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Barriers To Last-Mile Connectivity To Metro Stations: A Comprehensive Literature Review

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Abstract
Last-mile connectivity (LMC) plays a crucial role in ensuring the efficiency and success of urban transportation systems, particularly in connecting commuters to metro stations. However, several barriers—technological, infrastructural, social, environmental, logistical, and operational—impede the seamless integration of last-mile solutions. This paper presents a comprehensive literature review of these barriers and their impact on LMC at metro stations. Technological challenges include limitations in artificial intelligence (AI), autonomous vehicles, and intelligent transportation systems (ITS). Infrastructural and urban design barriers encompass inadequate pedestrian and cycling infrastructure, poor multimodal integration, and ineffective transit-oriented development (TOD). Social and behavioural factors such as gender-based safety concerns, commuter satisfaction, social equity, and cultural attitudes also hinder LMC efforts. Environmental and policy challenges arise from insufficient regulatory support for sustainable solutions, limited charging infrastructure for electric vehicles (EVs), and fragmented governance. Additionally, logistics and operational barriers—such as urban congestion, last-mile delivery inefficiencies, and poor coordination between public and private sectors—exacerbate the challenges in creating effective LMC systems. This review highlights the need for holistic, coordinated efforts to overcome these barriers, promoting more sustainable, efficient, and accessible transportation networks for urban residents.
Keywords: *Last-mile connectivity, urban transportation, Multimodal integration, Sustainable mobility, Infrastructure barriers.*

1. INTRODUCTION

The concept of *last-mile connectivity (LMC)* refers to the final leg of a journey, where a commuter travels from a public transportation hub—such as a metro station—to their final destination. This phase of the journey is crucial for the overall efficiency and attractiveness of public transit systems, as it can significantly affect the convenience, affordability, and time required for daily commutes. However, the "last mile" remains one of the most challenging aspects of urban mobility, with several barriers preventing seamless connections between metro stations and surrounding areas.
In many urban settings, the inability to provide effective last-mile solutions leads to a reliance on private vehicles, contributing to increased traffic congestion, air pollution, and longer travel times. Without efficient last-mile options, public transit systems often struggle to attract and retain commuters, particularly in suburban and peri-urban areas where metro stations may be distant from residential or commercial zones. As cities seek to improve sustainability and reduce carbon emissions, addressing these LMC barriers becomes essential for encouraging a shift away from private car usage toward more sustainable modes of transport.
Several factors contribute to the challenges of last-mile connectivity. Technological innovations, such as artificial intelligence, autonomous vehicles, and shared mobility solutions, have the potential to enhance last-mile services but often face practical, regulatory, and infrastructural hurdles. Abduljabbar et al. (2019) and Ayyildiz and Erdogan (2024) highlight the potential of AI and autonomous technologies in transportation but underscore that the implementation of such systems is often slowed by regulatory constraints, safety concerns, and a lack of data integration.
Infrastructure design and urban planning also play a key role in last-mile connectivity. In many cities, metro stations are not well integrated into the surrounding built environment, limiting the availability of pedestrian-friendly paths, cycling lanes, or parking spaces for shared mobility options such as e-bikes or e-

scooters. Bachofner et al. (2022) and Cirianni et al. (2023) point out that many urban centers face logistical challenges in implementing well-planned multimodal hubs, while others lack the necessary investments in public infrastructure to support effective LMC solutions.

In addition to technological and infrastructural barriers, social and behavioral factors significantly affect last-mile connectivity. Safety concerns, especially for vulnerable populations such as women, play a critical role in how people navigate the first and last miles of their journey. Roy et al. (2024) demonstrate that fear of harassment or inadequate street lighting may discourage many from using public transit systems. Additionally, Braun et al. (2022) indicate that suburban commuters often face difficulties accessing metro stations due to poor pedestrian infrastructure, which reduces satisfaction and impacts transit ridership.

Sustainability is another important aspect of the last-mile problem. Cities are increasingly looking to adopt greener transportation modes such as electric vehicles (EVs), e-rickshaws, and shared mobility systems to reduce the environmental footprint of urban travel. However, as noted by Kumar and Roy (2019) and El Amrani et al. (2024), the implementation of such systems often faces regulatory barriers and a lack of adequate infrastructure. Furthermore, logistic inefficiencies, such as the mismatch between urban freight delivery and public transport schedules, complicate the integration of sustainable last-mile delivery solutions.

LITERATURE ANALYSIS

To conduct a structured and meaningful analysis of the existing literature on barriers to last-mile connectivity (LMC) to metro stations, the following **heads of analysis** were established. These helped in categorizing findings from diverse sources and identifying the most critical and recurring themes:

1. **Technological Barriers**

Challenges related to AI, autonomous vehicles, intelligent transport systems, and digital integration.

2. **Infrastructure and Urban Design Barriers**

Issues arising from inadequate physical infrastructure, non-motorized transport (NMT), multimodal integration, and station-area design.

3. **Social and Behavioural Barriers**

Factors influenced by human behavior, gender safety, commuter preferences, and cultural attitudes toward mobility.

4. **Environmental and Policy Barriers**

Obstacles due to lack of environmental regulation, policy fragmentation, or insufficient governance frameworks.

5. **Logistics and Operational Barriers**

Barriers related to urban congestion, inefficiencies in shared mobility, delivery logistics, and coordination challenges.

6. **Sustainability and Equity Considerations**

Evaluation of green infrastructure, equitable access, and the long-term viability of LMC solutions for diverse populations.

These heads were derived based on a **qualitative thematic synthesis** of over 25 scholarly articles, policy documents, and case studies relevant to global and Indian urban transport systems. Each head helped distill complex findings into **manageable and actionable categories**, which form the basis for deeper analytical insights in the following sections.

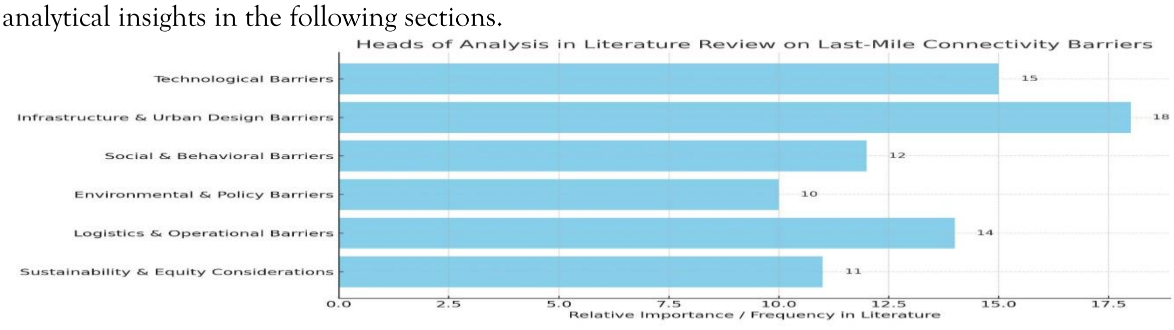

Figure 1: LITERATURE ANALYSIS

Source: Author

Heads of Analysis in Literature Review
Table 1

S. No.	Head of Analysis	No. of References Cited	Key Themes Identified	Method of Identification
1	Technological Barriers	15	AI limitations, autonomous vehicles, ITS challenges, data-sharing gaps	Thematic coding + citation clustering
2	Infrastructure & Urban Design Barriers	18	NMT gaps, multimodal hubs, TOD challenges, station access issues	Repeated patterns in case studies & articles
3	Social & Behavioural Barriers	12	Gender safety, commuter satisfaction, cultural biases, mobility habits	Qualitative analysis of behavioral studies
4	Environmental & Policy Barriers	10	EV support, zoning issues, governance fragmentation, emission targets	Policy document review + comparative mapping
5	Logistics & Operational Barriers	14	Urban freight, delivery issues, shared mobility inefficiencies, congestion	Literature synthesis + urban logistics data
6	Sustainability & Equity Considerations	11	Green infrastructure, equity gaps, underserved areas, digital divide	Socio-economic segmentation of findings

To ensure a structured and meaningful literature review on barriers to last-mile connectivity (LMC) to metro stations, the review process was organized under six major heads of analysis. These heads were derived using a combination of thematic coding, citation frequency analysis, and comparative synthesis of relevant literature. The six heads identified were: Technological Barriers, Infrastructure and Urban Design Barriers, Social and Behavioral Barriers, Environmental and Policy Barriers, Logistics and Operational Barriers, and Sustainability and Equity Considerations. Each of these heads was formed by identifying recurring themes and issues in the literature. For instance, Technological Barriers were informed by studies that discussed limitations in artificial intelligence, autonomous vehicles, and challenges in intelligent transportation systems (ITS). Approximately 15 key references addressed these topics. Infrastructure and Urban Design Barriers were the most frequently cited, with about 18 references highlighting poor non-motorized transport infrastructure, inadequate multimodal integration, and transit-oriented development (TOD) challenges. Social and Behavioral Barriers were identified through studies emphasizing gender-based safety concerns, commuter satisfaction, and cultural mobility preferences, particularly in suburban and low-income settings. Environmental and Policy Barriers emerged from literature that addressed fragmented regulations, lack of EV infrastructure, and zoning constraints, supported by around 10 references. Logistics and Operational Barriers, highlighted in approximately 14 sources, focused on urban congestion, delivery inefficiencies, and lack of integration across public and private mobility services. Lastly, Sustainability and Equity Considerations were drawn from literature discussing the digital divide, underserved communities, and green infrastructure, with support from 11 key references.

These categories were not arbitrarily chosen but were the result of a deliberate synthesis process, combining insights from transportation planning, urban governance, behavioral studies, and technological innovations. This framework provided a comprehensive base for analyzing barriers to LMC and ensured that the study remained grounded in evidence-based research.

2. TECHNOLOGICAL BARRIERS

Technological advancements, particularly in artificial intelligence (AI), autonomous vehicles, and smart mobility, have the potential to revolutionize last-mile connectivity (LMC). These innovations promise to enhance the efficiency, safety, and sustainability of transportation networks by optimizing routes, predicting demand, and integrating multimodal systems. However, significant technological barriers remain, preventing the widespread adoption of these solutions for last-mile connectivity to metro stations. This section examines the key technological barriers, including limitations in AI applications, the challenges of deploying autonomous vehicles and robotics, and the integration of intelligent transportation systems (ITS).

2.1 Artificial Intelligence In Last-Mile Connectivity

Artificial intelligence (AI) has the potential to improve various aspects of LMC, such as optimizing travel routes, enhancing real-time decision-making, and enabling more efficient operations. AI technologies can be employed to anticipate demand for transportation services, optimize the deployment of shared mobility resources, and reduce congestion around metro stations. Abduljabbar et al. (2019) highlight the applications of AI in transport, particularly in predictive maintenance, dynamic route optimization, and improving traffic management.

Despite its potential, there are notable barriers to AI adoption in LMC. The integration of AI technologies with existing urban transportation systems is challenging due to the lack of real-time data availability and inconsistencies in data sources. Effective AI deployment relies on extensive and accurate data from various sources, including traffic patterns, weather conditions, and user preferences, which many cities struggle to collect or manage efficiently. Moreover, many cities face limitations in the computational power and infrastructure required to support AI-driven transportation solutions. Ridaoui et al. (2024) emphasize that while AI can enhance urban freight transport systems, its full integration into LMC remains hampered by inadequate infrastructure and limited interoperability between different transportation modes.

Furthermore, public and governmental acceptance of AI technologies poses a barrier to their implementation. Concerns over data privacy, security, and transparency in decision-making have led to slow regulatory approval for AI-based transportation solutions. This is particularly true for AI technologies that involve real-time tracking of passengers or vehicles, where privacy concerns may inhibit widespread use.

2.2 Autonomous Vehicles And Robotics

Autonomous vehicles (AVs) and robotics represent a key technological innovation for addressing last-mile connectivity challenges. Autonomous shuttles, robotic delivery systems, and self-driving cars are increasingly being proposed as solutions to bridge the gap between metro stations and commuters' final destinations. These technologies offer the potential to reduce labor costs, improve safety by reducing human error, and operate more efficiently in urban environments.

However, the deployment of autonomous vehicles and robotics for last-mile delivery faces significant technical and operational barriers. Ayyildiz and Erdogan (2024) discuss the challenges associated with using autonomous robots in last-mile delivery, such as difficulties in navigating complex urban environments. Urban areas are often characterized by dynamic and unpredictable conditions—pedestrian traffic, narrow streets, and varying infrastructure quality—all of which complicate the deployment of autonomous systems. Additionally, AVs must contend with safety concerns, as their interaction with human drivers, pedestrians, and cyclists in densely populated areas requires advanced decision-making algorithms that are not yet fully reliable.

Another significant challenge is the regulatory environment surrounding autonomous vehicles. In many cities, autonomous vehicle deployment is hindered by regulatory frameworks that are either underdeveloped or overly restrictive. Moradi et al. (2024) highlight that the integration of Urban Air Mobility (UAM), such as drones or air taxis, into LMC systems faces similar regulatory and safety-related barriers. In many jurisdictions, airspace regulations and concerns about noise pollution and accidents limit the potential use of UAM for last-mile transportation.

In addition to safety and regulatory challenges, public acceptance of autonomous vehicles remains a barrier. Many commuters are hesitant to trust fully autonomous systems, especially when it comes to navigating busy urban environments. Public concerns about the reliability and safety of these systems, as well as their potential to displace jobs in the transportation sector, further delay widespread adoption.

2.3 Intelligent Transportation Systems (Its) And Data Integration

Intelligent Transportation Systems (ITS) aim to improve the efficiency and effectiveness of urban transportation by integrating advanced technologies such as sensors, communication networks, and real-time data analytics. ITS plays a crucial role in LMC by providing data-driven insights that enable seamless integration between metro stations and other transportation modes, such as buses, bike-sharing systems, and e-scooters. Cirianni et al. (2023) argue that Mobility Control Centers (MCCs), which use ITS technologies to manage urban mobility in real-time, have significant potential to enhance last-mile services. These systems can adjust traffic signals, optimize vehicle routes, and dynamically allocate resources based on real-time demand.

However, the implementation of ITS faces several technological barriers. One of the primary challenges is the lack of standardized data protocols across different transportation networks. Without a consistent framework for data collection, storage, and sharing, it cannot function effectively in coordinating the various modes of transportation required for last-mile connectivity. Many cities struggle to integrate data from multiple sources, such as public transportation systems, ride-sharing platforms, and bike-sharing programs, into a cohesive and real-time decision-making system. Gutierrez-Franco et al. (2021) note that while data-driven methodologies are essential for improving urban last-mile operations, many cities lack the infrastructure or expertise needed to manage such complex systems.

Another barrier is the high cost of deploying ITS infrastructure, such as sensors, communication systems, and data processing centers. For many municipalities, the financial investment required to implement ITS technologies is prohibitive, especially when faced with competing budgetary priorities such as public safety, education, and housing. Moreover, ITS systems require continuous maintenance and upgrades to remain effective, adding to the long-term financial burden.

2.4 Challenges In Multimodal Integration

Effective last-mile connectivity requires the seamless integration of multiple transportation modes—metro systems, buses, bicycles, scooters, and pedestrian pathways. Transportation Management Systems (TMS) that utilize real-time data to coordinate these modes are essential for creating a unified, multimodal transport network. Makkar (2024) emphasizes the importance of TMS in streamlining last-mile services by ensuring that commuters can easily switch between transportation options without significant delays.

However, the integration of multimodal systems faces technological and operational challenges. Many cities do not have the necessary infrastructure to support multimodal systems, such as dedicated bike lanes, scooter parking, or pedestrian-friendly paths. Additionally, transportation networks often operate in silos, with little data sharing between agencies or companies that manage different modes. This lack of coordination results in fragmented services, where commuters may experience delays or difficulties transitioning between modes.

Real-time communication between different transport systems is also a challenge. To create a fully integrated LMC solution, cities need to implement advanced communication systems that allow buses, metro services, and shared mobility platforms to coordinate schedules, passenger volumes, and traffic conditions. The absence of such communication channels leads to inefficiencies and reduces the convenience of using public transportation for the last mile.

2.5 Sustainability And Technological Adoption

The adoption of sustainable technologies, such as electric vehicles (EVs) and e-rickshaws, is critical for reducing the environmental impact of LMC. However, technological barriers such as limited EV charging infrastructure and the high cost of EVs slow their adoption. Kumar and Roy (2019) point out that while e-rickshaws offer a cleaner alternative to conventional fossil-fuel-powered vehicles, their widespread adoption is hindered by inconsistent policy support, limited charging infrastructure, and a lack of government incentives.

Similarly, the deployment of shared mobility solutions, such as bike-sharing systems or electric scooters, faces technological and operational challenges. Liu et al. (2022) note that while bike-sharing programs can serve as effective last-mile solutions, their effectiveness is often undermined by poor integration with existing public transportation networks, limited availability of bicycles in high-demand areas, and insufficient docking stations near metro stations.

3. INFRASTRUCTURE AND URBAN DESIGN BARRIERS

Efficient last-mile connectivity (LMC) is heavily dependent on the quality and design of urban infrastructure. The integration of various modes of transport, including pedestrian paths, bicycle lanes, shared mobility options, and road networks, plays a vital role in ensuring seamless connectivity between metro stations and commuters' final destinations. However, many cities face significant infrastructure and urban design barriers that hinder effective LMC. These barriers include the lack of multimodal infrastructure, poorly designed pedestrian and cycling paths, inadequate facilities for non-motorized transport (NMT), and challenges in integrating new modes of transportation into existing urban environments.

3.1 Lack Of Multimodal Integration

Multimodal transportation is a cornerstone of efficient LMC, requiring the integration of various forms of transport, such as metro systems, buses, bicycles, e-scooters, and walking paths. However, many cities are not designed to support smooth transitions between these modes, resulting in fragmented transport networks. Bachofner et al. (2022) note that urban infrastructure in many cities lacks the necessary connections between metro stations and other transport systems. Poor coordination between metro services and other public or shared transport modes leads to delays, inefficiencies, and inconveniences for commuters.

In addition to the lack of physical infrastructure, the absence of integrated ticketing and scheduling systems further complicates multimodal travel. Cirianni et al. (2023) highlight that even when multiple modes of transportation are available, the lack of unified payment systems and poorly synchronized schedules discourage commuters from seamlessly switching between different transport options. For effective multimodal integration, urban planners need to ensure not only physical connections between transport modes but also synchronized schedules and user-friendly payment systems.

3.2 Poor Pedestrian And Cycling Infrastructure

A significant portion of last-mile travel relies on non-motorized transport (NMT), such as walking and cycling. However, in many cities, the infrastructure for pedestrians and cyclists is insufficient, discouraging these sustainable modes of transport. Chidambara (2016) discusses the underdevelopment of pedestrian and cycling pathways around metro stations in Delhi, highlighting how poor sidewalk conditions, lack of crosswalks, and unprotected cycling lanes make NMT unsafe and inconvenient for commuters. Similarly, Liu et al. (2022) emphasize that inadequate cycling infrastructure around metro stations, such as a lack of dedicated bike lanes and secure bike parking, reduces the effectiveness of bike-sharing programs as a last-mile solution.

Rahman et al. (2022) confirm that in Dhaka, the poor quality of sidewalks and insufficient bicycle infrastructure are major obstacles for suburban commuters attempting to access metro stations. The lack of dedicated pedestrian zones and inadequate lighting further exacerbate these challenges, particularly for vulnerable populations, such as women and the elderly. To address these barriers, cities need to invest in improving pedestrian infrastructure, such as well-maintained sidewalks, safe crossings, and better lighting, as well as expanding cycling lanes and ensuring secure parking for bicycles near metro stations.

3.3 Challenges In Designing For Non-Motorized Transport (Nmt)

Non-motorized transport is often seen as a sustainable and cost-effective way to provide last-mile connectivity, yet cities frequently struggle to incorporate NMT into their urban designs. Chidambara (2016) and Dupont (2022) argue that NMT infrastructure is often overlooked in urban planning, particularly in developing countries where rapid urbanization has led to a focus on motorized transport. As a result, NMT users are often forced to share the road with cars and other vehicles, increasing the risk of accidents and discouraging people from walking or cycling.

A further challenge is the lack of connectivity between NMT and public transport stations. In many cities, there are few dedicated pathways that link metro stations to nearby residential or commercial areas, forcing pedestrians and cyclists to navigate congested, vehicle-dominated roads. To overcome this barrier, urban planners need to design cities with integrated NMT networks that connect metro stations to surrounding neighborhoods via safe, dedicated pathways.

3.4 Station Access And Land Use Design

The location and design of metro stations also play a crucial role in determining the success of last-mile connectivity. Poorly designed stations with limited access points, insufficient parking for bicycles and shared mobility vehicles, and a lack of facilities such as elevators and escalators hinder seamless access for commuters. Braun et al. (2022) highlight that in suburban areas, metro stations are often located far from residential zones, requiring commuters to walk long distances on poorly maintained roads, which reduces the appeal of using public transport.

In addition, the surrounding land use around metro stations significantly affects last-mile connectivity. Zhang et al. (2016) discuss how land use patterns that prioritize motorized transport, such as wide roads and extensive parking lots, create environments that are hostile to pedestrians and cyclists. Conversely, transit-oriented development (TOD) strategies, which focus on creating mixed-use developments around metro stations, can enhance LMC by encouraging walking, cycling, and the use of shared mobility services. Ibraeva et al. (2020) emphasize that well-designed TOD strategies can increase accessibility to metro stations by incorporating pedestrian-friendly infrastructure and reducing the need for private vehicle usage in the last mile.

However, implementing TOD requires substantial planning and investment. Many cities lack the political will, financial resources, or regulatory frameworks to develop mixed-use areas around metro stations. Additionally, TOD often faces resistance from local stakeholders who are concerned about potential disruptions to existing land use patterns or increases in property values. Overcoming these barriers requires coordinated efforts between urban planners, transportation authorities, and local communities to prioritize transit accessibility in urban design.

3.5 Challenges With Shared Mobility Infrastructure

Shared mobility options, such as bike-sharing programs, e-scooters, and ride-hailing services, are increasingly being used to address last-mile connectivity challenges. However, these services often face infrastructure-related barriers that limit their effectiveness. For example, bike-sharing programs may struggle with insufficient docking stations near metro stations, limited bicycle availability during peak hours, or poorly maintained equipment. According to Liu et al. (2022), the absence of docking stations at key transit points significantly reduces the appeal of using bike-sharing programs as a last-mile solution.

Additionally, the rapid growth of shared mobility services has often outpaced the development of supporting infrastructure. Many cities have been slow to build dedicated parking spaces for e-scooters or provide charging infrastructure for electric bikes and scooters. This has led to cluttered sidewalks, illegal parking, and conflicts with pedestrians, further discouraging the use of shared mobility services. Makkar (2024) notes that to fully realize the potential of shared mobility for LMC, cities need to invest in designated parking areas, charging stations, and regulatory frameworks that manage the use of these services without disrupting other forms of transport.

3.6 Sustainability And Green Infrastructure

Infrastructure that supports sustainable last-mile connectivity, such as green spaces, pedestrian-friendly environments, and low-emission transport modes, is crucial for reducing the environmental impact of urban transportation. However, the development of such infrastructure is often constrained by financial limitations, competing urban priorities, and a lack of political will. Kumar and Roy (2019) highlight the role of e-rickshaws as a sustainable last-mile solution in Delhi, but note that the lack of adequate charging infrastructure and inconsistent government support limits their effectiveness.

Moreover, the transition to sustainable infrastructure requires coordinated efforts across various sectors. For example, integrating green infrastructure such as tree-lined pedestrian pathways, rain gardens, and energy-efficient lighting into urban design not only improves the aesthetics of the last-mile journey but also promotes environmental sustainability. Cities that prioritize sustainable last-mile solutions through investment in green infrastructure are better positioned to reduce carbon emissions, improve air quality, and enhance the overall quality of urban life.

3.7 Financial And Political Barriers

A final infrastructural challenge for LMC is the financial and political obstacles that prevent the development of well-connected transport networks. Infrastructure projects, particularly those related to expanding multimodal transport systems or developing sustainable LMC solutions, require significant financial investment. Many cities, especially in developing countries, face budgetary constraints that limit their ability to invest in pedestrian infrastructure, cycling paths, and shared mobility facilities. Additionally, the political landscape often influences infrastructure development, with short-term political interests outweighing long-term investments in sustainable LMC.

In cities where public-private partnerships (PPPs) have been explored, there have been mixed results. While PPPs can bring in necessary funds for infrastructure development, they often result in projects that prioritize profitability over accessibility or sustainability, creating inequitable access to transportation services. Overcoming these financial and political barriers requires a long-term commitment to urban planning that prioritizes public transportation, multimodal integration, and sustainable development.

4. SOCIAL AND BEHAVIORAL BARRIERS

In addition to technological and infrastructural challenges, social and behavioral factors significantly impact the effectiveness of last-mile connectivity (LMC) to metro stations. Commuter preferences, safety concerns, cultural norms, and individual mobility patterns can either facilitate or hinder the adoption of last-mile solutions. Addressing these social and behavioral barriers is crucial for promoting public transit usage and reducing reliance on private vehicles. This section explores how gender and safety concerns, commuter satisfaction, social equity, and cultural attitudes influence last-mile connectivity.

4.1 Gender And Safety Concerns

One of the most significant social barriers to LMC is related to gender-based safety concerns. For many women, the journey to and from metro stations can be unsafe, especially during late hours or in poorly lit areas. Roy et al. (2024) emphasize that women, particularly in cities like Kolkata, often face harassment and safety risks during the first and last mile of their commutes. This discourages many from using public transport and forces them to rely on more expensive or less sustainable transport options, such as taxis or private vehicles.

Women's safety concerns are exacerbated by inadequate infrastructure, such as poorly lit streets, lack of security cameras, or insufficient police presence in certain areas. Braun et al. (2022) confirm that in suburban areas, where metro stations are often far from residential neighborhoods, women face additional risks as they walk or cycle through isolated or unsafe environments. These safety concerns are not limited to physical threats but also include concerns about verbal harassment and other forms of social intimidation.

To address these barriers, urban planners and transportation authorities must focus on creating safer, more secure environments for all commuters, especially women. This can include better lighting around metro stations, installing surveillance cameras, improving the visibility of police or security personnel, and ensuring that first/last-mile modes of transportation, such as shared mobility services, are equipped with safety features like tracking and panic buttons. Moreover, promoting gender-sensitive urban design, such as incorporating well-lit pedestrian paths and providing safe spaces for waiting or parking, can help alleviate these concerns.

4.2 Commuter Satisfaction And Preferences

Commuter satisfaction plays a key role in determining the effectiveness of last-mile connectivity. A commuter's experience during the last mile can influence their decision to use public transportation in the future, as dissatisfaction with the last segment of the journey may deter them from choosing metro systems for their overall commute. Braun et al. (2022) and Park et al. (2021) highlight that commuter satisfaction is closely linked to factors such as convenience, reliability, comfort, and accessibility. In areas where pedestrian infrastructure is inadequate, shared mobility services are unreliable, or transitions between transport modes are inefficient, commuter satisfaction tends to be low.

Suburban commuters, in particular, face challenges in accessing metro stations due to long walking distances, poor road conditions, and a lack of alternative transport options. These barriers often lead to frustration, delays, and discomfort, which ultimately reduce the appeal of public transit. Park et al. (2021) found that the built environment around metro stations, including the availability of benches, shade, and shelter, significantly impacts commuter loyalty and overall satisfaction.

To enhance commuter satisfaction, cities need to prioritize the development of user-friendly last-mile solutions that cater to the needs and preferences of diverse commuters. This includes ensuring easy access to shared mobility services, improving pedestrian infrastructure, and providing amenities such as seating, shade, and clear signage around metro stations. Additionally, offering affordable, efficient, and well-maintained options for the last mile can improve the overall commuting experience, encouraging more people to use public transportation.

4.3 Social Equity And Access To Last-Mile Solutions

Social equity is another important consideration in the context of LMC. In many cities, access to efficient last-mile solutions is often unequal, with low-income and marginalized communities facing greater challenges in accessing public transit systems. These communities are frequently located in areas where metro stations are less accessible, and they may lack the financial means to use shared mobility services such as bike-sharing or ride-hailing. This results in a significant mobility gap, where certain groups are disproportionately affected by poor last-mile connectivity.

Ranjan and Kumar (2024) argue that addressing last-mile connectivity in urban transportation networks requires a focus on ensuring equitable access to transportation options for all socio-economic groups. Low-income neighborhoods often lack the infrastructure and investment needed to provide effective last-mile solutions, such as well-maintained sidewalks, affordable bike-sharing services, or reliable bus connections. As a result, residents of these areas may face longer, more difficult commutes, further exacerbating social inequality.

In addition, the digital divide can create barriers to accessing shared mobility services, many of which require the use of smartphones, apps, or digital payment systems. For individuals without access to these technologies, especially in lower-income areas, shared mobility options may be inaccessible. To promote social equity in last-mile connectivity, cities need to invest in infrastructure and services that cater to the needs of underserved populations, such as affordable transportation options, subsidies for shared mobility services, and physical infrastructure improvements in low-income areas.

4.4 Cultural Attitudes Toward Mobility

Cultural attitudes and norms also shape the way people approach last-mile connectivity. In many societies, private vehicle ownership is seen as a symbol of status and convenience, making it difficult to encourage the use of public transportation and shared mobility services. For example, in some cities, cultural preferences for private cars over shared modes of transport result in lower adoption rates of bike-sharing programs, e-scooters, or public buses for last-mile travel. This cultural barrier is particularly strong in car-dependent societies, where public transportation is often perceived as less reliable, less convenient, or only for low-income individuals.

Chidambara (2016) and Liu et al. (2022) argue that cultural attitudes towards cycling and walking also affect the success of last-mile solutions. In some regions, cycling may be seen as an undesirable or impractical mode of transport, particularly in countries where hot climates, pollution, or traffic conditions make it difficult to cycle. Similarly, walking long distances to or from metro stations may be culturally discouraged, especially in regions where pedestrian infrastructure is inadequate or where walking is not seen as a viable commuting option.

To overcome these cultural barriers, cities need to invest in public awareness campaigns that promote the benefits of public transportation and shared mobility services. Education programs can help change perceptions by emphasizing the convenience, cost savings, and environmental benefits of using public transit for last-mile connectivity. Additionally, cities can incentivize the use of shared mobility options through subsidies, discounts, or loyalty programs that make these services more attractive to commuters.

4.5 Behavioral Patterns And Resistance To Change

Resistance to changing mobility habits is a common behavioral barrier to improving last-mile connectivity. Many commuters are accustomed to using private vehicles or traditional transport methods, and they may be reluctant to switch to new, more sustainable modes of transport for the last mile. Even when shared mobility services, bike-sharing programs, or public transport improvements are introduced, there can be a significant lag in adoption due to ingrained habits, convenience factors, or perceived barriers to switching.

Hess (2012) found that older adults, in particular, may be resistant to changing their commuting patterns, preferring to use private vehicles or avoid public transport due to concerns about accessibility or safety. Similarly, commuters who are accustomed to driving may find it difficult to adjust to multimodal transport systems that require more complex trip planning, switching between modes, or walking longer distances.

To encourage behavioral change, transportation planners need to focus on making last-mile solutions as convenient and user-friendly as possible. This includes simplifying access to shared mobility services, reducing waiting times for transfers, and providing clear, accessible information about transit options. Additionally, introducing incentives for public transport use, such as discounted fares for multimodal trips or subsidies for bike-sharing, can help overcome resistance to change and encourage more people to adopt sustainable last-mile solutions.

5. ENVIRONMENTAL AND POLICY BARRIERS

Environmental sustainability and policy frameworks are integral to the success of last-mile connectivity (LMC) initiatives. However, barriers related to environmental impacts, regulatory policies, and governance often impede the effective implementation of LMC solutions. These challenges include the lack of coordinated environmental policies, the need for regulatory frameworks to support new transportation technologies, and the complexities of urban planning policies that limit sustainable development. This section explores the environmental and policy-related barriers to last-mile connectivity and highlights the necessary steps to overcome them.

5.1 Environmental Impact Of Last-Mile Connectivity Solutions

As cities strive to reduce their carbon footprint and promote sustainable urban mobility, the environmental impact of last-mile connectivity solutions becomes a critical factor. Many LMC solutions, including the use of electric vehicles (EVs), shared mobility services, and non-motorized transport (NMT), offer potential environmental benefits, such as reducing greenhouse gas emissions and improving air quality. However, implementing these solutions on a large scale faces several environmental barriers.

One of the main challenges is the insufficient infrastructure for electric vehicles and other low-emission transport options. Kumar and Roy (2019) highlight that although e-rickshaws in Delhi provide a sustainable alternative for last-mile connectivity, the lack of charging stations and maintenance infrastructure limits their effectiveness. Similarly, the deployment of electric bikes and scooters is often hampered by inadequate charging facilities and the environmental costs associated with battery production and disposal.

Additionally, shared mobility solutions, while environmentally beneficial in theory, may not always lead to reduced emissions in practice. If these services are not well-coordinated with public transport, they can increase congestion and contribute to emissions. Dupont (2022) notes that the environmental benefits of first- and last-mile solutions depend heavily on their integration with public transportation systems. When poorly integrated, shared mobility services can encourage more trips in personal vehicles, exacerbating traffic congestion and negating their potential environmental advantages.

Moreover, NMT options such as cycling and walking, which have minimal environmental impact, are often underutilized due to poor infrastructure, making it difficult for cities to promote greener last-mile solutions. To address these barriers, cities need to invest in the development of green infrastructure, such as electric vehicle charging stations, secure bike parking, and expanded pedestrian zones, while ensuring that these modes are well-integrated with public transport systems.

5.2 Policy And Regulatory Barriers

Policy frameworks play a critical role in determining the success of last-mile connectivity solutions. However, regulatory barriers often hinder the adoption of innovative and sustainable LMC strategies. For example, many cities lack cohesive policies to support the integration of emerging technologies, such as autonomous vehicles (AVs), electric vehicles, and shared mobility services, into public transportation systems.

The introduction of AVs, drones, and other autonomous technologies has the potential to revolutionize last-mile delivery and passenger transport. However, Moradi et al. (2024) point out that regulatory frameworks for AVs are often underdeveloped, particularly in urban environments. Strict regulations around safety, insurance, and liability slow down the deployment of these technologies. Governments face challenges in keeping up with the pace of technological advancements, and the lack of standardized regulations creates uncertainty for companies looking to invest in AV-based LMC solutions.

Similarly, policies that promote electric vehicles are often inconsistent or insufficient to encourage widespread adoption. Andrei et al. (2024) argue that while there are efforts to promote sustainable practices in transportation, the lack of coordinated policy support—such as subsidies, incentives for EV purchase, and robust infrastructure development—prevents the mass adoption of electric vehicles for last-mile travel. Without supportive policies that incentivize the transition to electric vehicles and ensure that public transportation is accessible, many cities struggle to shift to more sustainable LMC solutions.

Additionally, zoning regulations and urban planning policies frequently present obstacles to last-mile connectivity. Zhang et al. (2016) emphasize that urban zoning laws often prioritize automobile infrastructure over pedestrian or bike-friendly designs, making it difficult to implement sustainable LMC solutions. Transit-oriented development (TOD) strategies, which encourage high-density, mixed-use development around metro stations, are often constrained by outdated zoning laws that limit land use diversity. Ibraeva et al. (2020) note that in many cities, a lack of policy coordination between transportation authorities and urban planners results in disjointed development that fails to promote integrated LMC systems.

5.3 Governance And Coordination Challenges

A key policy-related barrier to improving last-mile connectivity is the fragmentation of governance structures responsible for urban transport planning. In many cities, transportation systems are managed by multiple agencies with different priorities and goals, making it difficult to coordinate policies and initiatives aimed at improving LMC. Cirianni et al. (2023) point out that mobility control centers (MCCs), which aim to manage urban mobility through the use of integrated technologies, are often hindered by a lack of cooperation between local, regional, and national transport authorities. This lack of coordination results in inefficient decision-making and delays in the implementation of LMC projects.

Furthermore, there is often a disconnect between public and private sector stakeholders involved in transportation planning. Shared mobility services, such as ride-hailing and bike-sharing programs, are typically operated by private companies, while public transportation is managed by government agencies. The lack of a unified governance framework that can effectively integrate these services creates barriers to developing a seamless last-mile connectivity solution. Gutierrez-Franco et al. (2021) argue that a more collaborative approach between public and private actors is needed to overcome these governance challenges and ensure that LMC systems are efficient, affordable, and environmentally sustainable.

In addition, political barriers frequently impede the long-term planning and investment needed to develop sustainable LMC systems. In many cities, transportation policies are shaped by short-term political interests, which often prioritize road expansion or vehicle-centric infrastructure over investments in public transportation or NMT solutions. Dupont (2022) points out that shifting these priorities requires sustained political will, public engagement, and a long-term commitment to sustainable urban mobility planning. Without this commitment, many cities remain locked into unsustainable transportation models that prioritize private vehicle use over public transit and last-mile solutions.

5.4 Sustainability And Urban Freight Integration

Urban freight plays an increasingly important role in last-mile connectivity, particularly as e-commerce and on-demand delivery services grow. However, integrating urban freight with passenger transportation systems presents several environmental and policy challenges. El Amrani et al. (2024) highlight that while urban freight delivery can be more sustainable when integrated with public transportation, there are few policies in place to facilitate this integration. Freight vehicles often compete with passenger transport for road space, increasing congestion and emissions during peak hours.

Additionally, the use of sustainable freight transport options, such as electric delivery vehicles or cargo bikes, is hindered by regulatory barriers that restrict their use in certain urban areas. Ridaoui et al. (2024) note that policies aimed at reducing emissions from freight transport, such as low-emission zones or congestion pricing, are often implemented without consideration for their impact on last-mile logistics. As a result, freight operators may face higher costs or restricted access to key areas, making it difficult to adopt more sustainable delivery practices.

To address these barriers, cities need to develop policies that encourage the integration of urban freight with public transport networks, such as by allowing shared use of bus lanes for freight vehicles or creating dedicated delivery hubs near metro stations. Moreover, governments can incentivize the use of low-emission vehicles for freight transport by offering subsidies, tax breaks, or preferential access to key urban areas for electric delivery vehicles and cargo bikes.

5.5 Policy Frameworks For Sustainable Mobility

The transition to sustainable last-mile connectivity solutions requires comprehensive policy frameworks that promote environmental sustainability, public transportation, and non-motorized transport. Andrei et al. (2024) emphasize the importance of policies that support the adoption of sustainable practices in transportation, including investment in green infrastructure, subsidies for electric vehicles, and incentives for using shared mobility services. However, many cities lack cohesive policy frameworks that prioritize sustainable urban mobility.

In cities where environmental policies are in place, they are often not fully integrated with transportation planning. For example, cities may implement policies aimed at reducing emissions, such as congestion pricing or low-emission zones, but fail to provide adequate public transportation or last-mile solutions for commuters who are discouraged from driving. This lack of policy alignment creates a disconnect between environmental goals and transportation realities, limiting the effectiveness of sustainability initiatives.

To overcome these policy barriers, cities need to adopt a holistic approach to transportation planning that integrates environmental, social, and economic goals. This includes aligning public transportation policies with environmental sustainability initiatives, promoting transit-oriented development, and creating incentives for the use of low-emission and non-motorized transport options. Furthermore, governments must ensure that policies supporting sustainable mobility are backed by sufficient investment in infrastructure, such as electric vehicle charging stations, cycling networks, and pedestrian-friendly urban design.

6. LOGISTICS AND OPERATIONAL BARRIERS

Effective last-mile connectivity (LMC) requires seamless coordination between various transportation modes, urban logistics, and operational frameworks. However, logistical and operational barriers often hinder the efficiency of last-mile systems, leading to delays, increased costs, and commuter dissatisfaction. These challenges are compounded by urban congestion, limited integration of transportation networks, inefficient routing systems, and the complexities of coordinating freight and passenger transport in dense urban environments. This section examines the key logistics and operational barriers to LMC, focusing on urban congestion, the integration of multimodal transportation systems, last-mile delivery challenges, and coordination issues between public and private sector players.

6.1 Urban Congestion And Traffic Management

One of the primary logistical barriers to last-mile connectivity is urban congestion. In many cities, traffic congestion creates significant delays and inefficiencies for both passenger transport and last-mile delivery services. Urban areas often experience high levels of vehicle congestion during peak hours, making it difficult for shared mobility services, public transportation, and freight vehicles to operate efficiently. As a result, the time and cost of last-mile travel increase, reducing the overall effectiveness of public transport systems.

Gutierrez-Franco et al. (2021) point out that traffic congestion significantly affects the timeliness and reliability of last-mile services, especially in areas where road networks are poorly designed or heavily congested. The impact of congestion is particularly acute for shared mobility services, such as ride-hailing or bike-sharing, as these modes rely on the availability of road space to function effectively. Similarly, urban freight delivery is hampered by traffic, leading to longer delivery times and increased emissions as vehicles remain idle in congested areas.

To address this barrier, cities must implement better traffic management systems, including dynamic traffic control, congestion pricing, and dedicated lanes for public transport and last-mile delivery vehicles. The use of intelligent transportation systems (ITS) and real-time data analytics can help optimize traffic flow, reducing delays for last-mile services. Additionally, encouraging the use of non-motorized transport, such as cycling or walking, for short trips can alleviate road congestion and improve overall transportation efficiency.

6.2 Challenges In Multimodal Integration

Seamless integration between different transportation modes is essential for effective last-mile connectivity. However, many cities struggle with the operational challenges of coordinating multimodal transport systems. Makkar (2024) highlights that while Transportation Management Systems (TMS) are designed to integrate multiple modes of transport, such as metro, bus, and bike-sharing systems, the lack of real-time data sharing and communication between these modes leads to inefficiencies and disconnected travel experiences.

The absence of synchronized schedules, limited real-time passenger information, and poorly designed transfer points between different modes of transport create significant obstacles for commuters. Braun et al. (2022) emphasize that suburban commuters, in particular, face difficulties in transitioning between transport modes, as metro stations are often not well connected to bus services or bike-sharing systems. This lack of coordination results in long waiting times and reduces the attractiveness of using public transportation for the entire journey.

To improve multimodal integration, cities need to invest in real-time data sharing platforms that allow different transport providers to coordinate schedules, optimize vehicle routing, and provide commuters with accurate, up-to-date information on transfer options. Additionally, improving the physical infrastructure that links different modes of transport—such as creating convenient, safe transfer points with clear signage—can help streamline the passenger experience and reduce travel time.

6.3 Last-Mile Delivery And Urban Freight Challenges

Urban freight delivery presents unique logistical challenges, particularly in the context of last-mile connectivity. As e-commerce and on-demand delivery services continue to grow, cities are facing increasing pressure to manage the flow of goods in urban environments while minimizing the impact on traffic congestion and emissions. Last-mile delivery is often the most expensive and time-consuming leg of the supply chain, with inefficiencies arising from complex urban layouts, narrow streets, and limited parking or loading zones.

El Amrani et al. (2024) discuss the difficulties of integrating freight delivery with passenger transport systems in urban areas. Freight vehicles must navigate congested city streets, often competing with passenger vehicles and public transport for road space. The lack of designated delivery zones near metro stations or in dense urban areas further complicates the process, leading to delays and increased delivery costs. Furthermore, the growing demand for same-day or on-demand delivery services exacerbates the pressure on urban logistics systems, requiring more frequent trips by delivery vehicles and contributing to congestion.

To address these challenges, cities can implement dedicated delivery hubs or micro-distribution centers near metro stations, allowing for more efficient transfer of goods to final delivery points. Additionally, encouraging the use of environmentally friendly last-mile delivery solutions, such as cargo bikes or electric delivery vehicles, can help reduce the environmental impact of urban freight. Shared use of bus lanes or creating dedicated lanes for delivery vehicles during off-peak hours could further alleviate congestion and improve delivery efficiency.

6.4 Operational Inefficiencies In Shared Mobility

Shared mobility services, such as bike-sharing, e-scooters, and ride-hailing, have the potential to provide effective last-mile solutions, but they often face operational inefficiencies that limit their effectiveness. These inefficiencies include issues related to vehicle availability, maintenance, and coordination with public transport. For instance, Liu et al. (2022) note that bike-sharing programs often struggle with the "rebalancing problem," where bikes are concentrated in low-demand areas while high-demand areas, such as metro stations, suffer from shortages during peak hours. Similarly, e-scooters and ride-hailing services may not be available when needed, particularly during busy commuting times or in underserved areas.

In addition to availability issues, the maintenance of shared mobility vehicles is a major operational challenge. Broken or poorly maintained bikes, e-scooters, and ride-hailing vehicles reduce the attractiveness of these services, leading to a lower adoption rate among commuters. The operational costs of maintaining fleets of shared mobility vehicles, along with the logistics of redistributing them to high-demand areas, create additional barriers to the effective deployment of these services.

To improve the operational efficiency of shared mobility services, cities and service providers must invest in better fleet management systems, leveraging real-time data to monitor vehicle availability, usage patterns, and maintenance needs. Dynamic pricing models that incentivize users to return bikes or scooters to high-demand areas can help solve the rebalancing problem. Additionally, integrating shared mobility services with public transport through a unified platform can encourage commuters to use these services as part of their daily commute, rather than relying on them as standalone solutions.

6.5 Coordination Between Public And Private Sectors

Effective last-mile connectivity often requires collaboration between public transportation authorities and private sector operators of shared mobility, logistics, and delivery services. However, coordination between these sectors is frequently lacking, leading to operational inefficiencies and missed opportunities for integrating services. Gutierrez-Franco et al. (2021) point out that many shared mobility services operate independently of public transportation systems, resulting in fragmented last-mile solutions that fail to fully meet commuter needs.

The lack of collaboration between public transport agencies and private operators also limits the ability to share data and optimize operations. Public transportation systems typically focus on moving large volumes of passengers over longer distances, while private mobility and logistics services address short-distance, last-mile needs. Without effective data sharing and operational coordination, these systems operate in silos, leading to disjointed service offerings and inefficiencies.

To overcome these barriers, cities need to foster public-private partnerships that enable better coordination of last-mile services. For example, cities can create regulatory frameworks that encourage private mobility operators to integrate their services with public transportation systems, allowing for the development of multimodal travel platforms that provide seamless connectivity. Additionally, shared data platforms that provide real-time information on vehicle availability, demand patterns, and traffic conditions can help both public and private operators optimize their services and reduce operational inefficiencies.

6.6 Sustainability In Operations

Sustainability is increasingly becoming a priority in urban transportation planning, but operational barriers often prevent the adoption of more environmentally friendly last-mile solutions. The use of electric vehicles (EVs) for last-mile delivery and shared mobility services can reduce emissions, but the lack of charging infrastructure and the high cost of EVs create operational challenges for cities and service providers. Kumar and Roy (2019) highlight that while e-rickshaws provide a sustainable alternative for last-mile connectivity in cities like Delhi, the lack of charging stations and support infrastructure limits their widespread use.

In addition, the operational costs associated with maintaining fleets of electric delivery vehicles or shared electric bikes and scooters can be prohibitively high, particularly in cities where subsidies or incentives

for sustainable transportation are lacking. These cost barriers, combined with the logistical challenges of operating electric fleets in dense urban areas, slow the adoption of sustainable last-mile solutions.
To overcome these operational barriers, cities need to invest in the development of charging infrastructure and provide financial incentives for the use of electric vehicles in last-mile logistics and shared mobility services. Encouraging the use of renewable energy sources for charging infrastructure can further enhance the sustainability of last-mile operations. Furthermore, promoting the adoption of low-emission delivery options, such as cargo bikes or electric vans, can help reduce the environmental impact of urban logistics while maintaining operational efficiency.

7. CONCLUSION

Effective last-mile connectivity (LMC) to metro stations is essential for the success of urban transportation systems, as it directly impacts commuter satisfaction, accessibility, sustainability, and the overall efficiency of public transit networks. However, numerous barriers—technological, infrastructural, social, environmental, logistical, and operational—impede the implementation of seamless LMC solutions.
Technological barriers, such as limitations in artificial intelligence (AI) deployment, the regulatory challenges of autonomous vehicles, and inadequate intelligent transportation systems (ITS) integration, prevent the full potential of cutting-edge solutions from being realized. Cities must invest in data-sharing frameworks, real-time decision-making tools, and coordinated regulatory policies to overcome these obstacles.
Infrastructural and urban design barriers, including insufficient multimodal integration, poorly maintained pedestrian and cycling paths, and inadequate transit-oriented development (TOD), further complicate LMC efforts. Cities must prioritize the development of pedestrian-friendly environments, robust cycling infrastructure, and integrated multimodal hubs to enhance the user experience and promote sustainable mobility options.
Social and behavioral barriers—such as gender-based safety concerns, commuter preferences, social equity issues, and cultural attitudes toward mobility—also play a crucial role in shaping the effectiveness of LMC solutions. Addressing these barriers requires urban planners and policymakers to focus on creating safe, equitable, and inclusive environments that meet the diverse needs of all commuters.
Environmental and policy barriers hinder the adoption of sustainable LMC solutions, particularly due to the lack of comprehensive policy frameworks, regulatory support for emerging technologies, and inadequate investment in green infrastructure. Coordinated policy efforts, public-private partnerships, and long-term planning are necessary to encourage sustainable last-mile transportation, including the use of electric vehicles (EVs), shared mobility, and non-motorized transport.
Lastly, **logistics and operational barriers**—such as urban congestion, inefficient multimodal coordination, and last-mile delivery challenges—further complicate the implementation of efficient LMC systems. Cities need to invest in traffic management, real-time data analytics, and innovative solutions for urban freight integration to improve the operational efficiency of last-mile services.

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