
(b) Diverse Vehicle Options: VaaS platforms provide a wide array of transportation options that extend far beyond the typical car. From electric bikes and scooters to vans and specialized vehicles designed for specific tasks such as deliveries or special events, these platforms ensure users have the flexibility to select the perfect vehicle for their unique needs.
(c) Digital Platforms and Connectivity: VaaS relies heavily on digital platforms and mobile apps to facilitate seamless booking, payment, and vehicle access. Users can reserve vehicles, track their usage, and manage payments through intuitive interfaces, enhancing convenience and accessibility.
(d) Integrated Services: Beyond vehicle access, VaaS platforms often integrate additional services such as insurance, maintenance, roadside assistance, and charging infrastructure for EVs. This holistic approach aims to provide a hassle-free and comprehensive mobility experience for users.
(e) Flexibility and Scalability: VaaS solutions offer flexibility in terms of subscription plans, allowing users to adjust their vehicle usage based on changing needs. For businesses, VaaS offers scalability by providing fleet management tools and analytics to optimize vehicle utilization and costs.
(f) Sustainability and Efficiency: By encouraging shared use and streamlining vehicle fleets, VaaS helps advance sustainability efforts by cutting down on total vehicle ownership, easing traffic congestion, and lowering emissions in cities. It also supports the switch to greener and more efficient transportation choices, including EVs.

(g) Data-Driven Insights: VaaS platforms leverage data analytics to gather insights into user behavior, vehicle usage patterns, and operational efficiency. This data-driven approach enables continuous optimization of services, fleet management, and user experiences.

VaaS represents a paradigm shift toward a more flexible, sustainable, and integrated approach to mobility, utilizing technology to provide customized solutions to the changing requirements of transportation ecosystems [64]. By treating vehicles as services rather than commodities, VaaS models prioritize user experience, environmental impact, and overall system performance, aligning with modern smart mobility frameworks [65].

Introducing VaaS comes with its own set of challenges. A major hurdle is the considerable investment needed for infrastructure, which includes maintaining a fleet of operational vehicles and the associated facilities. This substantial upfront cost, along with ongoing operational expenses, can pose a significant obstacle, particularly in areas with constrained financial resources. Effective integration requires seamless coordination among government agencies, private operators, and technology providers, often complicated by bureaucratic inefficiencies and lack of collaboration. Achieving widespread user acceptance demands a cultural shift from car ownership to sharing, addressing concerns about reliability and convenience [63]. This transition requires tackling issues around the dependability, accessibility, and ease of use of shared vehicles in contrast to privately owned ones. Additionally, safeguarding data privacy and security poses a significant challenge. Effectively managing and securing the extensive data produced by VaaS platforms is essential for upholding user trust and meeting regulatory requirements. Additionally, regulatory and policy frameworks must be revised or created to support the VaaS model, ensuring it aligns with broader urban mobility objectives and tackles issues like traffic management, environmental impact, and equitable access.

3.2. Integration of Modern Smart Mobility Concepts into Kinshasa's Existing Infrastructure

It is evident that integrating any of the modern smart mobility concepts previously presented has the potential to transform Kinshasa's transportation system and address its main challenges, such as traffic congestion, lack of sufficient public transport, and environmental issues. However, implementing these concepts in all cases will necessitate significant infrastructure improvements and careful strategic planning. The following text summarizes the main requirements for the implementation of each concept.

3.2.1. Mobility-as-a-Service

MaaS is a new idea that brings together different kinds of transportation services into one easy-to-use on-demand platform. In Kinshasa, the integration of public transit, car-sharing, bike-sharing, and ride-hailing into a unified system accessible via a smartphone app could streamline transportation options and make getting around much easier. This would make it easier for people to plan, book, and pay for their trips all in one place, making transportation more efficient and user-friendly. To make MaaS work in Kinshasa, the city's technology infrastructure needs to be improved. Having reliable Internet, widespread use of smartphones, and a good digital payment system are essential. Additionally, gathering data from different transport providers and providing real-time updates will require advanced data management systems and cooperation among various groups involved in transportation [66].

3.2.2. Car Sharing

Car sharing offers a way to decrease the number of personal vehicles on the road, which can help ease traffic congestion and cut down on emissions. Instead of owning a car, users have the option to rent one whenever they need it. In Kinshasa, this service could be especially useful in high-traffic areas and places where parking is scarce. For car sharing to be effective, the city must develop a network of accessible parking spots designated for shared vehicles. These spots should be strategically located near public transit hubs, residential areas, and commercial centers. Additionally, the city needs to invest in user-friendly car-sharing platforms and ensure that vehicles are regularly maintained and readily available.

3.2.3. Micro-Mobility

Micro-mobility, which includes solutions like electric scooters and bikes, offers a flexible and eco-friendly mode of transportation for short-distance travel. This is especially relevant in Kinshasa, where last-mile connectivity remains a significant challenge. To integrate micro-mobility, Kinshasa will need to build dedicated bike lanes and scooter paths to ensure the safety of riders. Additionally, docking stations for bikes and scooters should be established at key locations such as public transit stations, business districts, and residential neighborhoods. Effective regulation and maintenance systems will be crucial to managing the micro-mobility fleet and preventing clutter and misuse.

3.2.4. Vehicle-as-a-Service

VaaS includes offerings such as ride-hailing and on-demand delivery, offering flexible, efficient, and often more affordable options compared to owning a vehicle. In Kinshasa, adopting VaaS could ease the strain on public transit and lessen the reliance on private cars. For successful implementation, a dependable network of service providers, a solid regulatory system, and a supportive digital infrastructure are essential. Prioritizing the safety and dependability of these services is crucial, which involves enforcing rigorous licensing standards, conducting regular vehicle inspections, and ensuring comprehensive insurance for service providers.

3.2.5. Electric Vehicles

Introducing EVs into Kinshasa's transportation network could greatly cut down on pollution and decrease the city's dependence on fossil fuels. Incorporating a range of electric options—such as buses, cars, and scooters—will contribute to a more sustainable and cleaner urban atmosphere. To facilitate this transition, Kinshasa should prioritize the establishment of widespread charging infrastructure, including fast-charging stations throughout the city. Moreover, offering incentives like tax breaks or subsidies for both EV purchases and the development of necessary infrastructure will help motivate individuals and businesses to make the switch. Additionally, creating supportive policies that encourage the use of renewable energy for powering these vehicles will maximize their environmental advantages.

3.2.6. Infrastructure Upgrades

The successful integration of previously presented smart mobility concepts requires comprehensive infrastructure upgrades in Kinshasa. Key areas for improvement include the following:

(a) Digital Infrastructure: enhancing Internet connectivity, expanding mobile network coverage, and implementing secure digital payment systems.
(b) Transport Infrastructure: building and maintaining dedicated lanes for bikes and scooters, creating parking spaces for car-sharing vehicles, and establishing EV charging stations.
(c) Data Management: developing integrated data platforms to manage real-time information from various transport services, ensuring seamless operation of MaaS.
(d) Policy and Regulation: crafting supportive policies that promote innovation in mobility services, ensure safety and reliability, and provide incentives for sustainable practices.

4. Examination of Successful Smart Mobility Implementations in Other Cities

In the following text, different approaches to smart mobility solutions are presented. Case studies are divided into two groups. The first group presents studies that were selected based on their innovativeness regarding the specific smart mobility concept. For each study, a summary of possible lessons to be learned is provided. The second group presents studies from cities with populations exceeding 10 million inhabitants that are comparable to Kinshasa in critical aspects such as population density, economic constraints, and infrastructural challenges. These examples should help gain a comprehensive understanding of smart mobility solutions by highlighting how additional cities worldwide have addressed specific challenges or their combination.

4.1. Studies on Successful Implementations of Specific Smart Mobility Concepts in Other Cities

4.1.1. Singapore's and Helsinki's Mobility-as-a-Service Ecosystems

Singapore stands as a global exemplar in redefining urban mobility through its innovative Mobility-as-a-Service (MaaS) ecosystem [67]. This innovative platform combines multiple transportation options, including public transit, ride-hailing, and bike-sharing, to provide a smooth and efficient travel experience. Led by the Land Transport Authority (LTA), Singapore's partnership with private operators has enhanced transportation access and established a new standard for sustainable and user-friendly urban mobility solutions.

The success of Singapore's MaaS model lies in its robust regulatory framework, characterized by clear guidelines and incentives that encourage private-sector participation while safeguarding commuter interests. Comparative studies between Singapore and cities like Kinshasa illuminate critical aspects such as regulatory agility, data-sharing protocols, and user acceptance rates, providing invaluable insights for cities navigating similar mobility challenges amidst rapid urbanization.

The regulatory framework in Singapore promotes fair competition among transportation providers while ensuring service quality and affordability for commuters [68]. Transparent data-sharing agreements facilitate the seamless integration of mobility services, enabling real-time route optimization, fare aggregation, and personalized travel recommendations [69]. By examining these regulatory mechanisms, Kinshasa and other growing cities can foster an ecosystem conducive to sustainable mobility innovation and equitable access to transportation options. Moreover, user adoption rates and preferences play a pivotal role in shaping MaaS effectiveness. Singapore's emphasis on user-centric design, intuitive mobile interfaces, and inclusive pricing models has garnered widespread acceptance among commuters. Comparative analysis can delve into user behavior patterns, satisfaction levels, and factors influencing mode choices, guiding cities in tailoring MaaS offerings to diverse urban populations with varying mobility needs [70]. The joint efforts of public agencies, private operators, and technology providers highlight the crucial role of public-private partnerships (PPP) in transforming urban mobility. By forming strategic alliances, these partnerships drive investments in infrastructure, foster technological progress, and ensure smooth integration of services. This collaborative approach sets the stage for developing sustainable, efficient, and robust urban transportation systems [71].

Helsinki's approach is based on the User-Centric Mobility Platform. This city stands as a beacon of innovation in urban mobility, showcasing a steadfast commitment to Mobility-as-a-Service (MaaS) principles that have redefined how people navigate the city. At the heart of this transformation is the Whim app, a groundbreaking platform that seamlessly integrates various transportation modes including public transit, taxis, car rentals, and bike-sharing services. This comprehensive approach has not only simplified the travel experience for Helsinki residents but has also set a global benchmark for user-centric mobility solutions [72].

A promising area for comparative research is user satisfaction. Helsinki's Whim app, known for its user-friendly interface, personalized travel planning, and dependable service, serves as a prime example. By analyzing user feedback, preferences, and adoption statistics, researchers can gain important insights into what drives high levels of satisfaction among users [73]. Insights gained from such analyses can guide cities like Kinshasa in designing user-friendly mobility platforms tailored to the needs and preferences of their diverse populations. Furthermore, Helsinki's MaaS model offers an opportunity to delve into pricing models and affordability considerations. The Whim app's flexible payment structures, subscription options, and bundled services have reshaped traditional notions of transportation costs, offering users cost-effective and convenient travel alternatives. Comparative studies can evaluate the impact of pricing strategies on user behavior, mode shift patterns, and overall transportation expenditure. Understanding the dynamics of pricing models within the context of MaaS can inform policymakers in Kinshasa on designing equitable and economically sustainable mobility solutions.

A critical aspect of Helsinki's success lies in its strategic partnerships between public and private entities, fostering collaboration toward a common goal of sustainable urban mobility [74,75]. Evaluating the efficacy of these partnerships in terms of service reliability, innovation diffusion, and regulatory compliance can provide actionable insights for cities like Kinshasa. By nurturing robust public–private partnerships, cities can leverage expertise, resources, and innovation to enhance transportation accessibility, reduce carbon footprints, and improve overall urban livability.

Singapore's MaaS ecosystem and Helsinki's wholesome approach can serve as a blueprint for urban mobility transformation globally, emphasizing the synergy between regulatory innovation, data-driven insights, user-centric design, and collaborative governance models. By leveraging lessons from presented experiences, cities like Kinshasa can navigate the complexities of urban mobility, foster innovation ecosystems, and create inclusive transportation networks that cater to the evolving needs of urban communities while advancing sustainable development goals. Through comparative research encompassing user satisfaction, pricing dynamics, and collaborative governance models, cities can unlock the full potential of smart mobility initiatives, fostering sustainable, inclusive, and user-centric urban environments for generations to come.

4.1.2. Barcelona's Superblocks

Barcelona's forward-thinking urban planning strategy, epitomized by the concept of "superblocks", represents a paradigm shift in city design and transportation management. Superblocks are designated areas within the city where cars are restricted, and pedestrian-friendly zones are prioritized, creating vibrant public spaces and mitigating traffic congestion. The Eixample district in Barcelona serves as a prime example of this innovative approach, showcasing the transformative potential of reimagining urban spaces. At the heart of Barcelona's superblocks concept is the idea of reclaiming streets for people rather than vehicles. By reducing vehicular traffic within these areas, Barcelona has successfully revitalized public spaces, encouraging social interactions, outdoor activities, and community engagement [72]. This approach not only enhances the quality of life for residents but also attracts visitors, contributing to the economic vitality of these neighborhoods.

A comparative analysis of Barcelona's superblocks can yield valuable insights for cities like Kinshasa embarking on spatial planning and urban rejuvenation endeavors. Firstly, examining the impact on air quality reveals how reduced traffic emissions within superblocks lead to cleaner air, contributing to public health improvements and environmental sustainability goals. Lessons learned from Barcelona can enrich Kinshasa's strategies for mitigating air pollution and promoting eco-friendly urban development practices.

Moreover, assessing the effects on community well-being unveils the social benefits of pedestrian-friendly environments. Barcelona's superblocks foster a sense of belonging, encourage active lifestyles, and create safer streets for pedestrians and cyclists. These positive social outcomes highlight the importance of prioritizing human-centric design principles in urban planning, an approach that Kinshasa can integrate into its neighborhood revitalization projects to enhance livability and social cohesion. In terms of economic efficiency, Barcelona's superblocks demonstrate how investing in pedestrian infrastructure and public spaces can stimulate local businesses, attract tourism, and enhance property values. The creation of vibrant, walkable districts fosters a conducive environment for small businesses, cultural activities, and placemaking initiatives, contributing to sustainable economic growth and urban vibrancy.

Lessons learned from Barcelona's superblocks can serve as a beacon of innovation in urban transformation, offering valuable lessons for cities worldwide, including Kinshasa. By focusing on creating pedestrian-friendly spaces, cutting down on reliance on cars, and encouraging community involvement, cities can build sustainable and livable neighborhoods that enhance both people's well-being and environmental care. Incorporating the concept of superblocks into urban planning can help forge a more resilient, inclusive, and dynamic future for Kinshasa and other cities.

4.1.3. Medellín's, Curitiba's, and Cape Town's Integrated Transportation Systems

Medellín, Colombia, stands as a beacon of success in the realm of integrated transportation systems, earning international acclaim for its innovative approach to mobility. Central to this success is the city's diverse and interconnected transportation infrastructure, which includes a modern metro system, cable cars traversing steep hillsides, and a network of efficient bus rapid transit (BRT) routes. These elements work synergistically to provide residents with reliable, accessible, and sustainable transportation options.

Medellín's strategic investments in its transportation infrastructure have brought about substantial benefits for both the city and its residents [76]. Enhanced accessibility across various neighborhoods has made travel more convenient, decreasing travel times and improving overall mobility [77]. A key highlight is the modern metro system, which offers a rapid and efficient transportation option, linking important city areas and alleviating road congestion. Additionally, the integration of cable cars into the city's transit network showcases Medellín's dedication to inclusivity and social equity. These cable cars provide aerial connections to neighborhoods on steep hillsides, thereby improving access to crucial services, education, and job opportunities for residents in formerly marginalized areas [78]. This emphasis on social inclusion not only boosts the quality of life but also strengthens community bonds and a sense of belonging. Moreover, Medellín's innovative bus rapid transit (BRT) networks further enrich the city's transportation landscape by delivering flexible, high-capacity transit options that complement existing systems. The dedicated bus lanes ensure efficient and reliable service, reducing reliance on private vehicles and supporting a more sustainable urban environment.

Comparative studies examining Medellín's integrated transportation systems can provide valuable insights for cities like Kinshasa. Key areas of analysis include the scalability of Medellín's approach to accommodate growing urban populations, the tangible impacts on urban development such as reduced congestion and improved air quality, and lessons learned in enhancing multimodal connectivity seamlessly. By studying Medellín's success story, Kinshasa can identify best practices, adapt strategies to its unique context, and chart a sustainable path toward efficient and inclusive urban mobility for its residents.

Curitiba, Brazil, has earned global recognition for its visionary integrated planning model, setting a benchmark for sustainable urban development worldwide [79]. At the heart of Curitiba's success lies a comprehensive strategy that prioritizes sustainable transportation, green spaces, and social equity, creating a harmonious urban environment that enhances the quality of life for its residents. Central to this model is Curitiba's acclaimed Bus Rapid Transit (BRT) system, which, when coupled with strategic land-use planning and environmental initiatives, has revolutionized urban mobility and community well-being.

Curitiba's approach to sustainable mobility is built around its groundbreaking Bus Rapid Transit (BRT) system, which serves as the foundation of its efforts [80]. Unlike traditional bus systems, Curitiba's BRT features dedicated lanes, pre-paid boarding, and efficient boarding processes, resembling a surface subway. This design minimizes congestion, reduces travel times, and provides a cost-effective alternative to private car usage. Comparative studies can delve into the BRT's operational efficiency, ridership patterns, and user satisfaction, offering valuable insights for cities like Kinshasa seeking to reduce car dependency and promote sustainable transit options.

Beyond transportation, Curitiba's integrated planning extends to land-use policies that prioritize mixed-use developments, pedestrian-friendly zones, and green spaces. By strategically clustering residential, commercial, and recreational areas around transit hubs, Curitiba encourages walkability, reduces sprawl, and fosters vibrant urban communities [81]. Comparative analysis can assess the spatial organization's impact on urban sprawl, community cohesion, and accessibility, informing Kinshasa's urban planning strategies to create livable neighborhoods and promote active transportation modes. Furthermore, Curitiba's environmental initiatives, such as extensive tree planting, green corridors, and waste management programs, demonstrate a holistic approach to sustainability.

These urban initiatives serve a dual purpose: they not only enhance the visual appeal of city landscapes but also significantly improve air quality, reduce heat island effects, and foster urban biodiversity. By evaluating and comparing these initiatives, we can gain a comprehensive understanding of their environmental impacts, strategies for public engagement, and underlying policy frameworks. This detailed analysis offers valuable insights that can guide Kinshasa in boosting its environmental sustainability and fostering a healthier living environment for its residents.

The success of Curitiba's integrated planning model underscores the importance of holistic, collaborative approaches to urban development. By integrating transportation, land-use planning, and environmental initiatives, Curitiba has not only improved mobility but also enhanced social equity and environmental resilience. Lessons learned from Curitiba's experience can guide Kinshasa and other cities in developing tailored, sustainable mobility strategies that prioritize people, planet, and prosperity, paving the way for inclusive and resilient urban futures.

Another example of a successful smart mobility solution can be found in Cape Town. Situated at Africa's southernmost tip, Cape Town has emerged as a benchmark for sustainable urban transport through its MyCiTi Bus Rapid Transit (BRT) system. Designed to provide efficient and accessible public transit across the city, the MyCiTi BRT represents a major step toward sustainable transportation [82]. In contrast to conventional bus services, the BRT system works harmoniously with other transport options, including dedicated bike lanes and pedestrian routes, promoting multimodal connectivity and lessening reliance on private cars [83].

The MyCiTi BRT system's success lies in its comprehensive approach to urban mobility, addressing key challenges such as traffic congestion, air pollution, and accessibility barriers. By prioritizing dedicated lanes for buses, the system ensures faster and more reliable commute times for passengers, encouraging greater uptake of public transit [84]. Additionally, integrating cycling lanes and pedestrian pathways fosters active transportation modes, enhancing the overall health and sustainability of urban areas. A comparative study of Cape Town's MyCiTi BRT system reveals important insights into its socio-economic effects and its alignment with wider urban development plans. Exploring the system's impact could include analyzing its ability to reduce carbon emissions, improve air quality, and boost public health by promoting increased physical activity among users. [85]. Additionally, analyzing how the system improves access to job centers, educational facilities, and recreational spaces provides a better understanding of its impact on socio-economic equity. Lessons from Cape Town's MyCiTi BRT system can be particularly instructive for enhancing mobility in Kinshasa's urban landscape. As Kinshasa grapples with rapid urbanization, traffic congestion, and limited public transit options, adopting elements of Cape Town's BRT model can offer transformative solutions. Integrating dedicated bus lanes, cycling infrastructure, and pedestrian-friendly pathways can improve mobility options for Kinshasa residents while reducing environmental impacts and fostering inclusive urban development.

The success of Cape Town's MyCiTi BRT system underscores the importance of proactive urban planning, stakeholder collaboration, and sustainable transport policies in shaping modern cities. By learning from global examples like Cape Town, Kinshasa can chart a path toward a more sustainable, equitable, and livable urban future, where efficient public transportation systems play a central role in enhancing quality of life for all residents.

4.2. Comparative Studies of Similar Initiatives in Other Cities

As urban populations swell, cities are under increasing pressure to develop efficient, sustainable public transportation systems [86]. The integration of advanced technologies and data analytics within smart mobility presents promising solutions to these challenges. This examination explores successful smart mobility implementations in seven cities with populations exceeding 10 million, comparable to Kinshasa in critical aspects such as population density, economic constraints, and infrastructural challenges.

4.2.1. São Paulo, Brazil

São Paulo, a city renowned for its massive size, has addressed its notorious traffic jams with a range of innovative mobility strategies. By utilizing an elaborate system of real-time traffic monitoring, the city leverages data from thousands of sensors to assess traffic patterns and modify signal timings as needed. The adaptive traffic signal control system adjusts light patterns based on current conditions, effectively minimizing delays and enhancing traffic efficiency [87]. Additionally, São Paulo has expanded its Bus Rapid Transit (BRT) system, which now spans over 100 km. The BRT system incorporates dedicated lanes to avoid congestion, smart ticketing solutions for quicker boarding, and real-time tracking to inform passengers of bus arrivals, thereby enhancing efficiency and reducing travel times.

4.2.2. Mumbai, India

Mumbai's approach to smart mobility focuses on integrating various modes of transport through a unified digital platform. The Mumbai Metro and suburban railway systems now offer seamless connectivity facilitated by smart cards and mobile ticketing apps, allowing passengers to switch between different transit modes effortlessly. The city's implementation of an Integrated Transport Management System (ITMS) has improved coordination and efficiency across various transit services. ITMS offers up-to-the-minute information on vehicle locations, which helps improve route planning and minimize delays [88]. Furthermore, Mumbai has integrated electric buses into its public transport network, resulting in reduced emissions and a cleaner urban atmosphere.

4.2.3. Lagos, Nigeria

Lagos has tackled its transportation issues by combining advanced and traditional methods. The Lagos Bus Services Ltd. (LBSL) has rolled out a new bus fleet that features GPS for live tracking and contactless payment systems, enhancing the efficiency and convenience of the transit network. Furthermore, the city has launched a trial program for ride-hailing services, carefully regulated to balance safety, cost, and compatibility with public transport. Lagos is also investigating data analytics to fine-tune bus routes and schedules according to passenger demand, striving to deliver more dependable and frequent service [89].

4.2.4. Jakarta, Indonesia

Jakarta's TransJakarta BRT system stands as a model of smart mobility. The city utilizes electronic ticketing and bus priority systems to enhance service reliability. Buses in the TransJakarta system are equipped with GPS and are monitored in real-time, ensuring punctuality and efficient operation [90]. Jakarta has introduced a smart parking system equipped with sensors to track parking space availability. This innovation aims to cut down on the time drivers spend looking for parking spots, thereby easing traffic congestion.

Additionally, the city is broadening its bike-sharing program by linking it with public transit stations, fostering a more integrated and multimodal transportation network.

4.2.5. Manila, Philippines

Manila has embraced smart mobility through its EDSA Busway project, which introduced dedicated lanes for buses along the busy EDSA corridor, significantly reducing travel time and improving punctuality [91]. The project is backed by a real-time passenger information system that keeps passengers updated on bus schedules through digital displays at stops and a mobile app. This system aids in managing passenger flow, minimizing overcrowding, and improving the travel experience. Additionally, Manila is testing electric buses and working on a comprehensive network of charging stations to facilitate their use.

4.2.6. Cairo, Egypt

Cairo's smart mobility efforts are exemplified by the Cairo Metro's adoption of automated fare collection and the development of a comprehensive mobile app for trip planning. The app provides live updates on train schedules and routes, enhancing the convenience and accessibility of public transportation. Additionally, the city is expanding its metro network to link more neighborhoods and lessen the dependence on personal vehicles. Cairo is also introducing advanced traffic management systems powered by artificial intelligence (AI) to improve traffic flow and ease congestion [92].

4.2.7. Dhaka, Bangladesh

Dhaka has focused on integrating technology with its public bus system to improve efficiency. The city's Bus Network Improvement Project includes the use of GPS tracking and automated fare collection, streamlining operations and enhancing service reliability. Additionally, Dhaka has started implementing dedicated bus lanes to expedite transit services amid heavy traffic [93]. The city is also developing an Integrated Transport System (ITS) that aims to coordinate various modes of transport, including buses, rickshaws, and ferries, through a single digital platform, providing real-time information and facilitating seamless transfers.

Each of these cities has faced challenges similar to those in Kinshasa, such as high population density, limited resources, and infrastructural constraints. Their successful implementation of smart mobility solutions—ranging from real-time data analytics to integrated ticketing systems—offers valuable insights. Kinshasa can draw lessons from these examples to develop its own smart mobility strategies, aiming to create a more efficient, sustainable, and user-friendly public transportation system. By concentrating on scalable and adaptable solutions, Kinshasa has the opportunity to use technology to tackle its specific transportation issues. Introducing smart mobility projects could enhance residents' quality of life, lower environmental impacts, and set an example for other rapidly growing megacities. Embracing these innovations will be vital for Kinshasa's future growth and evolution, helping it stay a lively and progressive urban hub.

4.3. Identification of Key Success Factors for Smart Mobility

The following text is dedicated to the overview of key success factors for smart mobility that were identified in case studies worldwide. It can provide valuable insights for Kinshasa and other cities that are starting their smart mobility journey. For each factor possible lessons to learn are indicated.

4.3.1. Leadership and Vision in Smart Mobility

Smart mobility initiatives thrive under the guidance of strong leadership and a clear vision, as demonstrated by Bogotá's transformation under Mayor Enrique Peñalosa's tenure. His forward-thinking strategy emphasized the importance of sustainable and fair transportation options, concentrating on minimizing dependence on private cars while boosting non-motorized transport methods. By prioritizing the creation of infrastructure for cycling and walking, the city enhanced safety and accessibility for those who commute without motor vehicles, which in turn eased traffic congestion and cut down on environmental pollution.

Lessons for Kinshasa:

(a) Setting clear objectives: Kinshasa can benefit from defining clear objectives for its smart mobility initiatives, aligning them with principles of sustainability, equity, and community well-being. A clear vision offers a roadmap for making decisions and guarantees that efforts are focused on achieving concrete results.
(b) Stakeholder engagement: Engaging diverse stakeholders, including government agencies, urban planners, community groups, and transportation experts, is crucial for building consensus and support for smart mobility initiatives. By fostering collaboration and inclusivity, Kinshasa can ensure that its mobility strategies address the diverse needs of its population.
(c) Incremental implementation: Bogotá's success was achieved through incremental and phased implementation of infrastructure projects, allowing for flexibility and adaptation to changing circumstances. Kinshasa can adopt a similar approach by starting with pilot projects or smaller-scale interventions to test the feasibility and effectiveness of smart mobility solutions before scaling up implementation.
(d) Data-informed decision-making: Leveraging data and technology for informed decision-making is essential in optimizing transportation planning and infrastructure investments. Kinshasa could leverage data analytics to understand traffic patterns, commuter habits, and infrastructure utilization, which would allow for more informed decision-making and better resource distribution.

By embracing the lessons from Bogotá's leadership and vision in smart mobility, Kinshasa can pave the way for a more efficient, equitable, and sustainable urban transportation system. With proactive leadership, stakeholder engagement, incremental implementation, and data-driven decision-making, Kinshasa can chart a path toward a future where mobility is accessible to all, contributing to the city's overall prosperity and livability.

4.3.2. Public Engagement and Co-Creation

A hallmark of successful smart mobility initiatives is robust public engagement and co-creation processes, wherein cities actively involve residents in designing and shaping transportation solutions. Vienna's approach stands out as a prime example, where citizen engagement played a pivotal role in developing smart mobility solutions that truly reflect the community's needs and preferences. In Vienna, residents had the opportunity to engage in decision-making, offering crucial insights and feedback on different elements of smart mobility planning [94]. Through town hall meetings, workshops, surveys, and digital platforms, residents were given a platform to voice their concerns, aspirations, and ideas for improving urban mobility. This inclusive approach ensured that the final solutions were not only technically sound but also aligned with the values and expectations of the community.

Lesson for Kinshasa:

(a) Embrace community input: Kinshasa has an opportunity to draw lessons from Vienna's approach by involving its community in the development and execution of smart mobility initiatives. By soliciting input from various stakeholders, including regular commuters, local enterprises, and advocacy groups, Kinshasa can gain a clearer insight into the particular mobility challenges and requirements of its population.
(b) Utilize participatory platforms: Kinshasa can leverage digital platforms and social media channels to facilitate broader public participation in smart mobility initiatives. By creating easy ways for residents to give feedback and work together, the city can make sure that everyone, including marginalized groups, has their voices heard and taken into account in the decision-making process.
(c) Co-create solutions: By involving residents in the co-creation of smart mobility solutions, Kinshasa can ensure that the final outcomes are user-centric and culturally

relevant. Collaborative design workshops, pilot projects, and community-led initiatives can foster a sense of ownership and empowerment among residents, driving greater acceptance and adoption of smart mobility measures.

(d) Build trust and transparency: Transparency and trust-building are essential pillars of successful public engagement. Kinshasa can prioritize open communication, accountability, and responsiveness to community feedback to build trust and confidence in its smart mobility initiatives.

By focusing on involving the public and fostering co-creation in the planning of smart mobility, Kinshasa can tap into the collective insight and creativity of its residents. This approach will enable the city to develop transportation solutions that are not only cutting-edge in technology but also socially inclusive, fair, and attuned to the varied needs of its urban community.

4.3.3. Adaptive Regulation in Smart Mobility

Adaptive regulation plays an important role in all successful smart mobility initiatives, as evidenced by transformative measures such as London's congestion charge and Paris's implementation of car-free days. These regulatory interventions showcase the ability of cities to proactively manage urban mobility challenges while fostering sustainable transportation practices.

Introduced in 2003, London's groundbreaking congestion charge has become a worldwide model for effectively managing traffic congestion and encouraging the use of alternative transportation methods. The charge levied on vehicles entering the city center during peak hours incentivizes commuters to explore public transit, cycling, or carpooling options [95]. Kinshasa can draw insights from London's experience to devise similar congestion pricing schemes tailored to its own traffic patterns and congestion hotspots. By strategically implementing congestion charges, Kinshasa can reduce traffic congestion, improve air quality, and generate revenue for sustainable mobility infrastructure investments.

Paris's initiative of car-free days in certain parts of the city illustrates the transformative potential of temporary regulatory measures in promoting sustainable urban mobility. By temporarily restricting vehicle access, cities can encourage active transportation, public transit usage, and community engagement in reimagining urban spaces [96]. Kinshasa can leverage this approach by periodically organizing car-free days in key districts or promoting car-free zones during weekends to promote walking, cycling, and public transit usage. Such initiatives not only reduce traffic congestion and emissions but also enhance the livability and vibrancy of urban areas.

By learning from global examples of adaptive regulation in smart mobility (see Table 2), Kinshasa can develop a holistic approach that combines regulatory innovation, infrastructure investments, and community engagement to create a more connected, efficient, and sustainable urban environment for its residents.

Table 2. Insights gained from adaptive regulation in the field of smart mobility.

Lesson	Description
Customized regulatory approaches	Tailor regulations like congestion pricing to address traffic bottlenecks and promote sustainable transportation.
Public engagement and awareness	Initiatives like car-free days for fostering public awareness and participation in alternative transportation.
Infrastructure investments	Prioritize investments in public transit, cycling lanes, and pedestrian-friendly infrastructure.
Data-driven decision making	Use data analytics to monitor regulatory effectiveness and optimize traffic management strategies.

4.3.4. Equity and Inclusivity in Smart Mobility

The cornerstone of successful smart mobility initiatives lies in their ability to ensure equitable access and inclusivity for all members of society. Cities such as Curitiba in Brazil and Medellín in Colombia have demonstrated a remarkable commitment to prioritizing equitable mobility solutions.

Curitiba's renowned Bus Rapid Transit (BRT) system, coupled with integrated feeder bus networks and pedestrian-friendly infrastructure, exemplifies a holistic approach to mobility planning. It is based on implementing integrated transit networks that consist of developing a well-connected public transit system that seamlessly integrates buses, BRT lines, and feeder services to cater to diverse communities across Kinshasa. Another important aspect is the prioritization of last-mile connectivity: the city is focusing on enhancing last-mile connectivity through feeder services, bike-sharing programs, and pedestrian pathways to ensure accessibility for residents from all neighborhoods.

Medellín's commitment to inclusive urban development extends to its transportation systems, with a focus on reducing mobility barriers and promoting accessibility for all. The city is emphasizing multi-modal integration by integrating various modes of transportation such as metro, cable cars, buses, and cycling infrastructure to provide a comprehensive and accessible mobility network. It also addresses socio-economic disparities by identifying areas with limited mobility options and strategically allocating resources to improve accessibility, particularly in underserved communities.

By embracing inclusive and equitable smart mobility strategies inspired by Curitiba and Medellín, Kinshasa can create a more accessible, connected, and livable urban environment where transportation barriers are minimized, and mobility options are optimized for everyone, irrespective of income or location. These lessons (see Table 3) underscore the importance of integrating equity considerations into infrastructure planning and fostering community engagement to build a resilient and inclusive urban mobility ecosystem.

Table 3. Insights gained regarding equity and inclusivity in the realm of smart mobility.

Lesson	Description
Design Transit-Oriented Developments (TOD)	Design plans centered on transit hubs to encourage mixed-use development, affordable housing, and convenient public transportation access.
Prioritize Universal Design	Incorporate universal design in infrastructure to accommodate diverse mobility needs, including elderly and disabled individuals.
Engage Communities in Planning	Involve local communities, advocacy groups, and stakeholders in planning to ensure projects meet residents' mobility needs and aspirations.

4.3.5. Achieving the Optimal Balance Between Data Privacy and Security in Smart Mobility

In smart mobility projects, safeguarding data privacy and security is crucial, as seen in cities like Toronto and Amsterdam. Toronto, for instance, emphasizes the importance of clear governance structures and robust data protection strategies to maintain privacy and security in its smart mobility efforts. Amsterdam, on the other hand, emphasizes a "privacy-by-design" approach integrated into smart mobility systems and infrastructure to safeguard privacy and security. A crucial role in protecting data in smart mobility plays infrastructure, together with transparency that is vital for establishing and upholding citizen trust in smart mobility initiatives. Kinshasa can learn from these cities in maintaining trust among citizens while utilizing data for innovative mobility solutions.

Kinshasa can foster trust among its citizens and unlock the transformative benefits of smart mobility for sustainable urban development by implementing a proactive strategy for data privacy and security (see Table 4). This involves utilizing transparent governance models, integrating privacy-by-design principles, and making significant investments in robust infrastructure.

Table 4. Lessons learned in the area of data privacy and security in smart mobility.

Lesson	Description
Establishing Clear Data Governance Policies	Develop clear policies for data collection, storage, sharing, and anonymization in smart mobility projects.
Engaging Stakeholders	Involve citizens, advocacy groups, and experts in shaping data governance to foster transparency and trust.
Conducting Privacy Impact Assessments (PIAs)	Conduct periodic Privacy Impact Assessments (PIAs) to detect and address potential privacy concerns in smart mobility initiatives.
Secure Data Storage Facilities	Invest in secure data storage with robust cybersecurity measures to protect sensitive mobility data.
Encrypted Communication Networks	Implement encrypted communication for data transmission between devices, sensors, and control systems.
Transparent Data Practices	Communicate openly about data collection purposes, usage policies, and privacy safeguards to citizens.
Engagement and Education	Conduct public awareness campaigns and workshops on data privacy, cybersecurity, and smart mobility benefits.

4.3.6. Fostering Cooperation for Smart Mobility Success

Collaboration among diverse stakeholders is a cornerstone of successful smart mobility initiatives, driving innovation, and ensuring holistic solutions. Cities around the globe have demonstrated effective collaboration models that Kinshasa could learn from. Here are the essential factors for successful partnerships in smart mobility projects:

(a) Government Leadership and Coordination—Example from Singapore: The Land Transport Authority (LTA) collaborates with private operators and technology companies to integrate various transportation modes seamlessly. Kinshasa can establish dedicated agencies or task forces to coordinate smart mobility efforts across government departments, fostering a cohesive approach to urban mobility planning.

(b) Private Sector Engagement and Innovation—Example from Barcelona: Private companies play a crucial role in Barcelona's superblocks initiative, contributing innovative solutions for urban mobility challenges. Kinshasa can incentivize private sector participation through public–private partnerships (PPPs) and innovation grants, encouraging the development of smart transportation solutions tailored to local needs.

(c) Community Participation and Stakeholder Engagement—Example from Helsinki: Helsinki engaged citizens in co-creating smart mobility solutions through platforms like the Whim app, enhancing user experience and acceptance. Kinshasa can organize public consultations, focus groups, and participatory workshops to gather insights from residents, ensuring that mobility solutions align with community priorities and preferences.

By making collaboration a core element of its smart mobility plan, Kinshasa has the opportunity to tap into the skills, resources, and innovative ideas of various stakeholders. This collaborative approach (see Table 5) can lead to the development of sustainable, inclusive, and efficient transportation solutions tailored for its expanding urban population. By forging strategic partnerships, investing in cutting-edge infrastructure, and actively involving the community, Kinshasa can create a more connected and livable city.

Table 5. Lessons learned in the area of fostering cooperation for smart mobility.

Lesson	Description
Integrated Transport Systems	Develop systems connecting various transit modes for seamless mobility. Collaborate with transport operators, city planners, and technology providers to optimize routes and enhance accessibility.
Smart Infrastructure Investments	Invest in smart traffic management, real-time data analytics, and digital signage to improve traffic flow and safety. Collaborate with technology companies and research institutions on innovative solutions.
Interdisciplinary Partnerships	Promote collaboration between urban planners, engineers, data scientists, and social scientists to develop well-rounded mobility solutions.
Capacity Building and Knowledge Sharing	Organize workshops and training to build capacities and share best practices and trends in smart mobility.

4.3.7. Enhancing Interoperability in Smart Mobility Through Effective Data Governance

In the field of smart mobility, cities that succeed recognize the importance of data governance for smooth operations and innovation. Efficient data management, especially in terms of interoperability, is essential for maximizing the advantages of smart mobility projects [97]. Drawing insights from international experiences and tackling data governance obstacles can greatly improve Kinshasa's smart mobility progress.

One side of this process consists of understanding the interoperability. Interoperability refers to the ability of different systems, devices, or applications to connect, communicate, and exchange data seamlessly. Cities like Singapore, Amsterdam, and Toronto have demonstrated excellence in establishing interoperable data ecosystems in their smart mobility initiatives. The second side involves the identification of best practices in data governance. Cities that effectively address data governance challenges are usually leaders in the field of smart mobility. Kinshasa can learn from successful data governance strategies implemented in cities like Helsinki, London, and Barcelona.

The successful introduction of the smart mobility concept comprises also infrastructure implications. Effective data governance is intertwined with infrastructure readiness and technological capabilities.

By prioritizing effective data governance practices (see Table 6), Kinshasa can optimize smart mobility initiatives, improving transportation efficiency, enhancing urban planning strategies, and ultimately creating a more connected and livable city for its residents. Collaboration, well-defined policies, data security, and substantial infrastructure investments are essential elements that can drive Kinshasa toward success in smart mobility.

Table 6. Lessons learned in the area of data governance in smart mobility.

Lesson	Description
Adopting Open Data Standards	Implement open data standards for integration and sharing of data from transportation networks, IoT devices, and urban sensors.
Promoting Data Collaboration	Encourage data sharing among government, private sector, and academic institutions, ensuring privacy and security.
Creating Transparent Data Guidelines	Develop robust data governance frameworks with well-defined policies for data collection, storage, sharing, and usage, ensuring compliance with international standards like GDPR.
Emphasizing Data Security and Privacy	Implement robust data security measures, encryption protocols, and anonymization techniques to protect sensitive information and build citizens' trust.
Building Data Infrastructure	Invest in data centers, cloud computing infrastructure, and edge computing technologies to manage and analyze vast amounts of mobility data in real time.
Deploying IoT and Sensor Networks	Implement IoT devices and sensor networks across transportation infrastructure to capture real-time data on traffic flows, vehicle movements, and passenger behaviors.

4.3.8. Behavioral Change in Smart Mobility

Promoting the shift of commuters from private cars to shared and sustainable transportation modes is essential for smart mobility initiatives. Behavioral change campaigns, guided by behavioral economics principles, are key in facilitating this transition [98]. Analyzing effective strategies and obstacles in behavioral change from international case studies can provide valuable insights for Kinshasa's smart mobility efforts.

As a first step, it is necessary to understand behavioral economics insights of local communities. Behavioral economics studies about human behavior in decision-making processes offer insights into why individuals make certain transportation choices. For this purpose, Kinshasa can use the following:

- Research and Analysis: conducting behavioral studies and surveys to understand commuting preferences, motivations, and barriers among residents.
- Nudging Techniques: applying behavioral "nudges," such as incentives for carpooling, rewards for using public transit, or gamification elements in mobility apps to encourage sustainable choices.

The next step should consist of learning from global success stories. Cities worldwide have implemented effective behavioral change strategies in smart mobility contexts. Kinshasa can draw inspiration from these experiences:

- Stockholm's Congestion Pricing: by implementing congestion pricing, Stockholm successfully nudged commuters toward alternative modes of transportation, reducing traffic congestion and emissions.
- Paris's Vélib' Bike-Sharing System: Paris's Vélib' program promoted cycling as a sustainable mode of transit through convenient and affordable bike-sharing services, influencing commuter behavior positively.
- New York City's Transit Marketing Campaigns: NYC's targeted marketing campaigns for public transit usage leveraged behavioral insights, showcasing the benefits of shared mobility options and encouraging transit ridership.

By effectively applying this process, transportation infrastructure can become a key driver of behavioral change. The design and functionality of infrastructure significantly impact commuter habits and preferences. Additionally, community involvement and education are vital. Through educational outreach, programs, and interactive workshops, communities can be better informed and encouraged to support and adopt sustainable transportation options.

By adopting a multifaceted approach that combines insights from behavioral economics (see Table 7), global success stories, infrastructure development, and community engagement, Kinshasa can effectively promote behavioral change toward sustainable and shared mobility practices. These initiatives help alleviate congestion and decrease pollution while also fostering a more livable, equitable, and resilient urban environment for everyone.

Table 7. Lessons learned in the area of behavioral change in smart mobility.

Lesson	Description
Prioritizing Public Transit Accessibility	Invest in efficient public transit systems, including BRT routes, reliable schedules, and user-friendly payment systems.
Promoting Active Transportation	Develop cycling lanes, pedestrian pathways, and safe infrastructure for micro-mobility options like e-scooters and shared bikes.
Integrating Technology Solutions	Implement smart mobility apps, real-time transit information, and seamless intermodal connectivity for enhanced user experience.
Awareness Campaigns	Launch campaigns to highlight the benefits of using shared and sustainable transportation modes.
Education Initiatives	Partner with schools, businesses, and communities to educate about transportation options and the importance of emission reductions and behavioral change.

4.3.9. Infrastructure Investment as the Backbone of Smart Mobility

Ensuring the success of smart mobility projects hinges on establishing a robust infrastructure. Municipalities worldwide recognize the significant role that infrastructure investment plays in fostering efficient transport systems, enhancing sustainability, and elevating the quality of life [99]. As Kinshasa begins its smart mobility initiative, it can draw valuable lessons from international instances of innovative infrastructure development and investment. Examples of key infrastructure elements are as follows:

- Inner-city Highways: Well-designed inner-city highways are crucial to urban mobility, ensuring the efficient movement of vehicles and alleviating traffic congestion. Kinshasa can learn from cities that have implemented well-designed inner-city highways, optimizing traffic management and improving overall accessibility within urban centers.
- Charging Stations: As the number of EVs increases, establishing a comprehensive network of charging stations becomes essential to facilitate their broader acceptance. Kinshasa can learn from other cities that have effectively implemented charging infrastructure, thereby encouraging the use of EVs and cutting down on transportation-related carbon emissions.
- Bike Lanes: Investing in dedicated bike lanes promotes active transportation and reduces reliance on motor vehicles, thereby mitigating congestion and enhancing air quality. Kinshasa can prioritize the development of bike-friendly infrastructure, encouraging cycling as a viable mode of urban mobility and improving public health outcomes.
- Transit Hubs: Transit hubs serve as vital nodes within urban transport systems, facilitating seamless transfers between different transportation modes. Kinshasa can learn from other cities that have emphasized the development of well-integrated transit hubs, thereby enhancing connectivity, simplifying travel for commuters, and promoting the use of public transportation.
- Underground Metros and Inner-city Railways: Subterranean metro systems and inner-city railways offer rapid, efficient, and sustainable mass transit options, reducing congestion and greenhouse gas emissions. Kinshasa can explore the feasibility of underground transit networks, leveraging their capacity to move large volumes of passengers swiftly across the city.

By investing in a diverse array of infrastructure elements such as inner-city highways, charging stations, bike lanes, transit hubs, and underground metros, Kinshasa can lay the groundwork for a successful smart mobility transformation. Investing strategically in infrastructure not only boosts transportation efficiency but also enhances environmental sustainability, social equity, and economic prosperity. By adopting global best practices in infrastructure development, Kinshasa can develop a resilient and innovative urban transport system that adapts to the evolving needs of its residents and supports inclusive growth and development.

5. Methodology for Integrating Artificial Intelligence (AI) and Large Language Models (LLMs) into Smart Mobility Solutions for Kinshasa

A Comprehensive Summary of Section 5:

Section 5 presents the quintessence of a comprehensive research framework for integrating AI and LLMs into smart mobility solutions for Kinshasa. The objective is to improve the city's multi-modal public transportation system by employing AI-driven tools, simulations, and data analysis methods. The approach emphasizes a sequential process to enable informed decision-making for transportation management, infrastructure improvement, and policy interventions. For a non-expert, briefly explained, an LLM is an advanced type of artificial intelligence that can understand, generate, and interpret human language. It has been trained on vast amounts of text data from books, articles, and websites, which allows it to answer questions, create written content, and carry on conversations much like a person. LLMs are powerful tools used for tasks like translation, summarizing text, and even helping solve complex problems by processing large sets of information. Essentially, they help computers better understand and communicate using natural human language.

This overall complex methodological approach consists of five core steps, which are described in more detail in the remaining parts of Section 5. **Here, we provide a comprehensive summary of the QUINTESSENCE all the main steps of the complex methodological approach, which is described further in Section 5:**

- **Step 1: Understanding the Current System and Transport Dynamics while involving LLMs**
  Step 1 focuses on gaining a thorough understanding of the current transportation system in Kinshasa. This involves a detailed examination of various aspects such as the quality of infrastructure, traffic flow, existing transit routes, and public transportation services. To achieve this, data are collected using a range of methods, including sensors and IoT devices that provide real-time information about vehicle numbers, speeds, and congestion points. Satellite images and geographic data are also used to assess road conditions and detect traffic bottlenecks. Additionally, public feedback is gathered through surveys and questionnaires to understand how residents experience the transportation system.
  LLMs are then employed to process the collected data. These models are particularly useful for analyzing vast datasets, helping to uncover patterns in congestion and identify recurring problem areas. LLMs also play a crucial role in interpreting urban planning documents and public feedback, making it easier to identify key insights and opportunities for improvement. The goal of this step is to build a comprehensive understanding of the transportation system, allowing for the identification of critical areas in need of attention and setting the foundation for future improvements.
- **Step 2: Stakeholder Engagement Analysis while involving LLMs**
  Step 2 involves engaging all the relevant stakeholders to ensure that the goals of the project align with the needs and expectations of the community. Stakeholders include government authorities involved in urban planning, transport experts, and local communities who are directly affected by traffic congestion. LLMs are used to summarize stakeholder input effectively, providing decision-makers with the most relevant information. These models also help in building consensus by analyzing feedback and highlighting common areas of agreement or disagreement. This process facilitates focused discussions, ensuring that the priorities of different stakeholders are understood. The aim of this step is to establish clear and realistic goals that address the needs of all parties involved, fostering a more inclusive and collaborative approach to tackling traffic congestion.
- **Step 3: Identifying Upgrade Opportunities, with the support of LLMs**
  Step 3 is about identifying opportunities for improvement and mapping out potential solutions to address the challenges in Kinshasa's transportation system. To do this, different scenarios are tested using advanced traffic simulation tools like VISSIM and SUMO, to name a few, which predict how traffic will flow under various conditions. These simulations help identify the most effective ways to reduce congestion, improve road safety, and optimize public transit routes.
  LLMs assist by analyzing the data collected from these simulations and extracting valuable insights. They can look at historical congestion patterns and predict where future bottlenecks might occur. By comparing different datasets, LLMs can categorize congestion events based on their causes, such as poor road conditions or increasing population density.
  In addition to understanding the current problems, this step focuses on identifying areas with the greatest potential for improvement. These areas could include upgrading road infrastructure, optimizing transit routes, or expanding services to underserved regions. By mapping these opportunities, the team can prioritize actions that will have the most significant impact on improving the overall efficiency and effectiveness of Kinshasa's transportation system.

- **Step 4: Introducing Smart Mobility Solutions, with the support of LLMs**
Step 4 introduces the implementation of smart mobility solutions as a key strategy for addressing the challenges identified earlier in the process. The focus here is on integrating advanced technologies that improve the efficiency, sustainability, and convenience of the transportation system. One major initiative is the development of Mobility-as-a-Service (MaaS) platforms, which combine various public transport services into a single, easy-to-use system. This integration makes it simpler for residents to access different types of transportation, ultimately encouraging the use of public transit.
Another important aspect is the promotion of electric vehicles (EVs) and smart traffic management systems. Encouraging the use of electric buses and taxis can help reduce both congestion and environmental pollution. To support this transition, infrastructure investments such as charging stations for EVs are identified as crucial. Additionally, smart traffic signals that can adjust based on real-time traffic conditions are proposed to optimize the flow of vehicles through busy intersections.
LLMs assist in analyzing public sentiment and feedback, collected from sources such as social media and community surveys, to gauge the public's perception of these smart mobility solutions. This ensures that any concerns or potential challenges are identified and addressed early in the process. By focusing on these advanced mobility solutions, the transportation system becomes more efficient and adaptable, meeting the evolving needs of Kinshasa's residents while supporting a more sustainable urban environment.
Once the solutions have been defined, they are implemented in selected areas to assess how well they work in real-world conditions. This involves testing new routes, optimizing bus schedules, and improving traffic signal coordination in areas where traffic congestion is most severe. Data gathered during these pilot projects help to evaluate the effectiveness of the solutions in reducing congestion, improving travel times, and increasing overall service reliability.
Predictive models, powered by LLMs, are used to simulate potential outcomes of these pilot tests. These models forecast the longer-term effects of the interventions on traffic flow, fuel efficiency, and public satisfaction. As the pilot tests proceed, the dynamic nature of LLMs allows adjustments to be made based on real-time data, ensuring the solutions remain flexible and adaptable to any challenges that arise.
By testing and refining the proposed measures during the pilot phase, this step provides valuable insights into how the solutions can be scaled across the entire city, ensuring that they are both practical and beneficial for Kinshasa's transportation system.
- **Step 5: Community Involvement and Education, with the support of LLMs**
LLMs do significantly support the "Community Involvement and Education" step by facilitating the engagement and communication between decision-makers and communities. LLMs can help simplify complex information about transport improvements and urban planning, making it easier for residents to understand proposed changes. Through natural language processing, LLMs can generate clear explanations, answer residents' questions, and provide insights during scenario planning workshops. These models can also assist in creating personalized educational content, tailoring it to different community groups' needs and preferences.
Moreover, LLMs can be integrated into interactive simulation platforms and virtual reality (VR) environments, where they can guide users through the proposed public transport improvements, station designs, and user journeys. By providing real-time feedback based on user interactions, LLMs can help participants explore different scenarios, understand trade-offs, and prioritize investments according to their preferences.
Additionally, in scenario planning workshops, LLMs can analyze community feedback, suggest alternative upgrade scenarios, and predict the outcomes of different

decisions. They can also support tools like UrbanSim by interpreting the results of simulations, offering recommendations based on data, and assisting participants in evaluating the pros and cons of various options.
In summary, LLMs do play a crucial role in improving community involvement by simplifying information, enhancing simulation experiences, and actively participating in discussions and scenario planning. This can lead to more informed and inclusive decision-making processes.

- **Step 6: Pilot Programs, Evaluation, and Continuous Improvement**
LLMs are very useful for supporting Step 6 in the smart mobility project by summarizing pilot program results and generating insights from the data collected during the pilot phase. They do help analyze and interpret large amounts of information from AI-integrated mobility interventions and user feedback, offering clear summaries to facilitate decision-making on whether to expand these initiatives. Additionally, LLMs can aid in real-time data analysis and provide sentiment analysis from user feedback to improve service quality and system responsiveness. Overall, LLMs do enhance the efficiency and effectiveness of the continuous improvement cycle.
- **Step 7: Policy Guidelines and Sustainable Funding**
LLMs are highly beneficial for Step 7 by analyzing legislative documents and policy proposals to identify any potential barriers to implementing AI-powered smart mobility solutions. They can and do help generate clear policy recommendations that align with the project's objectives and ensure regulatory compliance. Furthermore, LLMs can assist in exploring sustainable funding models by utilizing AI-driven data analytics to make informed recommendations for optimizing infrastructure investments and enhancing operational efficiency. This support can help policymakers make well-informed decisions, driving forward smart urban transportation initiatives in Kinshasa.

Globally, LLMs play a crucial role at every stage of the process by performing various essential functions. They analyze vast amounts of unstructured data, such as public feedback and policy documents, to extract valuable insights. LLMs also facilitate communication between diverse stakeholders, making collaboration more efficient by summarizing and organizing input from various sources. Additionally, they contribute to simulating outcomes, allowing for predictive modeling that tests different scenarios before physical implementation. Furthermore, LLMs enable dynamic adaptation by continuously adjusting strategies based on real-time data analysis.

This methodology integrates data-driven insights, stakeholder involvement, and the flexibility offered by LLMs to enhance Kinshasa's public transport system. By focusing on technological innovation, particularly AI and LLMs, this approach ensures that the system becomes sustainable, efficient, and adaptable to the evolving needs of an expanding urban population. In a resource-constrained environment like Kinshasa, these tools offer a comprehensive solution for managing traffic congestion and improving public transit infrastructure.

5.1. Research Design and Approach for Smart Mobility Integration in Kinshasa: An AI (Artificial Intelligence) and LLMs (Large Language Models) Supported Research Approach and Simulation Studies

This sub-section delves into the comprehensive research design and approach required to significantly upgrade Kinshasa's rather primitive multi-modal public transportation system, aligning it with the demands of a bustling metropolis. Efficiently integrating previously presented smart mobility concepts like MaaS, car sharing, micro-mobility, VaaS, and EVs into Kinshasa's multi-modal road infrastructure demands a comprehensive research design and approach. The process of the implementation of these concepts should take place in a logical sequence of steps that are presented in Figure 6.

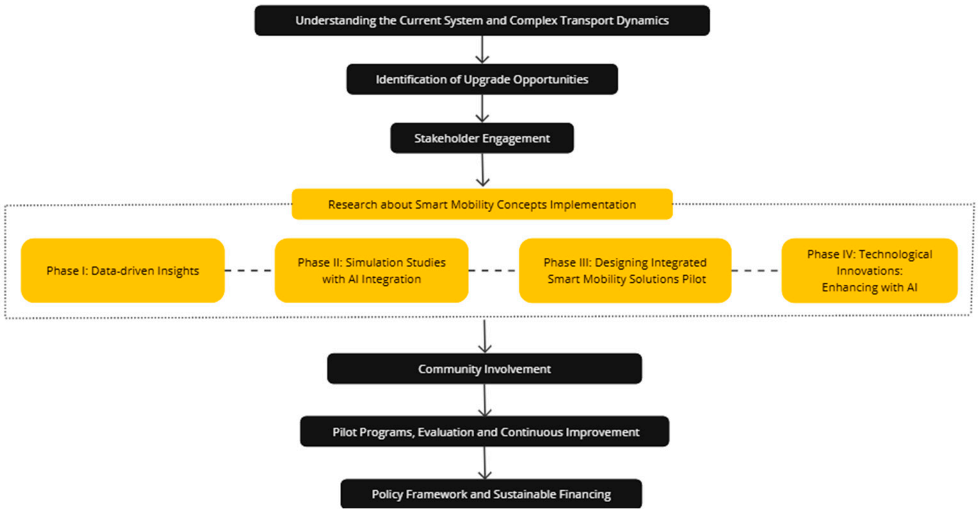

Figure 6. Research design for smart mobility integration into an existing transport system.

A detailed description of these steps is provided below. This text outlines the methodologies, tools, and strategies essential for this transformative process. Highlighting the importance of comprehensive simulation research, this approach leverages advanced software, AI, and LLM technologies to support informed decision-making and achieve optimal outcomes.

1. Step: Understanding the Current System and Complex Transport Dynamics

The initial phase consists of a thorough examination of Kinshasa's transportation ecosystem. Comprehensive data collection and analysis form the foundation for effective upgrade planning. This includes analyzing current road networks, public transit systems, traffic patterns, infrastructure deficiencies, and future population projections. To begin with, it is essential to conduct thorough data collection by compiling comprehensive information on current transportation modes, infrastructure status, ridership trends, and traffic patterns. This can be achieved through extensive surveys, IoT sensors, and satellite imagery. Following this, an infrastructure assessment is necessary. This involves analyzing the present condition of the infrastructure and pinpointing congestion areas, safety risks, and regions needing urgent attention. This assessment should be followed by a service evaluation that consists of an analysis of service reliability, frequency, accessibility, and affordability across different transport modes [100]. This analysis is needed for a nuanced understanding of user experiences and pain points. By harnessing LLM technologies, such as natural language processing (NLP) for sentiment analysis of public feedback and understanding complex urban planning documents, researchers can gain nuanced insights into the multifaceted challenges of the city's transportation landscape.

2. Step: Stakeholder Engagement

Engagement with diverse stakeholders is pivotal for success. This includes government entities, private sector players, urban planners, transportation experts, academia, and community representatives. Collaborative partnerships ensure a holistic approach, alignment of goals, and integration of local insights into planning processes. Engaging key stakeholders through data-driven insights ensures alignment with city-wide goals. It is needed to demonstrate the potential benefits and impacts of proposed upgrades, aiding decision-makers in policy formulation and budget allocation to government bodies. Then, transport operator consultation on service improvements should be realized, to assess fleet performance, route efficiencies, and capacity optimizations. It should be followed by ensuring community participation using integrating simulation-based interactive platforms that would allow residents to visualize proposed changes, provide feedback, and participate in co-designing transportation solutions. Also, LLM technologies can be used to aid in synthesizing vast amounts of stakeholder input and generating actionable recommendations for decision-makers.

3. Step: Identification of Upgrade Opportunities

Within upgrade initiatives, it is important to support evidence-based decision-making, for example, in the form of simulation studies. They can serve to quantify congestion reductions, travel time savings, and environmental benefits that will be a result of Infrastructure Enhancement. Then, the analyses and performance simulations for different vehicle types (e.g., electric buses, mini-vans) should be conducted to determine optimal fleet compositions balancing cost-effectiveness, emissions reductions, and passenger comfort a lifecycle cost. Subsequently, robust IT systems, mobile applications, and communication platforms should be designed to improve user experience and operational efficiency. This aspect involves modernizing the vehicle fleet by integrating advanced technologies. Utilizing real-time simulations of passenger movements, fare collections, and service disruptions can achieve this modernization.

4. Step: Research about Smart Mobility Concepts Implementation

This pivotal phase in the smart mobility implementation process involves researching how smart mobility concepts can be applied in specific conditions. Understanding the impact of these concepts on the entire urban mobility ecosystem is essential. The findings will serve as the foundation for strategic planning and decision-making. A blend of simulation methods and empirical research can be employed. To provide context and a deeper understanding of user needs and preferences, conducting surveys and interviews with stakeholders and target groups is recommended. These qualitative insights will complement the data obtained from simulations. Before implementing system-wide infrastructure changes and policy interventions, it is advisable to simulate commuting behavior, travel patterns, and transport mode choice using agent-based modeling (ABM) [101]. Equally important is the modeling of traffic dynamics, signal timing and transit operations, optimization of route designs, bus schedules and intersection configurations through traffic flow simulation [102]. Microsimulation tools such as VISSIM or SUMO can be used for this purpose.

The study of implementing smart mobility concepts can be broken down into a series of interconnected stages, each necessitating its own distinct set of tools and methodologies:

4. Step/Phase I. Data-driven Insights

- A mix of quantitative and qualitative methods such as surveys, GPS tracking, and travel diaries to capture real-time mobility data, commuter preferences, and pain points.
- Utilizing data analytics and visualization tools can provide valuable insights into traffic patterns, congestion points, transportation mode preferences, and peak travel periods. Additionally, LLM technologies can analyze unstructured data from sources like social media, news articles, and online forums to detect underlying trends and sentiments related to transportation challenges.

4. Step/Phase II. Simulation Studies with AI Integration

- Advanced simulation software like VISSIM (See URL: https://www.ptvgroup.com/fr/produits/ptv-vissim; accessed on 1 April 2024), Aimsun (See URL: https://www.aimsun.com/), or SUMO (See URL: https://eclipse.dev/sumo/; accessed on 1 April 2024) integrated with AI techniques such as advanced machine learning algorithms, deep learning models, and forecasting methodologies.
- AI-powered simulations enable researchers to model complex traffic scenarios, predict demand patterns, optimize route planning for MaaS users, and dynamically adjust traffic signals based on real-time data. LLM technologies have the capability to improve simulation outcomes by producing synthetic data to address deficiencies in real-world datasets and by simulating a more extensive array of scenarios.

4. Step/Phase III. Designing Integrated Smart Mobility Solutions

Selection of the most appropriate tools depends on the smart mobility concept that would be implemented into the existing transport system. The recommended tools for each of the smart mobility services are as follows:

- Mobility-as-a-Service Integration: AI-driven platforms for seamless integration of various transport modes, optimizing journey planning, real-time updates, and personalized recommendations for users. LLM technologies can aid in generating natural language descriptions of recommended routes and services, enhancing user understanding and engagement.
- Car Sharing and VaaS Solutions: AI algorithms for fleet management optimization, demand prediction, dynamic pricing, and route optimization for shared mobility services. LLM technologies can assist in generating personalized communication with users, providing trip suggestions, promotions, and feedback prompts.
- Micro-Mobility Solutions: AI-driven solutions for fleet management, optimal positioning of stations, demand-responsive services, and improving safety for micro-mobility vehicles. LLM technologies can process user-generated data to pinpoint high-demand areas for micro-mobility services and create easily understandable explanations of safety protocols and regulations.
- EV Infrastructure: AI-powered analytics to identify optimal locations for EV charging stations based on usage patterns, integrate smart grid technologies for efficient energy management, and forecast charging demand for effective infrastructure planning. LLM technologies can assist in summarizing technical reports and regulations related to EV infrastructure deployment, facilitating decision-making for policymakers and stakeholders.

4. Step/Phase IV. Technological Innovations: Enhancing with AI

- Intelligent Traffic Management: AI-driven traffic signal optimization, adaptive traffic flow control, predictive congestion management, and anomaly detection for proactive maintenance. LLM technologies can analyze historical traffic data and generate insights on traffic patterns, bottlenecks, and potential interventions.

Smart Parking Solutions: AI-powered parking management systems for real-time parking availability updates, dynamic pricing adjustments, automated valet services, and efficient space utilization. LLM technologies can analyze user reviews and feedback to identify areas for improvement in parking services and generate personalized recommendations for drivers.

5. Step: Community Involvement and Education

The next step consists of empowering communities in the decision-making process. For this purpose, interactive simulation platforms can be used. Proposed public transport improvements, station designs, and user journeys can be presented to residents through virtual reality (VR) simulation. Furthermore, it is appropriate to organize scenario planning workshops to explore different upgrade scenarios, evaluate trade-offs, and prioritize investments based on community priorities and preferences. Scenario modeling tools such as UrbanSim can be used for this purpose.

6. Step: Pilot Programs, Evaluation, and Continuous Improvement

Continuous monitoring and adaptive strategies ensure ongoing performance optimization. Initiate pilot projects in targeted areas to test AI-integrated smart mobility interventions in real-world scenarios. Collect user feedback, monitor AI-driven system performance metrics, and conduct rigorous evaluations to refine strategies and address challenges before full-scale implementation. LLM technologies can assist in summarizing pilot program results and generating insights for scaling successful initiatives to other areas of the city. After implementing smart mobility solutions, it is important to perform real-time data analysis. This involves monitoring the performance of the transport system, detecting anomalies, and triggering adaptive responses, such as dynamic adjustments to traffic routing during peak hours. For this purpose, the integration of IoT sensors and platforms is required. It is also advisable to implement user feedback mechanisms within mobile applications and customer service channels, using sentiment analysis and AI-based insights to iteratively improve service quality, responsiveness, and inclusiveness.

7. Step: Policy Guidelines and Sustainable Funding

Collaborate intensively with policymakers to create regulations and incentives that advance AI-powered smart mobility solutions while ensuring data privacy and security. Encourage innovation in AI technologies for urban transportation. Investigate sustainable financing models that utilize AI-driven data analytics to optimize infrastructure investments and enhance operational efficiency. Utilize LLM technologies to analyze legislative documents and policy proposals, identify implementation barriers, and formulate policy recommendations.

This proposed research framework, supported by comprehensive simulation studies, sets the stage for a significant enhancement of Kinshasa's multi-modal public transport system. Utilizing data-driven insights, fostering stakeholder partnerships, employing cutting-edge simulation technologies, and engaging the community, Kinshasa can develop a contemporary, efficient, and eco-friendly transportation network. This initiative aims to improve mobility, minimize environmental impact, and elevate the quality of life for residents, establishing a model for smart urban transportation in the region.

5.2. Maximizing Data Insights and Decision-Making with Large Language Models (LLMs) in the Smart Mobility Integration for Kinshasa

The effective modernization of Kinshasa's public transport system and the integration of smart mobility solutions require sophisticated data collection methodologies. This comprehensive approach includes surveys, interviews, case studies, and field sensor data and makes strategic use of LLMs [103]. The following text outlines the innovative and qualitative advantages of these methods over traditional, non-LLM-based approaches.

5.2.1. Surveys Revolutionized by LLMs

Conventional survey analysis typically depends on preset categories and manual coding, which restricts the breadth of insights. Utilizing advanced LLMs equipped with complex natural language processing (NLP) abilities enables the analysis of open-ended survey responses. This approach reveals nuanced sentiments and emerging themes, transcending the restrictions of predetermined categories. This dynamic analysis enables researchers to capture subtle shifts in public opinion, preferences, and concerns related to transportation, providing a richer understanding of informed decision-making [104]. In practical terms, this means that instead of relying solely on preset survey questions, LLMs can process and interpret responses in a more human-like manner. They can monitor shifts in sentiment over time, assess the impact of external events on public opinion, and uncover subtle trends that conventional analysis methods might overlook. For example, LLMs can determine whether the public's attitude toward a new transit project is favorable because of enhanced accessibility or unfavorable due to disturbances in current routes, offering valuable insights for policymakers.

5.2.2. Interviews Enhanced with LLM Insights

Conducting interviews generates qualitative data crucial for understanding stakeholders' perspectives. LLMs streamline interview analysis by automating transcription, extracting key phrases, and performing sentiment analysis at scale. This automation reduces human bias, speeds up analysis processes, and uncovers latent insights buried within interview transcripts. By integrating LLM insights, researchers can identify sentiment trends, sentiment shifts, and outliers, enriching qualitative data with quantitative dimensions for comprehensive analyses [105]. In contrast to manual interview analysis, where researchers may overlook subtle cues or spend excessive time transcribing and coding data, LLMs offer a scalable and accurate solution. They can discern not only positive and negative sentiments but also subtle emotions like uncertainty, excitement, or frustration, offering a comprehensive perspective on stakeholders' attitudes. This nuanced analysis is particularly valuable when exploring complex topics such as the public perception of new mobility solutions or community responses to infrastructure changes.

5.2.3. Case Studies Empowered by LLM Analysis

Typically, the examination of case studies requires the manual extraction and synthesis of information, a method that is often labor-intensive and prone to mistakes. LLMs are adept at handling unstructured case study data, uncovering patterns, correlations, and causal relationships across varied datasets. Utilizing machine learning algorithms, LLMs can forecast potential outcomes based on historical data, enabling decision-makers to simulate different scenarios, evaluate risks, and refine strategies before execution [106]. This data-driven approach minimizes uncertainty and maximizes the effectiveness of infrastructure investments and policy decisions.

Examining case studies is crucial for grasping best practices and insights gained from cities that have effectively modernized their transportation systems and incorporated smart mobility solutions. Traditionally, this task requires manual extraction and synthesis of pertinent information, making it laborious and prone to human error. However, incorporating LLMs revolutionizes this analytical process by automating data extraction, enhancing accuracy, and delivering more profound insights.

LLMs can analyze extensive volumes of unstructured data from case studies, uncovering significant patterns, correlations, and causal links that human analysts might miss [107]. By leveraging natural language processing capabilities, LLMs can sift through extensive documents, extracting relevant details about strategies, challenges, outcomes, and contextual factors that influenced the success or failure of mobility initiatives. Moreover, LLMs enable the synthesis of information across multiple case studies, providing a comprehensive view of various approaches and their effectiveness. For example, LLMs can compare the impact of different policy measures, technological implementations, and community engagement strategies across diverse urban contexts. This comparative analysis helps in identifying common success factors and potential pitfalls, offering valuable insights for tailoring solutions to Kinshasa's unique environment. LLMs also facilitate predictive analytics by applying machine learning algorithms to historical data from case studies [108]. This capability allows decision-makers to simulate various scenarios and assess potential outcomes based on empirical evidence. For instance, by understanding how similar cities managed traffic congestion or integrated EVs, stakeholders in Kinshasa can predict the likely impact of similar interventions and optimize their strategies accordingly. Furthermore, the use of LLMs in case study analysis supports evidence-based decision-making by providing robust, data-driven recommendations. These insights empower policymakers to prioritize initiatives, allocate resources efficiently, and craft interventions that are scalable and sustainable. The capability to swiftly process and analyze vast amounts of qualitative data guarantees that the lessons drawn from global best practices are thoroughly and effectively incorporated into Kinshasa's transportation planning and execution strategies.

The main potential of LLMs consists in revolutionizing the analysis of case studies by automating data extraction, enhancing the accuracy of insights, enabling comparative and predictive analysis, and supporting evidence-based decision-making [103]. By adopting this forward-thinking strategy, Kinshasa can harness international expertise to create effective and locally tailored smart mobility solutions, resulting in a transportation system that is more efficient, sustainable, and inclusive.

5.2.4. Field Sensor Data Transformed with LLM Analytics

Field sensor data, including traffic cameras, GPS devices, and environmental sensors, capture real-time insights critical for transportation management. LLMs enhance sensor data analysis by identifying traffic patterns, predicting congestion hotspots, and correlating environmental factors with mobility trends. Advanced deep-learning models integrated with LLMs can detect anomalies, optimize resource allocation, and support predictive maintenance strategies for infrastructure [109]. This proactive approach ensures efficient traffic flow, reduced emissions, and improved overall mobility experience for residents and commuters.

LLMs analyze vast datasets, uncovering traffic patterns and congestion points to optimize road networks and signal timings [110]. Predicting future congestion allows for proactive measures like dynamic traffic management and congestion pricing, improving traffic flow and reducing travel times. LLMs also correlate environmental sensor data with traffic patterns, aiding city planners in promoting EVs and green spaces to enhance air quality. Integrating data from smart mobility services, such as ride-sharing and bike-sharing platforms, enhances analytical capabilities. LLMs can analyze usage data from these services to discern demand trends and optimize service distribution. For example, studying ride-sharing data helps in adjusting vehicle availability and positioning, while bike-sharing data aids in determining the optimal locations for bike stations. Advanced deep-learning models can identify anomalies in sensor data, swiftly pinpointing traffic incidents or infrastructure issues for immediate action, ensuring safety and minimizing disruptions. LLMs also enhance resource allocation by fine-tuning public transit schedules and guiding infrastructure placement, thereby reducing wait times and alleviating overcrowding. Furthermore, LLMs facilitate predictive maintenance by analyzing sensor data to predict infrastructure failures, allowing for timely repairs and prolonging asset lifespans. This holistic approach improves traffic flow, mitigates congestion, and enhances overall mobility experiences.

Integrating LLMs with field sensor data and smart mobility service data transforms transportation management. This approach provides actionable insights that enhance efficiency, sustainability, and the quality of life for Kinshasa's residents.

5.2.5. Integrated Approach with LLM Technologies

The integrated approach combining traditional data collection methods with LLM technologies represents a leap forward in data-driven decision-making for urban mobility. LLMs facilitate a seamless flow of insights across datasets, enabling the cross-validation of findings and comprehensive trend analysis [111]. By leveraging advanced machine learning algorithms within LLM frameworks, stakeholders can build predictive models for demand forecasting, optimize service delivery, and tailor mobility solutions to evolving needs. This agility and foresight empower cities like Kinshasa to adapt to dynamic challenges, optimize resource utilization, and enhance urban livability sustainably.

Integrating LLMs into various data collection techniques significantly enhances the precision, quality, and speed of data analytics within Kinshasa's transportation sector. Leveraging LLMs' strengths in natural language processing, machine learning, and predictive analytics enables stakeholders to gain comprehensive insights into transportation patterns, user behaviors, and infrastructure demands. This data-centric strategy ensures that Kinshasa's mobility projects adapt effectively, promoting sustainable urban growth, improving public services, and elevating the quality of life for its citizens.

6. Feasibility Analysis

The feasibility analysis framework in this study is built upon a comprehensive, multi-dimensional approach that assesses smart mobility solutions through the lenses of technological, economic, regulatory, social, and environmental perspectives. Each dimension is thoroughly evaluated to ensure that the proposed solutions are not only innovative but also sustainable, scalable, and well-suited to the unique challenges faced by Kinshasa. The process begins by identifying Kinshasa's specific urban mobility challenges, such as congestion, inadequate infrastructure, and environmental concerns, and then systematically evaluates each of the five key factors.

The first dimension, technological feasibility, assesses the compatibility of Kinshasa's existing infrastructure with proposed smart mobility technologies and considers the availability, integration, and scalability of these technologies within the local context. Economic feasibility focuses on the financial sustainability of these solutions by examining their cost–benefit ratios, long-term economic impact, and potential funding sources, ensuring that the city's limited resources are used effectively. The regulatory feasibility component reviews the alignment of smart mobility solutions with current government policies and regulations, also emphasizing the importance of stakeholder engagement and public–private partnerships to facilitate implementation.

The social feasibility aspect is crucial in determining public acceptance, accessibility, and safety. This dimension ensures that the proposed solutions are inclusive and cater to the needs of all demographics, particularly underserved populations, while also addressing cultural attitudes toward new technologies. Finally, environmental feasibility evaluates the potential of smart mobility solutions to reduce emissions, improve air quality, and support Kinshasa's long-term sustainability goals. By addressing these interdependent factors, the analysis provides a holistic view of the viability of implementing smart mobility concepts in Kinshasa, ensuring that the solutions are both technically and socially adaptable to the city's evolving needs.

6.1. Methodology: Criteria for Feasibility Analysis Selection

The purpose of the feasibility study is to evaluate the prospects of implementing smart mobility solutions and an intermodal public transportation system within Kinshasa's road infrastructure. This assessment relies on stringent selection criteria to ensure a thorough examination of the proposed initiatives. It considers technical, economic, environmental, social, and institutional dimensions, aiming to deliver a comprehensive perspective on the project's feasibility (see Table 8).

From a technical perspective, the analysis examines the compatibility of existing infrastructure, evaluating whether the current road systems can accommodate new technologies and intermodal systems without requiring significant alterations [112]. The assessment also considers the presence and advancement of smart mobility technologies, including IoT, real-time data analytics, and mobile apps for public transportation. Another crucial element is operational efficiency, focusing on potential enhancements in traffic management, congestion alleviation, and the optimization of public transit schedules via intelligent systems [113]. Furthermore, the scalability of the smart mobility solutions is considered to ensure their capacity for future expansion as the city's population and transportation demands grow.

Economic feasibility is determined by conducting a comprehensive cost–benefit analysis, weighing the investment and operational expenses against anticipated economic gains, such as decreased travel time and fuel costs. This analysis pinpoints possible funding avenues, including government allocations, international assistance, and private sector investments, while also evaluating the project's long-term financial viability. Additionally, market demand is examined by considering factors like population density, urbanization rates, and current transportation trends to assess the need for smart mobility solutions among Kinshasa's residents.

Institutional feasibility involves reviewing existing policies and regulations to identify potential barriers or facilitators for implementing smart mobility solutions and recommending necessary adjustments to the legal framework. The capacity of local government agencies and institutions to manage, operate, and maintain the new systems is evaluated, identifying training and capacity-building needs. Given the importance of stakeholder collaboration, this study involves identifying essential stakeholders—such as governmental agencies, private sector partners, and community organizations—and evaluating their respective roles.

Table 8. Selection criteria for a feasibility analysis of a smart mobility system in Kinshasa.

Category of Analysis	Selection Criteria	Main Content
Technological Feasibility	Infrastructure compatibility	Assessing current road infrastructure and its ability to support new technologies without extensive modifications.
	Availability and maturity of smart mobility technologies	Applying IoT, real-time data analytics, and mobile applications for public transport.
Economic Feasibility	Cost-benefit analysis	Comparing investment and operational costs against expected economic benefits (e.g., reduced travel time, fuel savings).
	Potential funding sources	Finding government budgets, international aid, and private sector investments.
	Financial sustainability	Evaluating long-term viability of the project.
	Market demand	Considering population density, urbanization rates, and existing transportation patterns.
Regulatory and Legal Feasibility	Policy and regulation review	Identifying potential barriers or facilitators for implementing smart mobility solutions and recommending legal adjustments.
	Capacity of local government	Evaluating ability to manage, operate, and maintain new systems; identifying training and capacity-building needs.
	Stakeholder collaboration	Identifying key stakeholders and assessing their roles.
Social and Cultural Feasibility	Accessibility	Improving accessibility for all residents, including marginalized and underserved communities.
	Public acceptance	Gauging through surveys, focus groups, and stakeholder engagement activities.
	Safety and security	Assessing potential for improving road safety and reducing accidents through better traffic management and real-time monitoring.
Environmental Feasibility	Emission reduction	Evaluating potential environmental benefits of improved traffic management and increased use of public transportation.
	Sustainability	Aligning with sustainable development goals and reducing the overall carbon footprint.
	Resource efficiency	Ensuring minimal environmental disruption during implementation and maintenance.

Social feasibility focuses on how the proposed smart mobility solutions improve accessibility for all residents, including marginalized and underserved communities. Public acceptance of smart mobility concepts is measured using surveys, focus groups, and stakeholder engagement initiatives to gauge perceptions and receptiveness. Additionally, safety and security are evaluated to explore the potential for enhancing road safety and reducing accidents through improved traffic management and real-time monitoring systems.

Environmental feasibility involves evaluating the potential environmental benefits of reducing emissions through improved traffic management and increased use of public transportation. The proposed smart mobility solutions are designed to be sustainable by aligning with sustainable development goals and minimizing the transportation sector's carbon footprint in the city. Moreover, the utilization of resources is meticulously assessed to minimize environmental impact throughout both the deployment and upkeep stages of these smart mobility systems.

The criteria for the feasibility analysis aim to establish a comprehensive framework for assessing the implementation and integration of smart mobility solutions and an intermodal public transportation system in Kinshasa. By evaluating technical, economic, environmental, social, and institutional factors, this methodology ensures a thorough and balanced analysis, facilitating informed decision-making and effective execution.

6.2. A Comprehensive Guide to Feasibility Analysis

The process of feasibility analysis for the successful implementation of smart mobility solutions in urban environments can be divided into the evaluation of individual feasibility aspects. Their prioritizing is crucial for effective decision-making. The recommended order based on best practices in urban planning, transportation studies, and sustainability research, is the following: Technological feasibility, Economic feasibility, Regulatory and Legal Feasibility, Social and Cultural feasibility, and Environmental feasibility. The main aspects of these analytic studies are summarized in Table 3. The different dimensions of the feasibility analysis are summarized in Table 9.

Table 9. The main aspects of different types of feasibility analyses.

Category of Feasibility Analysis	Content	Main Output
Technological Feasibility	Evaluation of the technological infrastructure required for smart mobility concepts	Assessment of the compatibility of existing systems with modern technologies
Economic Feasibility	Cost–benefit analysis of implementing smart mobility solutions	Identification of potential funding sources and financial models
Regulatory and Legal Feasibility	Review of current regulations and legal structures pertaining to smart mobility	Recommendations for necessary regulatory adjustments
Social and Cultural Feasibility	Analysis of social acceptance and cultural adaptability of smart mobility concepts	Potential impact of smart mobility concepts on local communities and residents
Environmental Feasibility	Assessment of the environmental impact of public transportation and smart mobility solutions	Information for minimizing negative environmental impacts and maximizing overall sustainability

The following text explores the essential aspects of each category of the feasibility analysis. It outlines the necessary steps for their effective realization and provides advice on possible threats and challenges.

6.2.1. Practicality of the Technology Implementation

Evaluating the technological preparedness of current infrastructure is crucial for the success of transportation projects. This assessment involves examining the city's digital framework, telecommunications systems, and the alignment of existing infrastructure with contemporary technologies. Integrating data analytics, IoT technology, and digital platforms can drastically enhance the effectiveness and dependability of transportation systems. These advanced tools and technologies contribute to more streamlined operations and improved service reliability [114]. Moreover, ensuring interoperability between different systems is essential to creating a cohesive and integrated transportation network [115].

For the effective realization of a technological feasibility study the following steps are recommended:

1. Perform a thorough evaluation of the transportation infrastructure to pinpoint areas needing enhancement and modernization. This involves examining the state of roads, bridges, and public transit facilities.
2. Invest in upgrading digital infrastructure and telecommunications networks to support smart mobility initiatives. This includes expanding broadband access and deploying IoT devices for real-time data collection.
3. Encourage collaborations between public entities and private enterprises to seamlessly incorporate smart mobility solutions into current transportation frameworks. Partnering with technology firms and startups can introduce cutting-edge innovations and advancements.

4. Focus on designing transportation systems with user-centric principles to guarantee accessibility and inclusivity for all. This involves soliciting feedback from diverse stakeholders, including commuters with disabilities and marginalized communities.
5. Launch pilot initiatives to evaluate the practicality and scalability of novel transportation solutions prior to widespread implementation. This approach enables incremental enhancements and reduces the risks linked to substantial investments.

6.2.2. Economic Feasibility

Smart mobility solutions offer a promising avenue toward achieving more efficient, sustainable, and accessible urban transportation networks. However, alongside technological advancements and innovation, there lies the crucial challenge of assessing the economic feasibility of implementing these solutions. It is important to be aware of the complexities of performing cost–benefit analyses (CBA), identifying potential funding sources and exploring different financial models tailored to smart mobility initiatives.

Cost–benefit analyses serve as the cornerstone for evaluating the economic viability of smart mobility projects [116]. The process begins by meticulously identifying and quantifying both the direct and indirect costs associated with implementation. Direct costs encompass the initial investment in technologies, infrastructure development, and ongoing operational expenses. Indirect costs, though more nuanced, must not be overlooked, encompassing environmental impacts, societal benefits, and potential externalities. Simultaneously, it is imperative to assess the myriad benefits that smart mobility solutions promise to deliver. These benefits extend beyond mere monetary gains and encompass reductions in traffic congestion, travel time savings, improvements in air quality, and enhanced societal well-being. Quantifying these benefits often involves sophisticated modeling techniques, drawing upon data analytics, and scenario planning to forecast the impacts accurately [117]. The heart of cost–benefit analysis (CBA) lies in assessing costs versus benefits. Metrics such as net present value (NPV), benefit–cost ratio (BCR), and internal rate of return (IRR) give stakeholders insights into the project's economic viability over its entire lifecycle. Additionally, sensitivity analysis strengthens these assessments by highlighting how the project's outcomes respond to different assumptions and external influences.

Obtaining sufficient financial resources is essential for the successful implementation of smart mobility initiatives [118]. There are numerous funding sources available, each with unique considerations and requirements. Traditional methods of financing include public budgets, grants from both governmental and non-governmental organizations, and international development funds. However, innovative approaches such as public–private partnerships (PPPs) and venture capital investments offer alternative pathways, fostering collaboration between the public and private sectors while mitigating financial risks [119]. Moreover, investigating value capture methods provides a chance to match the funding of smart mobility initiatives with the value they create. Approaches like tax-increment financing, land value capture, and development impact fees allow municipalities to claim a share of the enhanced property values and economic advantages arising from transportation enhancements.

Choosing suitable financial models is crucial for maintaining the long-term viability of smart mobility projects. Implementing user fees, congestion pricing, and road tolls can create revenue streams, control demand, and encourage sustainable travel habits. Additionally, revenue-sharing partnerships with private sector entities offer further funding opportunities, utilizing their expertise and resources to expedite project execution. Integrating innovative financing methods like green bonds and social impact bonds ensures that funding aligns with broader goals of sustainability and social equity [120]. These tools allow investors to back projects that produce tangible environmental and social advantages, thereby accessing fresh sources of funding for smart mobility initiatives.

6.2.3. Regulatory and Legal Feasibility

In an era marked by rapid urbanization and technological advancement, the landscape of public transportation is undergoing a profound transformation. The emergence of smart mobility solutions promises increased efficiency, sustainability, and accessibility. However, this evolution necessitates a careful examination of existing regulatory frameworks to ensure alignment with the demands of this new paradigm.

The current regulatory landscape surrounding public transportation is a patchwork of laws and policies designed for a different era. While these regulations have served their purpose, they often fail to accommodate the complexities of smart mobility systems [121]. From ride-sharing platforms to autonomous vehicles, new technologies are challenging traditional notions of transportation regulation [122]. Key areas of concern include data privacy, liability, and interoperability standards [123].

To facilitate the seamless integration of smart mobility solutions into existing transportation ecosystems, several regulatory adjustments are recommended:

1. Flexible Frameworks: Regulators should adopt agile, technology-neutral frameworks that can adapt to rapidly evolving innovations. This approach enables regulators to foster innovation while safeguarding public safety and consumer rights.
2. Collaborative Governance: Effective regulation requires collaboration between government agencies, industry stakeholders, and community representatives. Establishing multi-stakeholder task forces can facilitate dialogue and consensus building around regulatory reforms.
3. Data Governance: As smart mobility systems rely on vast amounts of data, regulators must establish robust data governance frameworks. These frameworks should prioritize privacy protection, data security, and transparency to build public trust in emerging technologies.
4. Liability Standards: Establishing clear liability standards is crucial for assigning responsibility when accidents or malfunctions occur within smart mobility systems. Regulatory bodies need to create liability frameworks that both encourage innovation and ensure accountability.
5. Interoperability Mandates: To ensure interoperability between different smart mobility services, regulators should mandate open standards and protocols. Interoperability facilitates seamless integration between various modes of transportation, enhancing user experience and system efficiency.

As public transportation develops into a more integrated and intelligent network, adaptable regulations become essential. Policymakers can maximize the potential of smart mobility by actively tackling regulatory issues and adopting innovative approaches, leading to safer, more efficient, and sustainable transport systems for everyone.

6.2.4. Cultural and Social Viability

In the fast-changing environment of modern cities, incorporating smart mobility principles into public transport systems is crucial for boosting efficiency, sustainability, and convenience. Nonetheless, the social and cultural acceptance of these innovations often remains underappreciated. A thorough examination of how these technological advancements align with various social groups and cultural contexts is essential. Grasping the views, preferences, and worries of community members is vital for the smooth adoption and enduring success of smart mobility solutions.

A critical component of this analysis involves assessing accessibility. This entails investigating how effortlessly all community members, irrespective of their socio-economic background or physical capabilities, can utilize these services [28]. Creating smart mobility solutions that are not only physically accessible but also accommodate cultural and linguistic diversity is crucial [124]. This might involve providing multi-language interfaces, accommodating diverse mobility needs such as wheelchair accessibility, and ensuring that routes and schedules cater to the needs of different demographic groups. Another crucial factor to evaluate is the impact of smart mobility on social equity. It is essential to scrutinize whether these advancements inadvertently exacerbate existing disparities or promote inclusivity. A thorough examination is needed to guarantee that such innovations do not unintentionally increase the divide between advantaged and disadvantaged groups [125]. This could entail targeted subsidies for low-income residents, flexible fare structures, or initiatives to address the digital divide by providing access to technology and digital literacy programs [126].

Closely tied to accessibility is the issue of affordability. Although smart mobility offers efficiency and cost savings, affordability is still a key consideration for widespread acceptance [127]. Maintaining affordability for these solutions across all societal sectors is crucial to cultivating fair and inclusive transportation systems.

Moreover, cultural factors greatly influence how smart mobility initiatives are perceived [128]. Each community possesses its unique set of norms, values, and habits, which must be carefully navigated to garner acceptance. From the integration of traditional modes of transport to respecting cultural practices related to communal travel, sensitivity to these nuances is vital for fostering positive engagement.

Equally important is the acknowledgment of potential disruptions to existing modes of transportation and local economies. While smart mobility offers numerous benefits, it may also challenge established norms and industries, necessitating strategies for mitigating negative impacts and fostering collaboration. The success of smart mobility hinges on its ability to align with the social fabric and cultural ethos of the communities it serves.

6.2.5. Environmental Feasibility

In a sustainable future, the integration of public transportation and smart mobility solutions can significantly mitigate environmental degradation. This thorough evaluation explores the environmental viability of integrating EVs and other green alternatives, with the goal of assessing their potential to lower carbon emissions and promote a more sustainable, eco-friendly atmosphere.

EVs, heralded as the cornerstone of eco-friendly transportation, promise a remarkable decrease in greenhouse gas discharges when compared to their traditional fossil fuel counterparts. By leveraging renewable energy sources and advancements in battery technology, EVs present a concrete route toward decarbonizing the transport industry [129]. Incorporating EVs into public transportation fleets can greatly reduce air pollution and enhance urban air quality. Nonetheless, environmental viability requires more than just the adoption of EVs. It also involves evaluating other smart mobility solutions, such as ride-sharing services, micro-mobility options like electric scooters and bicycles, and efficient public transit systems. By encouraging multimodal transportation and decreasing dependence on single-occupancy vehicles, these approaches not only help ease traffic congestion but also lower carbon emissions and support sustainable urban growth.

The evaluation highlights the crucial role of infrastructure development and policy measures in promoting the adoption of environmentally friendly transportation options. Essential steps such as investing in charging stations, offering incentives for EV purchases, and enforcing emission regulations are vital to achieving the environmental advantages of public transport and smart mobility initiatives. The shift toward sustainable transportation solutions necessitates a unified effort from both policymakers and the public. By adopting EVs, encouraging smart mobility alternatives, and prioritizing environmental factors in urban planning, we can pave the way for a cleaner, healthier future for upcoming generations. This evaluation can act as a roadmap toward a more sustainable transportation framework.

7. Discussion

Efficient, sustainable transportation solutions are essential in modern urban environments. Kinshasa currently faces significant transportation challenges, including severe congestion, inadequate infrastructure, and limited public transportation options. These issues result in increased travel times, decreased road safety, environmental degradation, and economic inefficiencies. Addressing these challenges is crucial for the city's sustainable development. Smart mobility presents a holistic approach to tackling these transportation challenges. An integrated approach is essential for developing efficient and sustainable urban transportation systems. By integrating technology, data-driven insights, and innovative transportation models, cities can optimize existing resources, enhance accessibility, and reduce carbon emissions. Kinshasa, as it moves toward the future of transportation, must carefully integrate smart mobility concepts into its infrastructure.

Through an examination of various smart mobility projects in cities globally, including those in less developed regions, Kinshasa has the opportunity to gain valuable insights, identify effective strategies, and tailor solutions to address its specific mobility challenges and goals for sustainable urban growth. Drawing lessons from these international examples can help guide policy decisions, infrastructure investments, and community involvement efforts to create a more connected, efficient, and enjoyable urban environment in Kinshasa and beyond.

The transition toward smart mobility in Kinshasa requires leveraging a wide range of global experiences and knowledge from cities around the world, both advanced and developing. By analyzing the successes and obstacles encountered by cities like Singapore, Barcelona, Helsinki, Medellín, Curitiba, Cape Town, and others, Kinshasa can develop informed strategies that suit its distinctive urban landscape and mobility challenges. From Singapore's groundbreaking Mobility-as-a-Service model to Barcelona's innovative superblocks and Helsinki's seamless transportation integration through the Whim app, each city offers specific insights that can be incorporated into Kinshasa's mobility planning. Comparative analyses can explore regulatory frameworks, data-sharing protocols, public–private collaborations, user engagement rates, and the societal and economic impacts of these projects, providing a detailed understanding for Kinshasa's policymakers and city planners.

Moreover, exploring the integrated transportation systems in Medellín, the sustainable urban planning model in Curitiba, and the multimodal MyCiTi BRT system in Cape Town can provide valuable perspectives for Kinshasa on infrastructure investments, fair access to transportation, and environmental sustainability. By learning about spatial planning, optimizing public transit, promoting active transportation, and engaging with the community from these cities, Kinshasa can work toward a more connected, efficient, and enjoyable urban environment. The lessons learned from global examples go beyond just technical solutions to include policy frameworks, governance structures, and approaches to citizen participation. Kinshasa can use these insights to make informed policy decisions that prioritize sustainable mobility, allocate resources efficiently, and promote collaboration between government agencies, private sector organizations, and community stakeholders.

By conducting a thorough feasibility analysis and drawing inspiration from successful case studies worldwide, a list of comprehensive recommendations for implementing specific smart mobility concepts in Kinshasa was prepared.

The results of the feasibility analysis suggest that while smart mobility solutions present significant potential for alleviating Kinshasa's urban mobility challenges, their implementation must be carefully aligned with the city's broader socio-political landscape. Kinshasa's current governance structures and regulatory frameworks, particularly those relating to urban transport and infrastructure development, require reform to fully support the integration of these solutions. The capacity of local government agencies to manage and operate smart mobility systems remains a critical concern, as does the need for effective collaboration between governmental bodies, private-sector partners, and international stakeholders. Furthermore, the analysis reveals potential regulatory hurdles, such as outdated transportation policies and limited stakeholder engagement, which could hinder the adoption of innovative mobility technologies. Addressing these issues through policy reforms, capacity building, and inclusive stakeholder dialogue is crucial for ensuring the long-term success of smart mobility solutions in Kinshasa.

Enhancing the city's transportation system calls for the creation of a Multimodal MaaS platform. This platform would effortlessly integrate multiple transportation modes, offering users a unified payment system, real-time updates, and convenient trip planning. Furthermore, enhancing the public transit system should be a priority. This can be achieved by investing in new buses, optimizing routes for efficiency, and implementing real-time tracking systems. Introducing bus rapid transit (BRT) lanes could also help prioritize public transit and reduce travel times significantly.

To tackle parking challenges, implementing smart parking solutions is essential. Utilizing dynamic pricing and real-time availability data can effectively regulate parking demand, especially in high-traffic areas. This approach encourages turnover and discourages prolonged parking in prime spots, thereby alleviating traffic congestion. Additionally, incorporating EVs into the transportation system is crucial for reducing emissions and promoting sustainable mobility. This could involve setting up EV charging stations and providing incentives and policies to encourage the adoption of EVs.

Implementing sophisticated traffic management systems is essential for enhancing traffic flow and alleviating congestion. These systems use real-time data, sensors, cameras, and AI to efficiently monitor and control traffic. Adopting data-driven strategies through analytics and predictive modeling can optimize route planning, enhance service reliability, and address the dynamic needs of transportation. Additionally, partnering with local universities and research institutions to gather and analyze transportation data will support informed decision-making processes. The integration of LLM technologies into the research process is instrumental in deriving the core findings of this study. These technologies can be used to process and analyze vast datasets, including real-time traffic patterns, commuter preferences, and infrastructure usage, collected through surveys, GPS tracking, and IoT devices. The LLMs do enable the synthesis of these unstructured data sources into actionable insights, identifying key mobility challenges and opportunities for improvement. For example, LLMs can be employed to simulate and predict traffic congestion trends, optimize vehicle fleet compositions, and forecast the impact of different smart mobility interventions. This data-driven approach, facilitated by LLM technology, does allow for a more nuanced understanding of Kinshasa's unique urban mobility dynamics, leading to targeted recommendations for policy and infrastructure investments. Additionally, LLMs can be used to assess public sentiment and preferences by analyzing open-ended survey responses, further informing the study's conclusions on the feasibility of proposed solutions.

Raising public awareness is essential for educating people about the advantages of smart mobility and encouraging sustainable transportation practices. To do this effectively, various communication platforms such as social media, radio, and community events should be leveraged to connect with a broad audience and enhance understanding of smart mobility solutions. Prioritizing community engagement in the design and implementation of smart mobility projects is key. Engaging the community via forums, workshops, and online platforms collects valuable feedback on transportation needs and preferences, facilitating the creation of solutions customized to the local context. Promoting active transportation options like walking and cycling can decrease dependence on motor vehicles and improve public health. Creating dedicated lanes and facilities for pedestrians and cyclists ensures safer and more sustainable transportation modes. Additionally, advocating for ride-sharing and carpooling is crucial to lessen the number of single-occupancy vehicles on the road, leading to more efficient use of current transportation resources.

Accessibility is a key criterion in the implementation of smart mobility and must not be overlooked. To make smart mobility solutions inclusive for all societal members, including individuals with disabilities and low-income communities, it is essential to provide transportation options like wheelchair-accessible vehicles. Additionally, introducing affordable fare programs can help ensure that everyone has equitable access to mobility services.

The primary obstacles encountered in implementing smart mobility solutions can be categorized into two main groups. The first involves addressing the varied needs and preferences of the population, ensuring accessibility for everyone, and overcoming potential resistance to behavioral changes. To effectively introduce smart mobility solutions in a city, it is crucial to focus on community involvement, data-informed decision-making, and increasing public awareness. Another group of possible challenges could include resistance from traditional stakeholders, regulatory hurdles, and potential safety concerns. To enhance the integration of smart mobility solutions within a city, it would be very beneficial to establish public–private partnerships. To fully harness the potential of smart mobility, it is crucial to engage with technology companies, transportation providers, and investors. These collaborations can tap into their specialized knowledge, extensive resources, and substantial investment opportunities. This collaboration would encompass joint pilot programs, research initiatives, and infrastructure development to expedite the innovation and deployment of smart mobility projects.

Additionally, establishing a robust policy and regulatory framework is critical to promoting the adoption of smart mobility solutions. This framework must tackle regulatory hurdles while safeguarding the well-being of all users. A thorough review and possible revision of current transportation policies, zoning laws, and land-use plans are necessary to effectively integrate emerging mobility trends and technologies.

Beyond technological progress, a comprehensive approach to smart mobility research must also address socio-economic and environmental considerations. Examining how transportation policies influence equity, affordability, and environmental sustainability is crucial to guarantee that smart mobility projects advantage all societal groups while reducing negative environmental impacts.

8. Conclusions

Kinshasa's current transportation ecosystem is marked by challenges, including traffic congestion, unreliable public transport, and limited infrastructure. Traditional modes of transportation, such as informal minibus networks and taxis, struggle to keep pace with the city's rapid urbanization, leading to inefficiencies and frustrations for commuters. The existing infrastructure is strained, often unable to accommodate the growing population's needs adequately. A comprehensive assessment of Kinshasa's public transport infrastructure reveals deficiencies in capacity, reliability, and accessibility. The informal nature of the minibus networks, while providing a degree of flexibility, also leads to issues such as overcrowding, irregular schedules, and safety concerns. Additionally, the lack of designated lanes for public transport exacerbates congestion, further hampering efficiency.

Adopting smart mobility strategies provides a promising solution to tackle Kinshasa's transportation issues. Implementing MaaS, along with car-sharing, bike-sharing, and micro-mobility programs, can significantly improve connectivity, alleviate congestion, and enhance urban living conditions. These smart mobility initiatives are crucial as the city experiences rapid growth and expansion. By prioritizing sustainability, equity, and innovation, Kinshasa can transform its transportation infrastructure, ushering in a new era of urban development and unlocking fresh opportunities for progress.

However, this process is fraught with many challenges that must be overcome. Resolving them requires thoughtful planning, collaboration, and a strong commitment to achieving sustainable and efficient smart mobility solutions. Advancing smart mobility in Kinshasa is a complex task that requires collaboration across different disciplines and creative thinking. Successful implementation requires collaboration between government agencies, private partners, and the community. As the city moves toward a more efficient transportation system, working together and being adaptable is crucial.

To implement Mobility-as-a-Service (MaaS) and other smart mobility solutions in Kinshasa, several key policy reforms and infrastructure investments are required. First, the city must prioritize the development of a Multimodal Mobility-as-a-Service platform that integrates all transportation modes with a unified payment system and real-time updates. This would necessitate the creation of dedicated public transit lanes, investment in charging stations for EVs, and data-sharing protocols across service providers. Additionally, regulatory reforms are needed to support public–private partnerships, enabling technology companies and transportation providers to collaborate effectively on smart mobility projects.

Establishing policies that incentivize EV adoption and improve traffic management systems will also be critical in ensuring the success of these initiatives.

By concentrating on the research areas outlined in this paper, Kinshasa can lay the groundwork for an urban transportation system that is more efficient, equitable, and sustainable. This strategy can boost economic growth and improve residents' quality of life. By fostering a clear vision and teamwork, the city can turn transportation challenges into opportunities for progress. Although the path forward may present difficulties, the aim of establishing a dynamic and inclusive Kinshasa with unlimited mobility is attainable. Embracing smart mobility provides an opportunity to shape Kinshasa's future and create a legacy of innovation for generations to come. Also, further inspiration, especially related to smart city concepts, can be obtained from various sources such as Refs. [127–132].

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