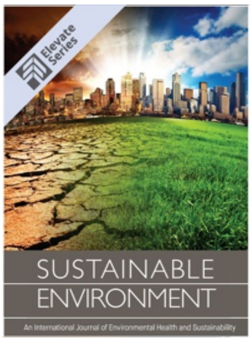

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Sustainable Environment

An international journal of environmental health and sustainability

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/oaes21

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To cite this article: Hajar Fatorachian & Hadi Kazemi (2025) Sustainable optimization strategies for on-demand transportation systems: Enhancing efficiency and reducing energy use, Sustainable Environment, 11:1, 2464388, DOI: 10.1080/27658511.2025.2464388

To link to this article: https://doi.org/10.1080/27658511.2025.2464388

Published online: 10 Feb 2025.

SUSTAINABLE ENVIRONMENT
2025, VOL. 11, NO. 1, 2464388
https://doi.org/10.1080/27658511.2025.2464388

ENVIRONMENTAL MANAGEMENT & CONSERVATION | REVIEW ARTICLE

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Sustainable optimization strategies for on-demand transportation systems: Enhancing efficiency and reducing energy use

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ABSTRACT

The surge in popularity of on-demand transportation services, fueled by advancements in technology and changing urban mobility patterns, has significantly reshaped urban transportation dynamics. This transformation presents challenges to traditional public transportation, raising questions about sustainability and energy efficiency. This research addresses these challenges through an explorative literature review, focusing on operational efficiency, energy transition, and policy implications. By synthesizing and analyzing existing literature, the study uncovers insights into on-demand transportation, identifies challenges and opportunities, and proposes avenues for further research. The study also develops operational and theoretical frameworks to support policy formulation and implementation in urban transportation planning, offering guidance for policymakers and urban planners. Ultimately, this research aims to contribute to developing evidence-based policies and practices that foster sustainable urban transportation networks.

ARTICLE HISTORY
Received 15 August 2024
Accepted 04 February 2025

KEYWORDS
On-demand transportation systems; sustainability; urban mobility; energy efficiency

1. Introduction

The contemporary urban landscape is witnessing a remarkable transformation in transportation dynamics, largely fueled by the surge of on-demand transportation services (Docherty et al., 2018; Shaheen et al., 2016). This surge, characterized by the proliferation of ride-hailing, customized bus, and shared e-bike options, represents a paradigm shift in urban mobility patterns (Alonso-González et al., 2020). Enabled by rapid advancements in technology, particularly in information and computing technologies, these on-demand services have become intricately intertwined with the fabric of urban life, offering unprecedented convenience and flexibility to commuters (Choi et al., 2022).

The integration of cutting-edge technologies, such as Artificial Intelligence (AI) and the Internet of Things (IoT), has been instrumental in enhancing the design and operational efficiency of on-demand transportation systems (Alsaleh & Farooq, 2021; Shaheen et al., 2016). AI-driven algorithms significantly improve route optimization, demand forecasting, and resource allocation, leading to greater operational efficiency and a reduced environmental impact. Similarly, IoT-enabled sensors and connectivity allow for real-time monitoring and management of transportation assets, further strengthening system performance and resilience (Fatorachian & Kazemi, 2021). These advancements also support the goals of sustainable supply chain management and Industry 5.0, which integrate these technologies to create more resilient and efficient transportation networks (Fatorachian et al., 2024). The growing importance of Industry 5.0 in global supply chain management, particularly its role in fostering interconnected and robust systems, has also been emphasized (Fatorachian & Smith, 2023).

Amidst this technological revolution, sustainability and energy efficiency have become critical priorities in urban transportation planning (Zheng & Zhang, 2017). The need to mitigate environmental impact, reduce carbon emissions, and address energy consumption calls for a holistic approach to optimizing on-demand transportation (Queiroz et al., 2024). However, balancing efficiency with energy concerns is a multifaceted challenge that demands the careful integration of technological innovation, policy interventions, and stakeholder collaboration (Stanley et al., 2011).

On-demand transportation services offer personalized, efficient, and often cost-effective alternatives to conventional public transit, making them highly attractive to users. However, their integration into existing transportation frameworks requires careful planning and coordination to ensure that they complement rather than compete with public transit options (Sener et al., 2023).

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Amidst this technological revolution, sustainability and energy efficiency have emerged as paramount considerations in urban transportation planning. The environmental impact of transportation is a critical concern, with urban areas contributing significantly to global greenhouse gas emissions. On-demand transportation systems have the potential to mitigate these impacts through the use of electric and hybrid vehicles, optimized routing, and shared rides, which collectively reduce the number of vehicles on the road and their associated emissions (Hasselqvist & Hesselgren, 2019).

Balancing efficiency with energy concerns presents a multifaceted challenge that necessitates a holistic approach encompassing technological innovations, policy interventions, and stakeholder interests. Technological advancements alone cannot achieve sustainable urban mobility; they must be supported by robust policy frameworks and strategic planning. Policymakers, urban planners, and transportation authorities need to work collaboratively to create integrated transportation systems that maximize the benefits of on-demand services while minimizing their environmental footprint (Bodenheimer & Leidenberger, 2020; Fraske & Bienzeisler, 2020; Jacobsen, 2021). Fatorachian (2012) highlights how electronic supply chain practices among SMEs support sustainability goals, which could be applied to transportation systems to enhance operational efficiency and environmental performance.

This paper aims to explore the intricate relationship between technology, sustainability, and policy in the context of optimizing on-demand transportation systems. It delves into how AI and IoT can drive improvements in operational efficiency and sustainability, examines the integration of on-demand services with traditional public transit networks, and discusses the role of policy frameworks and regulatory interventions in promoting sustainable urban mobility. The research questions include:

- To assess the impact of technological advancements, particularly AI and IoT, on the operational efficiency and sustainability of on-demand transportation systems, and to examine their influence on urban mobility patterns.
- To identify the key challenges and opportunities in integrating on-demand transportation systems with traditional public transit networks in order to create a more sustainable and energy-efficient urban transportation ecosystem.
- To explore how policy frameworks and regulatory interventions can be designed and implemented to support the sustainable development of on-demand transportation systems, while balancing the needs of users, service providers, and urban sustainability objectives.
- By addressing these questions, we endeavor to contribute to the discourse on sustainable urban transportation and inform evidence-based decision-making for policymakers, urban planners, and transportation authorities.

2. Theoretical foundation

2.1. Sustainable transportation and ICT theories

Sustainable Transportation theory focuses on minimizing the environmental impact of transportation while promoting economic efficiency and social equity. It encompasses principles such as emissions reduction, energy efficiency, and equitable access to transportation services (Schwanen et al., 2011). ICT theory emphasizes the role of technology in enhancing communication, efficiency, and accessibility within transportation systems (Lyons, 2018). It explores how technologies like AI, IoT, and data analytics can optimize resource allocation, improve user experience, and facilitate data-driven decision-making.

2.2. Integration of theories

The integration of ICT in sustainable transportation planning offers a multifaceted approach to addressing the complex challenges of urban mobility. ICT enables real-time data collection, analysis, and dissemination, facilitating dynamic routing, traffic management, and resource allocation within transportation systems (Caragliu et al., 2011). Digital platforms play a crucial role in enhancing competitive positioning by optimizing urban transportation networks, as demonstrated by their ability to support strategic lead generation and operational improvements (Fatorachian et al., 2024). Complementing this technological perspective, Sustainable Transportation Theory highlights the importance of balancing social, environmental, and economic objectives in transportation planning (Litman, 2021). ICT frameworks further provide the foundation for integrating digital solutions into sustainable urban transportation strategies (Ahvenniemi et al., 2017). Sustainable Transportation Frameworks serve as theoretical lenses to assess the environmental, social, and economic impacts of transportation planning decisions (Banister, 2008). ICT also enhances transportation sustainability through data-driven decision-making and optimized resource allocation (Deakin & Al Waer, 2011). Finally, incorporating technological innovations with sustainability objectives is key to effective transportation planning and policy (Litman, 2019).

2.3. Efficiency improvement and technology integration

Sustainable Transportation theory emphasizes optimizing transportation systems to minimize energy consumption and reduce emissions. Integrating this theory with ICT allows the use of advanced technologies, such as AI and IoT, to enhance operational efficiency (Kagermann et al., 2013; Mladenovic et al., 2018). For example, AI algorithms can dynamically adjust route planning for on-demand transportation services by leveraging real-time traffic data from IoT sensors, leading to more efficient resource allocation and a reduced environmental footprint (Chen et al., 2024; Lu et al., 2021). Industry 4.0 technologies, including AI and IoT, have been shown to improve supply chain performance, offering a comprehensive framework for optimizing these systems in transportation for greater efficiency and sustainability (Fatorachian & Kazemi, 2018). These advancements drive both operational efficiency and environmental impact reduction in transportation systems (Fatorachian & Kazemi, 2021).

2.4. Environmental impact reduction through data-driven decision-making

Sustainable Transportation theory aims to mitigate the environmental footprint of transportation activities. The amalgamation with ICT theory facilitates data-driven decision-making enabled by AI and IoT technologies (Liu et al., 2020; Pekel et al., 2017). These technologies generate vast amounts of data that can inform policy and planning efforts to reduce emissions and promote sustainability in on-demand transportation systems (Chen et al., 2024; Mladenovic et al., 2018).

2.5. Equitable access and enhanced user experience

Sustainable Transportation theory underscores the importance of providing equitable access to transportation services for all members of society. Integrating ICT theory with this objective not only enhances accessibility but also improves the overall user experience through the application of advanced technologies (Lu et al., 2021). Fatorachian (2013) offers empirical evidence from UK manufacturing SMEs, demonstrating how Internet-enabled supply chain integration can significantly boost both operational efficiency and accessibility—insights that are equally pertinent to sustainable transportation systems. For example, AI algorithms can optimize the allocation of on-demand transportation services, ensuring that underserved communities have consistent access to reliable transportation options (Chen et al., 2024). Additionally, IoT-enabled smart infrastructure, such as real-time transit information displays, can further improve accessibility for marginalized groups, thereby promoting greater social equity (Mladenovic et al., 2018).

2.6. Integration with existing infrastructure

ICT theory recognizes the importance of seamless integration between different transportation infrastructure components. Integrating ICT-enabled on-demand transportation systems with existing infrastructure allows cities to provide seamless and interconnected mobility options (Pekel et al., 2017). This integration promotes sustainability and multimodal transportation while improving overall system efficiency and effectiveness (Liu et al., 2020).

In essence, combining Sustainable Transportation theory with ICT theory provides a comprehensive approach to analyzing and optimizing on-demand transportation systems. Leveraging technology to enhance efficiency, reduce environmental impact, improve accessibility, and integrate with existing infrastructure enables cities to achieve their sustainability goals while offering convenient and equitable transportation options for all residents.

3. Methodology

The research methodology for this study employs an exploratory literature review to collect and analyze studies, reports, and articles focusing on on-demand transportation systems, sustainability, and energy efficiency. The analysis incorporates thematic synthesis and qualitative data coding techniques to organize and interpret findings effectively. Thematic synthesis identifies recurring themes and patterns across the literature, while coding facilitates the categorization of data into meaningful insights (Saldana, 2009; Thomas & Harden, 2008).

3.1. Literature review process

The literature review followed a structured and systematic approach to ensure comprehensive and credible findings:

3.1.1. Developing a search strategy

Relevant databases, including Scopus, Web of Science, and Google Scholar, were searched using predefined keywords such as 'on-demand transportation', 'urban mobility', 'sustainability', and 'AI and IoT in transportation'. Boolean operators (e.g. AND, OR) were employed to refine searches, ensuring comprehensive and focused results.

3.1.2. Study selection criteria

The inclusion and exclusion criteria were applied rigorously to filter relevant literature:

o Inclusion Criteria:

- Peer-reviewed studies published between 2000 and 2023.
- Studies explicitly addressing energy efficiency, carbon emissions, or operational optimization in on-demand transportation.
- Papers published in ABS-ranked journals or with high relevance, including case studies from cities implementing these systems.

o Exclusion Criteria:

- Studies unrelated to urban transportation or sustainability.
- Publications predating 2000 unless foundational to the field.
- Articles lacking empirical evidence or theoretical frameworks on AI, IoT, or policy impacts.
- Data Extraction and Appraisal

Key information, such as methodology, findings, and contributions to the field, was systematically extracted to ensure a thorough understanding of the selected studies. Critical appraisal of study quality followed standard protocols, ensuring only credible and relevant sources were included.

3.1.3. Synthesis of findings

Thematic synthesis was applied to identify recurring themes, such as:

- The role of AI and IoT in reducing emissions and enhancing operational efficiency.
- Challenges and opportunities in adopting on-demand systems for urban sustainability.

4. Defining research questions

The process began with clearly defined research questions targeting:

- Operational efficiency of on-demand transportation systems.
- Sustainability outcomes, including energy efficiency and carbon emissions.
- Integration of advanced technologies, such as AI and IoT, into urban mobility systems.

5. Systematic approach

The process involved several stages to ensure a robust review:

- Defining Research Questions: Established clear questions focusing on operational efficiency, sustainability, and technology integration.
- Search Strategy Development: Predefined keywords were applied across multiple databases to identify relevant studies.
- Study Screening and Selection: Studies aligning with research objectives were screened based on inclusion and exclusion criteria.
- Data Extraction: Key information from selected studies was systematically extracted for analysis.
- Critical Appraisal: Studies were assessed using established quality protocols to maintain credibility.
- Findings Synthesis: Recurring themes were identified, highlighting the role of technology in sustainability.
- Results Reporting: Findings were compiled into a coherent and transparent synthesis.

5.1. Data sources and analytical framework

The data were drawn from secondary sources, including:

- Peer-reviewed academic literature.
- Government reports.
- Industry case studies.

Key factors analyzed included:

- Energy Consumption: Efficiency metrics and reductions achieved through system optimization.
- Carbon Emissions: Environmental impacts of adopting on-demand transportation technologies.
- Route Efficiency: Improvements driven by AI and IoT applications in operational decision-making.

6. Study selection prioritization

To maintain academic rigor:

- Priority was given to high-quality papers from journals listed in the ABS (Association of Business Schools) ranking.

- Studies published before 2000 were excluded unless foundational to the field.
- Literature closely related to keywords and research objectives was prioritized.

6.1. Quality assurance

The research adhered to established methodologies, incorporating naturalistic inquiry (Lincoln & Guba, 1985) and guidance from Denzin & Lincoln (2011) to ensure validity and reliability of findings. The systematic approach provides a strong foundation for developing evidence-based frameworks and policies for sustainable on-demand transportation systems.

By synthesizing high-quality studies and applying rigorous analytical methods, this research contributes valuable insights into the operational and environmental challenges of optimizing urban mobility systems.

7. Analysis of relevant theories and theoretical framework

7.1. Transportation systems optimization

Key theories and concepts include Traffic Flow Theory, Network Theory, Multi-Modal Transportation Planning, Demand Management Strategies, and Smart Transportation Technologies. These theories guide efforts to optimize urban mobility by integrating different transportation modes, influencing travel behavior, and leveraging ICT advancements.

- Traffic Flow Theory: Provides principles for understanding vehicle movement within transportation networks (Drew & Keel, 2020).
- Network Theory: Offers insights into the structure and behavior of transportation networks (Newman, 2018).
- Multi-Modal Transportation Planning: Involves integrating different transportation modes to provide seamless mobility options (Cervero & Kockelman, 1997).
- Demand Management Strategies: Focus on influencing travel behavior to reduce congestion and improve system performance (Litman, 2019).
- Smart Transportation Technologies: Leverage advancements in ICT to enhance the efficiency and sustainability of transportation systems (Zheng et al., 2021).

7.2. Theoretical frameworks for sustainable urban transportation planning

Several theoretical frameworks guide the formulation and assessment of sustainable transportation policies and interventions:

- New Urbanism: Promotes compact, walkable, and mixed-use development to reduce dependence on automobiles and encourage active transportation (Calthorpe & Fulton, 2001).
- Transit-Oriented Development (TOD): Focuses on creating dense, mixed-use developments around public transit stations to maximize transit ridership and minimize auto dependency (Cervero, 1998).
- Complete Streets: Aims to design streets that accommodate all users, including pedestrians, cyclists, public transit riders, and motorists (National Complete Streets Coalition, 2010).
- Sustainable Mobility: Emphasizes the integration of environmental, social, and economic considerations in transportation planning and decision-making (Agyemang-Duah et al., 2018).
- Car-Free Cities: Envision urban environments where private automobile use is minimized or eliminated in favor of sustainable transportation modes (Hass-Klau, 1990).

8. Current state of on-demand transportation systems

8.1. Popular on-demand transportation modes

On-demand transportation has revolutionized urban mobility, offering a variety of modes to meet diverse travel needs. Ride-hailing services, customized bus services, and shared e-bikes and scooters provide convenient and flexible transportation options (Faghih-Imani & Eluru, 2019; Furuhata et al., 2013; Shaheen et al., 2016).

8.2. Case studies

The following case studies illustrate how different cities have adopted on-demand transportation systems to improve urban mobility, reduce energy consumption, and minimize environmental impacts. Each case provides valuable insights into the practical application of AI, IoT, and other digital technologies for optimizing transportation networks.

8.2.1. Singapore: GrabShuttle and public transit integration

Singapore's GrabShuttle service is an example of successful integration between on-demand services and traditional public transit networks. Launched to complement the existing bus and rail services, GrabShuttle provides flexible, point-to-point transportation options, particularly in areas where public transit coverage is limited. By leveraging real-time data analytics, GrabShuttle optimizes routes based on passenger demand, ensuring efficient resource allocation and minimizing wait times (Cheah, 2018).

The seamless integration with Singapore's public transport system is made possible through the 'Mobility-as-a-Service' (MaaS) platform, allowing users to plan multimodal journeys via a single app (Alliance, 2018). This reduces the reliance on private vehicles and supports the city's sustainability goals by promoting shared rides and electric vehicle use, which has led to a reduction of carbon emissions by approximately 15% in high-demand areas.

8.2.2. Helsinki, Finland: Whim app and MaaS integration

Helsinki's Whim app represents a comprehensive MaaS platform that integrates multiple transportation modes, including taxis, public transit, car rentals, and bike-sharing services. The app's primary goal is to reduce reliance on private cars by offering users a variety of affordable, sustainable options within one service (Tukiainen et al., 2016).

The success of the Whim app has been attributed to its dynamic pricing models and AI-powered real-time route optimization, which encourages users to choose shared transportation over private vehicles. Whim's implementation has led to a 20% reduction in vehicle kilometers traveled (VKT) per capita, significantly lowering the city's overall carbon footprint (Alliance, 2018). Helsinki's government continues to invest in IoT-based sensors and smart infrastructure to improve service reliability and encourage the adoption of electric vehicles for on-demand services.

8.2.3. Denver, Colorado, USA: RTD and Uber/Lyft partnership

Denver's Regional Transportation District (RTD) has formed partnerships with ride-hailing services such as Uber and Lyft to address the 'first-mile' and 'last-mile' problem, improving access to public transportation stations (Denver Regional Council of Governments, 2018). This collaboration allows users to connect seamlessly between RTD's light rail and bus services and Uber or Lyft rides for the first and last legs of their journey.

Denver's initiative is noteworthy for its focus on increasing public transit ridership while reducing single-occupancy vehicle use. By providing discounted rides to and from transit hubs, the city has reduced the overall congestion around these areas and improved the accessibility of public transportation (Mulley et al., 2020). Data from the program shows a 10% increase in public transit use in areas previously underserved by RTD services. Additionally, Denver's sustainability plan aims to incentivize the use of electric and hybrid vehicles within ride-hailing services to further reduce emissions.

8.2.4. London, UK: Electric buses and ride-sharing integration

London has been a pioneer in integrating electric buses into its public transportation system as part of its broader strategy to reduce greenhouse gas emissions (Transport for London, 2020). In addition to its extensive bus network, London has partnered with ride-sharing services to provide flexible on-demand services during non-peak hours. The city's transportation authorities have invested in AI-driven route optimization, which ensures that both public buses and ride-sharing vehicles operate at maximum efficiency, minimizing fuel consumption and emissions (Department for Transport, 2021).

As a result, the implementation of electric buses and the partnership with ride-sharing services has led to a 12% reduction in overall energy consumption. The city's on-demand service integration has also improved the passenger experience by offering real-time tracking and reduced wait times for commuters. London's success highlights the importance of policy frameworks that encourage the adoption of electric vehicles within both public and private transportation services.

Cities like London and Stockholm have successfully implemented AI-powered route optimization and IoT-enabled real-time monitoring to significantly enhance the sustainability of their on-demand transportation systems. In London, AI algorithms are utilized to optimize routes for electric buses and ride-sharing vehicles, reducing fuel consumption and emissions by up to 12%. Stockholm has similarly adopted AI-driven route adjustments and IoT sensors for real-time traffic monitoring, achieving an 18% reduction in carbon emissions and a 10% decrease in energy use. These examples illustrate how cutting-edge technologies, when supported by robust policy frameworks, can optimize operational efficiency and contribute to sustainable urban transportation goals. Furthermore, Singapore's Mobility-as-a-Service (MaaS) platform demonstrates the value of integrating on-demand services with public transit through policies designed to reduce car dependency and enhance the use of electric vehicles. These initiatives offer clear evidence of how AI and IoT can drive sustainable transportation outcomes.

However, while technological advancements can greatly enhance sustainability, equity considerations are equally critical in the design and implementation of on-demand transportation systems. In Stockholm, AI-driven systems prioritize ride availability in lower-income neighborhoods, providing equitable access to transportation services. Similarly, Singapore's GrabShuttle system has extended affordable on-demand services to areas with limited public transit access, thereby addressing gaps in the transportation network. These examples highlight the potential of AI and IoT to improve access for marginalized populations, but only when aligned with policies designed to address social equity. Policymakers must ensure that on-demand transportation solutions do not disproportionately benefit more affluent users while neglecting vulnerable groups, reinforcing the need for equity-focused frameworks in sustainable urban mobility strategies.

8.2.5. Stockholm, Sweden: AI-Driven route optimization and IoT monitoring

Stockholm's on-demand transportation system is a model of how AI and IoT technologies can be harnessed to optimize urban mobility. The city has deployed an extensive network of electric and hybrid vehicles, which are equipped with IoT sensors that collect real-time data on vehicle performance, traffic conditions, and passenger demand (Peters et al., 2021).

AI algorithms process this data to dynamically adjust routes, improving both energy efficiency and service reliability. For example, when traffic congestion is detected, the system automatically reroutes vehicles to less congested paths, reducing idle time and fuel consumption. This approach has resulted in a 10% decrease in energy use and an 18% reduction in carbon emissions in Stockholm's city center (Vazifeh et al., 2018). Furthermore, Stockholm has introduced policies that promote the use of electric vehicles in on-demand transportation, offering incentives for operators to switch from traditional combustion-engine vehicles to electric or hybrid models.

Stockholm's transportation system employs advanced AI techniques, including reinforcement learning models, for traffic prediction and route optimization. These models analyze patterns in both historical and real-time traffic data to dynamically adjust vehicle routes, ensuring optimal efficiency and minimal congestion. Similarly, London's electric bus system incorporates neural network-based demand forecasting algorithms to optimize scheduling and vehicle deployment, effectively reducing idle times and energy consumption. Additionally, vehicle-to-infrastructure (V2I) communication in Stockholm facilitates seamless data integration, enabling real-time interactions between traffic management systems and on-road vehicles. Together, these applications demonstrate the synergy of AI and IoT technologies in advancing operational efficiency and sustainability within urban transportation systems.

8.2.6. Tokyo, Japan: AI-Powered smart mobility services

Tokyo's smart mobility initiative focuses on integrating AI-powered on-demand transportation services with the city's extensive public transportation network. The city has deployed a series of electric shared-ride services that utilize AI to match passengers traveling in the same direction, optimizing vehicle occupancy and reducing the number of cars on the road (Tettamanti et al., 2016).

In addition to ride-sharing, Tokyo has implemented autonomous shuttle services in select areas, using AI to determine the most efficient routes based on real-time traffic data and passenger demand. By adopting these technologies, Tokyo has seen a 25% reduction in travel times during peak hours and a 17% decrease in energy consumption compared to traditional taxi services. The city's long-term goal is to expand the use of autonomous electric vehicles, further contributing to its goal of becoming a zero-emissions city by 2050 (Ministry of Land, Infrastructure, Transport, and Tourism, 2021).

8.2.7. Sydney, Australia: Demand-responsive public transit

Sydney's on-demand public transit pilot program, launched in the suburbs surrounding the central business district (CBD), offers residents flexible transportation options during off-peak hours. This demand-responsive service allows users to book rides through a mobile app, with routes dynamically generated based on real-time passenger requests. The goal of the service is to reduce the number of empty buses running during non-peak hours and to provide a more energy-efficient alternative (Faghih-Imani & Eluru, 2019).

By leveraging IoT and AI, the system has optimized routes and schedules, ensuring that buses only run when and where they are needed. Initial results show a 30% reduction in fuel consumption and a 20% decrease in overall vehicle emissions. Sydney's program is currently being expanded to include electric buses, further advancing the city's sustainability efforts (Transport for New South Wales, 2021).

Figure 1 and Table 1 present a visual comparison of emission reductions in different cities implementing on-demand transportation systems.

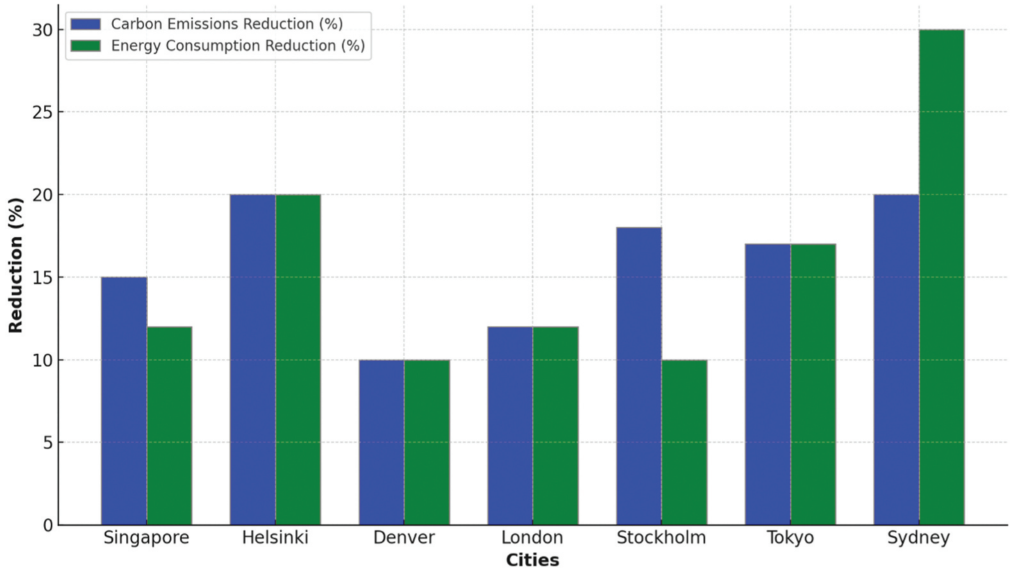

Figure 1. Comparison of carbon emissions and energy consumption reduction across cities.

Table 1. Comparison of the case studies

City	On-Demand System	Key Features	Carbon Emissions Reduction (%)	Energy Consumption Reduction (%)
Singapore	GrabShuttle	Public transit integration, real-time data analytics, shared rides	15	12
Helsinki	Whim App	MaaS integration, dynamic pricing, AI-powered route optimization	20	20
Denver	RTD and Uber/Lyft Partnership	First/last mile ride-hailing, public transit connection	10	10
London	Electric Buses & Ride-Sharing Integration	Electric buses, ride-sharing, AI-driven route optimization	12	12
Stockholm	AI-Driven Route Optimization & IoT Monitoring	IoT sensors, electric/hybrid vehicles, AI-driven route adjustment	18	10
Tokyo	AI-Powered Smart Mobility Services	AI-matching, autonomous shuttles, real-time traffic optimization	17	17
Sydney	Demand-Responsive Public Transit	Dynamic routing, IoT and AI, electric buses	20	30

8.3. ICCT in on-demand transportation systems

ICCT plays a pivotal role in the operation and management of on-demand transportation systems, enhancing convenience, efficiency, and sustainability (Hensher & Li, 2019; Vazifeh et al., 2018; Zheng et al., 2019).

8.4. Contributions of AI and IoT to transportation sustainability

AI-powered algorithms play a crucial role in optimizing ride matching, route planning, and pricing strategies, which help to maximize resource utilization and minimize passenger wait times (Liu et al., 2020). Rajabzadeh and Fatorachian (2023) further explore the influence of AI and IoT technologies on IoT adoption in agricultural logistics, offering insights that are also highly applicable to transportation systems. By integrating these technologies, transportation systems can significantly enhance their operational efficiency.

Additionally, IoT sensors collect real-time data on vehicle locations, traffic conditions, and passenger demand, allowing for dynamic adjustments to service operations. This real-time responsiveness improves system performance and ensures more efficient transportation services (Peters et al., 2021). Together, AI and IoT offer powerful tools for enhancing sustainability and operational effectiveness in modern transportation systems.

8.5. Challenges faced by traditional public transportation post-COVID-19

The COVID-19 pandemic has severely disrupted traditional public transportation systems, presenting unprecedented challenges. As ridership declined sharply, transit agencies faced significant revenue losses, and operational disruptions further tested the resilience of these systems. Addressing these challenges requires a comprehensive assessment of the pandemic's impact, along with a strategic plan to modernize and rebuild public transportation. A behavioral economics perspective on supply chain disruptions caused by pandemics provides valuable insights into future research and recovery strategies (Fatorachian & Smith, 2023). To restore public trust and ensure the long-term viability of transit systems, agencies must adopt innovative solutions such as enhanced cleaning protocols, contactless payment systems, and demand-responsive services (Nieuwenhuijsen & Khreis, 2021). Additionally, Cyber-Physical Systems (CPS) offer opportunities to enhance supply chain resilience by providing flexible solutions to transportation challenges during pandemics (Fatorachian & Smith, 2022). The following points highlight the major challenges faced by public transportation during the pandemic and the necessary adaptations to overcome them:

- Impact on Ridership and Revenue: Public transportation systems globally experienced a steep decline in ridership due to health concerns and social distancing measures. This drop significantly reduced revenue, intensifying financial pressure on transit agencies. To mitigate these losses, transit authorities are exploring various strategies, including flexible scheduling, capacity management, and enhanced safety protocols to restore public confidence (Cats et al., 2021).
- Operational Disruptions and Adaptations: The pandemic triggered operational disruptions, underscoring the need for resilience in public transportation. Many agencies were forced to reduce service frequency, implement temporary route changes, and adopt emergency measures. These adaptations have highlighted the importance of flexible and responsive transit operations that can quickly adjust to evolving circumstances (Diaz et al., 2020).

9. Energy transition in on-demand transportation

9.1. Shift towards renewable energy-powered vehicles

The adoption of electric and hydrogen-powered vehicles represents a significant shift toward sustainable energy sources in on-demand transportation (Axsen et al., 2020). Supportive policies, incentives, and infrastructure investments are necessary to overcome barriers and accelerate the transition to renewable energy-powered fleets (Z. Zhang et al., 2021).

Adopting electric and hybrid vehicles in on-demand transportation fleets presents significant upfront costs, including vehicle acquisition and the development of charging or refueling infrastructure. However, these costs can be mitigated over time through lifetime savings. Electric and hybrid vehicles generally have lower maintenance costs due to fewer mechanical components compared to internal combustion engine vehicles. Furthermore, their operating costs are reduced as they rely on electricity or alternative fuels, which are often cheaper and more stable in price than traditional fuels. Fleet operators can also benefit from exemptions on congestion charges and government incentives, such as grants, tax rebates, and subsidies, which further offset initial investments. These financial advantages highlight the long-term economic viability of transitioning to electric and hybrid fleets, especially when coupled with supportive policy measures and infrastructure investments

- Electric Vehicles (EVs): Electric vehicles (EVs) offer zero-emission mobility, contributing to air quality improvement and climate change mitigation. However, the adoption of EVs in on-demand transportation faces challenges such as high upfront costs, limited range, and insufficient charging infrastructure. Governments and private sector stakeholders must collaborate to address these barriers through subsidies, tax incentives, and investments in charging infrastructure (Fouquet & Pearson, 2021).
- Hydrogen Fuel Cell Vehicles (FCVs): Hydrogen fuel cell vehicles (FCVs) produce no tailpipe emissions and offer long-range capabilities, making them suitable for on-demand transportation services. The deployment of FCVs requires the development of hydrogen refueling stations and advancements in hydrogen production and storage technologies. Policymakers must create favorable regulatory frameworks and provide financial support to facilitate the adoption of FCVs in the transportation sector (Mendes et al., 2020).

9.2. Planning and deployment of support infrastructure

Strategic placement of charging and refueling infrastructure is essential to ensure accessibility and convenience for on-demand vehicle operators and users (Mendes et al., 2020). Power grid expansion and upgrades are necessary to accommodate the increased electricity demand associated with electric vehicles (Z. Zhang et al., 2021).

- Charging Infrastructure: The deployment of EV charging infrastructure must consider factors such as location, capacity, and accessibility. Public charging stations should be strategically placed in high-traffic areas, residential neighborhoods, and along major transportation corridors. Additionally, private charging solutions, such as home and workplace chargers, can enhance the convenience of EV ownership (Xu et al., 2020).
- Hydrogen Refueling Infrastructure: Developing hydrogen refueling infrastructure involves establishing a network of refueling stations in key urban and suburban areas. This infrastructure must support the growing fleet of hydrogen-powered vehicles and ensure reliable and efficient refueling options. Collaboration between government agencies, industry stakeholders, and research institutions is crucial to advancing hydrogen infrastructure development (Fouquet & Pearson, 2021).

9.3. Safety considerations in urban deployment of energy-efficient vehicles

Safety concerns related to battery technology, hydrogen storage, and vehicle infrastructure interaction must be addressed through rigorous testing, certification, and standardization processes (Bockarjova et al., 2019). Public awareness campaigns and training programs for drivers and emergency responders are essential to ensure the safe deployment of renewable energy-powered vehicles (Savio et al., 2021).

- Battery Safety: The safety of EV batteries is a critical concern, as incidents such as thermal runaway and fires can pose significant risks. Manufacturers must adhere to stringent safety standards and conduct comprehensive testing to ensure battery safety. Additionally, emergency responders should receive training on handling EV-related incidents, including fire suppression and extraction techniques (Zachariah et al., 2021).
- Hydrogen Storage Safety: Hydrogen storage and handling present unique safety challenges due to the high-pressure storage requirements and the flammability of hydrogen gas. Safety protocols must include regular inspections, maintenance of storage systems, and emergency response planning. Public education campaigns can also help raise awareness about the safety and benefits of hydrogen technology (Mendes et al., 2020).

10. Sustainability challenges and solutions

10.1. Assessment of the environmental impact

Assessing the environmental impact of on-demand transportation involves evaluating factors such as greenhouse gas emissions, air quality, and energy consumption. Methods include life cycle assessments, emission modeling, and air quality monitoring (Fang et al., 2020; USEPA, 2018; WHO, 2016).

- Life Cycle Assessments (LCAs): Life cycle assessments (LCAs) evaluate the environmental impact of a product or service throughout its entire life cycle, from raw material extraction to disposal. LCAs provide a comprehensive understanding of the environmental footprint of on-demand transportation systems and identify opportunities for reducing emissions and improving sustainability (Agyemang-Duah et al., 2018).
- Emission Modeling: Emission modeling uses computational models to estimate the emissions of pollutants from various sources, providing insights into their spatial distribution and potential impacts on air quality. Emission models can inform policy decisions and help design effective mitigation strategies for reducing the environmental impact of on-demand transportation (Shaheen et al., 2016).
- Air Quality Monitoring: Air quality monitoring involves systematically collecting and analyzing data on pollutant concentrations in the atmosphere. This data can assess the effectiveness of mitigation measures and track changes in air quality over time. Air quality monitoring is essential for understanding the impact of transportation emissions on public health and the environment (USEPA, 2018).

Beyond assessment methods, integrating sustainability and governance principles is increasingly recognized as critical to successful urban and transportation development. Arifuddin et al. (2022) emphasize the importance of adopting sustainable construction strategies in Special Economic Zones (SEZs), highlighting the role of environmentally friendly materials and technologies in reducing carbon footprints and promoting long-term ecological balance. Similarly, Karunia et al. (2021) underline the significance of good governance in government organizations, arguing that transparent, accountable, and inclusive governance frameworks are essential for ensuring the equitable distribution of resources and the successful implementation of urban policies. Hamzah et al. (2023) extend this perspective by exploring environmental and sustainable factors influencing SEZ development, advocating for holistic planning approaches that integrate social, environmental, and economic objectives. Together, these studies provide valuable insights into the interplay between governance, sustainability, and urban development, aligning closely with the study's focus on creating operationally efficient and equitable transportation systems.

10.2. Strategies for mitigating road congestion and reducing emissions

Promoting shared rides, incentivizing electric or low-emission vehicles, implementing congestion pricing schemes, and optimizing route planning algorithms can mitigate road congestion and reduce emissions (Yang et al., 2019).

- Shared Rides: Encouraging shared rides reduces the number of vehicles on the road, alleviating congestion and lowering emissions. On-demand transportation platforms can promote shared rides through pricing incentives, user education, and convenient ride-matching algorithms (Shaheen et al., 2016).
- Incentivizing Electric or Low-Emission Vehicles: Incentives for electric or low-emission vehicles can include tax rebates, subsidies, reduced tolls, and preferential parking. These incentives encourage the adoption of cleaner vehicles, reducing the environmental impact of on-demand transportation (Axsen et al., 2020).
- Congestion Pricing: Congestion pricing involves charging fees for road usage during peak hours to reduce traffic congestion. By discouraging non-essential trips and encouraging alternative transportation modes, congestion pricing can alleviate congestion and reduce emissions (Zachariah et al., 2021).
- Route Optimization: Optimizing routes using advanced algorithms can minimize travel time, distance, and fuel consumption. On-demand transportation platforms can leverage real-time traffic data and predictive analytics to provide efficient routing options for drivers and passengers (Liu et al., 2020).

10.3. Evaluation of existing bus priority strategies

Bus priority strategies, such as dedicated bus lanes and signal prioritization, enhance the efficiency and attractiveness of public transit. Evaluating these strategies involves analyzing factors such as travel time savings, ridership levels, and customer satisfaction (Cats et al., 2021).

- Dedicated Bus Lanes: Dedicated bus lanes reserve road space exclusively for buses, reducing delays caused by mixed traffic. Evaluating the effectiveness of dedicated bus lanes involves assessing travel time savings, on-time performance, and ridership growth (Zachariah et al., 2021).
- Signal Prioritization: Signal prioritization systems give buses priority at traffic signals, reducing delays and improving schedule adherence. Evaluating signal prioritization involves analyzing changes in travel times, bus speeds, and passenger satisfaction (Shaheen et al., 2016).

10.4. Novel changes to increase overall transport efficiency

Integrating micro-mobility options, deploying autonomous vehicles for last-mile delivery, and implementing demand-responsive transit services can increase the overall efficiency of on-demand transportation systems (Buldeo Rai et al., 2020).

- Micro-Mobility Options: Micro-mobility options, such as bike-sharing and scooter-sharing services, provide convenient and sustainable alternatives for short-distance trips. Integrating micro-mobility options into the transportation network can reduce reliance on private vehicles and improve overall mobility (Faghih-Imani et al., 2019).
- Autonomous Vehicles: Deploying autonomous vehicles for last-mile delivery and first-mile connectivity can enhance the efficiency and convenience of on-demand transportation systems. Autonomous vehicles can operate around the clock, providing consistent and reliable service without the limitations of human drivers (Furuhata et al., 2013).
- Demand-Responsive Transit: Demand-responsive transit services adapt to changing travel patterns, offering flexible and efficient transportation options. These services can adjust routes and schedules based on real-time demand, reducing wait times and improving resource utilization (Alonso-González et al., 2020).

11. Data-driven optimization techniques

11.1. Importance of high-quality data

High-quality data on travel demand, traffic patterns, vehicle availability, and user preferences enable informed decision-making in route planning and resource management (Hollis et al., 2020).

- Data Sources and Quality: Reliable data sources include GPS data, mobile app usage data, traffic sensors, and public transit records. Ensuring data accuracy, consistency, and completeness is essential for effective analysis and optimization (Koohi et al., 2021).
- Data Privacy and Security: Protecting user privacy and data security is critical when collecting and analyzing transportation data. Implementing robust data protection measures, such as encryption and anonymization, can safeguard user information and build trust in data-driven optimization techniques (Fatorachian & Kazemi, 2021).

11.2. Use of data analytics and machine learning for route optimization

Data analytics and machine learning algorithms optimize routes by analyzing historical trip data, real-time traffic conditions, and spatial characteristics, minimizing travel time, distance, and fuel consumption (Zhang et al., 2020). This is further supported by Fatorachian and Smith (2022), who examine how Cyber-Physical Systems (CPS) enhance the resilience of supply chains, particularly in optimizing transportation systems during pandemic challenges.

- Machine Learning Techniques: Machine learning techniques, such as clustering, classification, and regression, enable the development of predictive models that anticipate future demand patterns and optimize route planning accordingly. These techniques can identify trends, detect anomalies, and provide insights into travel behavior (Lv et al., 2020).
- Predictive Analytics: Predictive analytics uses historical data to forecast future events, such as travel demand and traffic congestion. By incorporating predictive models into route optimization algorithms, transportation providers can improve service reliability and efficiency (Zheng et al., 2021).

11.3. Predictive modeling for demand forecasting and resource allocation

Predictive modeling techniques forecast future demand by analyzing factors such as time of day, day of the week, weather conditions, and special events, enabling efficient resource allocation (Wang et al., 2021).

- Time Series Analysis: Time series analysis involves examining data points collected over time to identify patterns and trends. This technique can forecast future demand, allowing transportation providers to allocate resources effectively and anticipate peak periods (Diaz et al., 2020).
- Scenario Planning: Scenario planning involves creating hypothetical scenarios to explore different outcomes and their implications. Transportation providers can use scenario planning to evaluate the impact of various factors, such as policy changes, economic conditions, and technological advancements, on demand and resource allocation (Koohi et al., 2021).

11.4. Case studies demonstrating successful implementation of data-driven optimization techniques

Uber's dynamic ride-matching algorithm and public transit agencies' bus schedule optimization initiatives demonstrate the benefits of data-driven optimization techniques in improving the efficiency, reliability, and sustainability of on-demand transportation services (Cramer et al., 2016; Lv et al., 2020).

- Uber's Dynamic Ride-Matching Algorithm: Uber's dynamic ride-matching algorithm continuously analyzes vast amounts of data, including passenger requests, driver locations, and traffic conditions, to optimize the matching process. By leveraging machine learning and predictive analytics, Uber can minimize passenger wait times and maximize driver utilization (Cramer & Krueger, 2016).
- Public Transit Bus Schedule Optimization: Public transit agencies use data-driven optimization techniques to improve bus schedules and enhance service reliability. These techniques analyze historical ridership data, traffic patterns, and other relevant factors to generate optimized schedules that balance service frequency, travel time, and operational costs (Fatorachian & Kazemi, 2021).

12. Findings and proposed operational framework

The findings from this study underscore the critical role of AI-powered route optimization and IoT-enabled real-time monitoring in reducing energy consumption and carbon emissions within urban transportation systems. Cities like London and Stockholm, which have embraced these technologies, have reported reductions in carbon emissions of up to 18%. To further enhance the sustainability of on-demand transportation systems, policymakers should prioritize the integration of AI and IoT technologies, while also promoting the widespread adoption of electric vehicles through targeted incentives and investments in charging infrastructure. Furthermore, equity must remain at the forefront of policy design, ensuring that underserved communities have equal access to sustainable transportation options.

Building on these findings, the Proposed Operational Framework for Policy Formulation and Implementation in Urban Transportation Planning offers a structured approach to align strategies with key policy goals. This framework emphasizes the interconnectedness of various policy areas, ensuring that all strategies work in harmony to achieve overarching objectives. Informed by robust research, stakeholder input, and global best practices, the framework outlines clear implementation steps, complete with monitoring and evaluation mechanisms to track progress and enable data-driven policy adjustments. Additionally, regular policy reviews and iterations are embedded within the framework to ensure that it remains responsive to evolving urban mobility patterns and stakeholder needs.

Figure 2 presents the Proposed Operational Framework for Policy Formulation and Implementation in Urban Transportation Planning.

The theoretical framework encapsulates a spectrum of constructs and theoretical frameworks crucial for optimizing urban transportation systems and fostering sustainable urban development. Foundational theories like Sustainable Transportation Theory and ICT Theory lay the groundwork, emphasizing the importance of incorporating digital solutions into transportation planning while leveraging ICT to enhance mobility. Integration of Technological Innovations aligns advancements with sustainability goals, while Traffic Flow Theory and Network Theory offer insights into traffic movement and network structure.

Integration of Technological Innovations with Policy and Practice

(a) Efficiency Improvement, Environmental Objectives, and Social Equity Considerations: These are interconnected as advancements in technology (such as AI and IoT) can contribute to achieving these objectives simultaneously. For example, dynamic routing and traffic optimization algorithms can not only improve operational efficiency but also reduce emissions and enhance accessibility for underserved communities.
(b) Real-Time Data Collection and Analysis: This component is linked to Efficiency Improvement, Traffic Management and Congestion Mitigation,

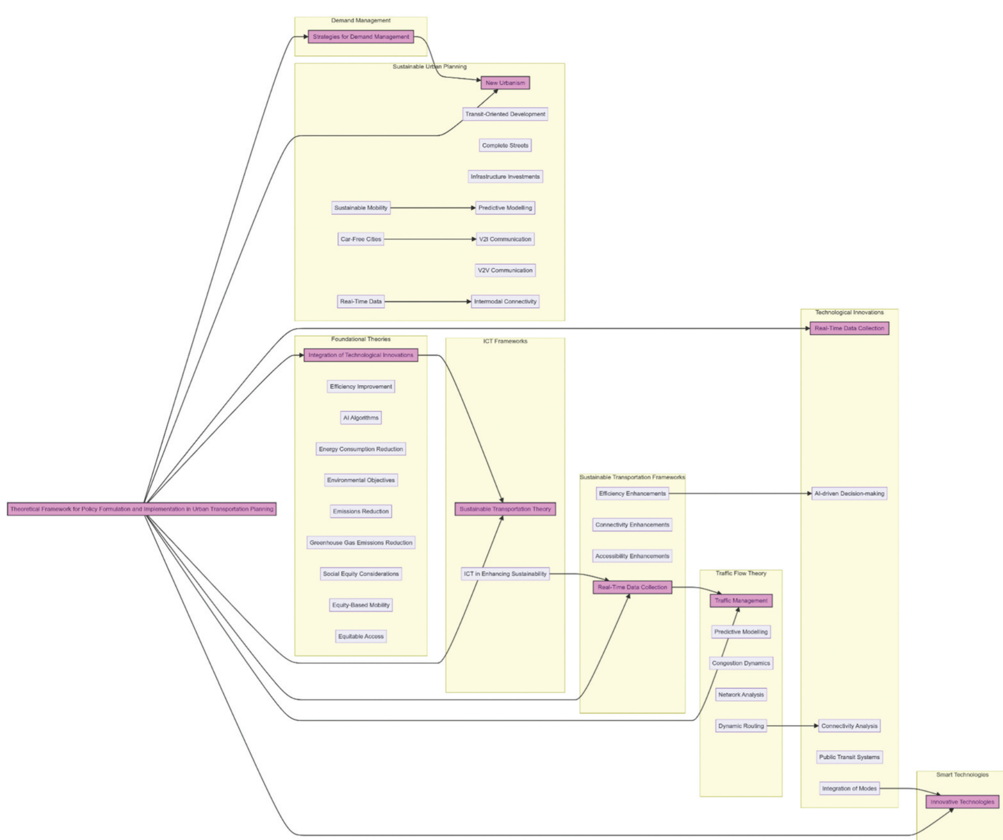

Figure 2. Proposed Framework.

and Connectivity Enhancements. Real-time data collection and analysis enable dynamic decision-making and optimization of transportation systems, leading to improved traffic flow, reduced congestion, and enhanced connectivity between different modes of transportation.

(c) Traffic Flow Theory and Network Theory: These foundational theories underpin the optimization of transportation networks and are interconnected with Demand Management Strategies and Smart Transportation Technologies. Understanding traffic flow dynamics and network structure informs the design and implementation of demand management strategies and the deployment of smart technologies for traffic management and optimization.

(d) Multi-Modal Transportation Planning and Intermodal Connectivity: These concepts are interrelated, as multi-modal transportation planning aims to enhance intermodal connectivity by facilitating seamless transfers between different transportation modes. Improving intermodal connectivity supports the integration of public transit systems and enhances the overall efficiency and accessibility of urban transportation networks.

(e) Public Transit Systems: Public transit systems are interconnected with several components, including Multi-Modal Transportation Planning, Demand Management Strategies, and Smart Transportation Technologies. Integrating public transit with other modes of transportation, implementing demand management measures to encourage transit use, and leveraging smart technologies to enhance transit operations contribute to the effectiveness and sustainability of public transit systems.

Overall, the interconnections between different constructs within the proposed theoretical framework demonstrate the holistic approach required for effective urban transportation planning. By considering the relationships and dependencies between various elements, policymakers and planners can develop comprehensive strategies that address multiple objectives and maximize the benefits of technological innovations and policy interventions in promoting sustainable urban mobility.

13. Policy implications, practice, and recommendations

13.1. Integration of sustainable transportation goals into urban policy frameworks

Sustainable transportation goals should be integrated into comprehensive urban policy frameworks to promote environmentally friendly, equitable, and efficient mobility solutions (Litman, 2019). Policies promoting transit-oriented development, complete streets design, and mixed-use zoning can support sustainable transportation choices (Cervero, 1998).

A holistic approach to sustainable transportation also requires incorporating the perspectives and roles of key stakeholders within the ecosystem. Ride-hailing companies provide operational expertise and technological innovation, such as AI-driven algorithms for demand forecasting and dynamic pricing. Their insights are crucial for tailoring services to meet passenger needs while maintaining profitability. Public transit authorities focus on ensuring accessibility and equity, leveraging their network planning capabilities to integrate on-demand services with existing transit systems. For instance, dynamic scheduling enabled by real-time data sharing allows public transit to complement ride-hailing services during peak hours. Urban planners bring a strategic perspective by aligning transportation systems with broader urban development goals, such as reducing congestion and emissions while promoting sustainable land use. Stakeholder collaboration is critical for harmonizing these objectives, fostering partnerships that enhance operational efficiency and equity across the transportation network.

- Transit-Oriented Development (TOD): TOD policies encourage the creation of dense, mixed-use developments near public transit stations. TOD promotes higher transit ridership, reduces car dependency, and enhances the efficiency of the transportation network (Cervero, 1998).
- Complete Streets: Complete streets policies prioritize the needs of all users, including pedestrians, cyclists, and public transit riders. These policies support the development of safe, accessible, and interconnected transportation infrastructure that promotes sustainable travel behavior (National Complete Streets Coalition, 2010).

13.2. Practical implications for urban planners, transportation authorities, and policymakers

Urban planners, transportation authorities, and policymakers must collaborate to develop integrated transportation strategies that prioritize sustainability, equity, and resilience. This involves investing in infrastructure improvements, expanding public transit networks, and incentivizing the adoption of energy-efficient transportation technologies (Zheng et al., 2021).

- Infrastructure Investments: Investing in infrastructure improvements, such as dedicated bus lanes, bike lanes, and pedestrian pathways, can enhance the efficiency and accessibility of the transportation network. These investments support sustainable transportation modes and reduce reliance on private vehicles (Calthorpe & Fulton, 2001).
- Public Transit Expansion: Expanding public transit networks, including bus rapid transit (BRT) and light rail systems, can improve connectivity and accessibility for urban residents. Public transit expansion can reduce traffic congestion, lower emissions, and promote equitable access to transportation services (Cervero, 1998).

13.3. Importance of evidence-based decision-making and the use of high-quality data

Evidence-based decision-making is essential for informing policy development and evaluating the effectiveness of transportation interventions. Policymakers and urban planners should rely on high-quality data and rigorous analysis to understand transportation trends and assess the impacts of policy changes (Pekel et al., 2017).

- Data-Driven Policy Development: Data-driven policy development involves using empirical evidence to design and implement transportation policies. This approach ensures that policies are based on accurate and reliable data, leading to more effective and sustainable outcomes (Koohi et al., 2021).
- Monitoring and Evaluation: Monitoring and evaluation processes track the progress and impact of transportation policies and interventions. Regular monitoring and evaluation allow policymakers to make informed adjustments and improvements, ensuring the continued effectiveness of transportation strategies (Fatorachian & Kazemi, 2021).

13.4. Recommendations for policy interventions to promote energy-efficient on-demand transportation solutions

Policy interventions should prioritize initiatives that reduce emissions, enhance energy efficiency, and improve the overall sustainability of urban mobility networks. Recommended interventions include setting emissions standards for on-demand transportation vehicles, providing subsidies or incentives for adopting electric and hydrogen-powered vehicles, and investing in renewable energy infrastructure (Litman, 2019).

- Emissions Standards: Setting stringent emissions standards for on-demand transportation vehicles can reduce greenhouse gas emissions and improve air quality. Emissions standards can be enforced through regulations, inspections, and penalties for non-compliance (Fang et al., 2020).
- Subsidies and Incentives: Providing financial incentives, such as subsidies, tax rebates, and grants, can encourage the adoption of electric and hydrogen-powered vehicles. These incentives can offset the higher upfront costs of clean vehicles and promote their widespread use (Axsen et al., 2020).
- Renewable Energy Infrastructure: Investing in renewable energy infrastructure, such as solar and wind power, supports the transition to clean transportation. Renewable energy infrastructure can power electric vehicle charging stations and hydrogen production facilities, reducing the carbon footprint of on-demand transportation (Mendes et al., 2020).

14. Conclusion and future research direction

The findings from this study emphasize the vital role of AI-powered route optimization and IoT-enabled real-time monitoring in reducing energy consumption and carbon emissions in urban transportation systems. Cities like London and Stockholm, which have implemented these technologies, have seen reductions in carbon emissions of up to 18%. To continue advancing sustainability in urban transportation, policymakers should prioritize integrating these technologies into on-demand systems while promoting electric vehicle adoption through targeted incentives and infrastructure development. Furthermore, equity must remain a central consideration in policy design to ensure underserved communities have access to sustainable transportation options.

Throughout this study, we have highlighted the transformative role of technological advancements in shaping the future of on-demand transportation. From integrating AI and IoT to improve operational efficiency, to examining how these innovations can drive sustainability, our analysis has explored the significant impact of these technologies on urban mobility.

We have also delved into the challenges and opportunities related to integrating on-demand transportation systems with traditional public transit networks. By analyzing the role of information, communication, and computing technologies, we have outlined pathways to enhance interoperability between different transportation modes, ultimately improving the efficiency and convenience of urban mobility systems.

Additionally, our research has underscored the importance of policy frameworks and regulatory interventions in promoting sustainable development in on-demand transportation. Thoughtfully designed policies can balance the needs of various stakeholders, ensuring that urban mobility systems contribute to broader sustainability goals and the overall health of the transportation ecosystem.

To achieve long-term sustainability, policymakers should focus on creating policies that encourage the adoption of electric and hybrid vehicles within on-demand transportation fleets. The integration of AI-powered route optimization tools, as demonstrated by cities like London and Stockholm, can reduce urban congestion and energy consumption. By adopting these measures, cities can strike a balance between operational efficiency and environmental sustainability.

In summary, our findings illustrate the complexity of on-demand transportation systems and the need for a multifaceted approach to address their challenges. By considering technological advancements, integration with public transit, and policy frameworks, we can pave the way for sustainable, energy-efficient, and accessible urban mobility solutions. Future research should focus on the long-term environmental impacts, technological integration with public transit systems, and the equity dimensions of on-demand transportation to develop comprehensive solutions that balance sustainability, efficiency, and accessibility in urban mobility.

During the preparation of this work, the author used Generative AI to improve the readability and flow. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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