Scientific Research Publishing

World Journal of Engineering and Technology, 2026, 14(3), 684-703
https://www.scirp.org/journal/wjet
ISSN Online: 2331-4249
ISSN Print: 2331-4222

Delivery of the Future: How the First-Mile, Last-Mile Problem Can Be Approached around the World

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How to cite this paper: Jardine, N., Brown, J., Perri, J., Baronsky, L., Honey, O. and Faghri, A. (2026) Delivery of the Future: How the First-Mile, Last-Mile Problem Can Be Approached around the World. *World Journal of Engineering and Technology*, **14**, 684-703.
https://doi.org/10.4236/wjet.2026.143043

Received: June 19, 2026
Accepted: August 25, 2026
Published: August 28, 2026

Abstract

The first-mile/last-mile (FMLM) problem has quickly emerged as one of the most significant transportation and logistics challenges facing modern urban environments. The final stage of passenger transportation and freight delivery is often the most inefficient, costly, and operationally complex portion of the transportation network. Growing e-commerce demand, increasing urban congestion, automobile dependency, and disconnected multimodal infrastructure have intensified the need for more effective FMLM solutions. This paper evaluates international approaches to addressing FMLM transportation challenges and examines how these strategies may be applied in the United States, specifically in Wilmington, Delaware. The research begins by analyzing global transportation and logistics systems that have successfully improved FMLM connectivity. China serves as a major case study due to its advanced last-mile logistics network, including decentralized parcel distribution centers, parcel locker systems, micro-delivery vehicles, autonomous delivery technologies, and third-party logistics integration. These systems have significantly reduced delivery inefficiencies while improving convenience for consumers. The paper also examines Amazon's integrated logistics and fulfillment network within the United States, highlighting how data analytics, artificial intelligence, route optimization, and strategically located distribution centers improve delivery performance and operational efficiency. In addition to freight-focused case studies, the paper investigates international multimodal transportation systems in countries such as the Netherlands, the United Kingdom, Japan, and Singapore. These countries emphasize context-sensitive roadway geometric design, protected bicycle infrastructure, transit-oriented development, curbside management, pedestrian accessibility, and integrated mobility systems. Unlike many automobile-oriented transportation systems within the United States, these international examples prioritize multimodal accessibility and coordinated transportation planning. The paper compares these international systems with current U.S. transportation practices, identifying key differences in roadway design philosophy, land-use integration, curbside allocation, and multimodal connectivity. A localized application of these concepts is then proposed for Wilmington, Delaware. The proposed recommendations include implementing micro-mobility hubs near the Wilmington Riverfront, smart parcel locker systems, protected bicycle lanes, pedestrian refuge islands, and expanded on-demand microtransit services based on the DART Connect model. These recommendations align with AASHTO geometric design principles and the Delaware State Freight Plan while addressing local congestion, accessibility, and multimodal transportation challenges. Finally, the paper explores future trends in FMLM transportation, including autonomous delivery systems, electric micro-mobility, Mobility-as-a-Service (MaaS), smart logistics platforms, and integrated transportation technologies. The findings of this study indicate that successful FMLM systems require coordinated infrastructure planning, multimodal transportation integration, advanced logistics technology, and context-sensitive roadway design. While differences in geography, density, and transportation culture may limit direct replication of international systems within the United States, the research concludes that many international strategies can significantly improve transportation accessibility, operational efficiency, sustainability, and overall mobility when adapted appropriately to local conditions.

Keywords

First-Mile/Last-Mile, Urban Freight, Multimodal Transportation, Last-Mile Delivery, Logistics Systems, Micro-Mobility

1. Introduction

Transportation systems all around the world face many complex challenges, including roadways, pedestrians, transit, and many more. While many issues need to be addressed, this paper focuses specifically on the FMLM problem. The FMLM refers to the current inefficient processes of the initial and final stages of transportation and delivery. This paper focuses on the last-mile aspect of the issue. Last-mile is most often seen as the final stage of a package's delivery to your door, or the final stage of transportation, when a person goes home. The last-mile portion is the most problematic because the final stage of freight delivery is energy-intensive and quite costly. The last mile can account for up to 41% of total supply chain costs [1]. The global market for last-mile delivery greatly reflects this statistic, growing from $184.2 billion in 2025 to a projected $277.76 billion in 2030 at a growth rate of roughly 8.6% [2].

In this paper, FMLM is treated as two distinct but related issues. The issues include passenger FMLM, which addresses how travelers reach and leave fixed-route transit stations, and freight FMLM, which addresses how packages move from a distribution center to the address of the individual who ordered them. The two case studies in Sections 3 and 4, involving Amazon and China, focus on freight FMLM and are evaluated based on delivery costs, delivery speed, and the overall delivery network. The international comparison in Section 6 and the transit component of the Wilmington, DE recommendations focus on passenger FMLM and are evaluated based on access, waiting times, and connectivity.

This paper discusses two international cases where a last-mile solution was successfully implemented to reduce costs and improve delivery efficiency. The first case study focuses on China, which has developed one of the most advanced systems in the world through decentralized distribution centers, parcel locker networks, micro-delivery vehicles, and other implementations. The second case study focuses on Amazon and its freight and delivery network. Amazon uses AI, real-time route optimization, and other technologies that are still growing to achieve its fast delivery speeds. Building on international and domestic cases, this paper proposes first- and last-mile solutions for Wilmington, DE, a local community facing many transportation and delivery challenges. Finally, this paper will compare the proposed solutions with those of other international strategies, such as those from the Netherlands, Japan, Singapore, and the United Kingdom.

2. Methodology

This research uses a comparative case study approach to examine how different countries and transportation systems address FMLM challenges. The purpose of the study is to identify successful international strategies for freight movement, multimodal transportation, and logistics efficiency, and to evaluate how these strategies could be adapted in the United States, specifically in Wilmington, Delaware. The research process began with a review of academic articles, transportation reports, freight planning documents, and logistics case studies on first- and last-mile transportation systems. Sources were selected based on their relevance to transportation engineering, urban planning, roadway design, logistics optimization, and multimodal accessibility. Particular attention was given to studies involving congestion reduction, delivery efficiency, public transportation accessibility, and emerging transportation technologies.

The sources used in this paper were found through a targeted search using academic databases (Google Scholar, Science Direct) and transportation agency publications. To find the correct information, searching terms included "first-mile last-mile", "last-mile logistics", "microtransit", and "parcel locker delivery" in addition to relevant country or company names. Case studies were selected based on three criteria. The first was documented outcomes (costs, wait times, or ridership data), followed by relevance to either freight or passenger FMLM, and applicability to a U.S city context. Some sources without verifiable data or clear methodology, such as a general industry blog post, were only used for background information and not for quantitative data.

A major focus of the research was analyzing international transportation systems that have demonstrated success in improving first- and last-mile connectivity. China was selected as one of the primary case studies because of its advanced e-commerce and logistics infrastructure. Research focused on parcel locker systems, decentralized distribution centers, crowdsourced delivery systems, third-party logistics providers, and micro-delivery technologies such as drones and autonomous delivery vehicles. These systems were examined to better understand how they reduce delivery costs, improve efficiency, and handle extremely high parcel volumes within dense urban areas.

The study also evaluated Amazon's integrated logistics network within the United States. Amazon was selected because of its highly optimized fulfillment and delivery system, which combines data analytics, artificial intelligence, route optimization, and strategically located fulfillment centers to improve delivery performance. Research related to Amazon focused on how advanced logistics planning and technology-driven operations improve efficiency across the entire supply chain, especially during the final delivery stage. The study also examined how machine learning, real-time routing systems, and automation technologies are reshaping modern freight operations.

In addition to freight systems, the research analyzed international multimodal transportation strategies from countries such as the Netherlands, Singapore, Japan, and the United Kingdom. These transportation systems were selected because they prioritize walking, cycling, public transit accessibility, and integrated land-use planning more than many automobile-oriented systems in the United States. Research focused on roadway geometric design, protected bicycle infrastructure, curbside management, pedestrian safety improvements, transit-oriented development, and multimodal network integration. These international systems were then compared to current transportation conditions commonly found throughout the United States.

After examining the international case studies, the research shifted toward developing localized recommendations for Wilmington, Delaware. Wilmington was selected because it faces many of the same transportation challenges as smaller American cities, including roadway congestion, automobile dependency, gaps in multimodal connectivity, and limited first- and last-mile transit accessibility. Existing transportation conditions and planning resources were reviewed using documents such as the Delaware State Freight Plan, WILMAPCO congestion management resources, and DART Connect planning information.

Based on the international findings, several conceptual transportation improvements were proposed for Wilmington. These recommendations include smart parcel locker systems, protected bicycle lanes, pedestrian refuge islands, micromobility hubs, and expanded on-demand microtransit services. Proposed roadway and infrastructure concepts were evaluated using AASHTO geometric design principles and Complete Streets design strategies to ensure consistency with accepted transportation engineering standards. The research also examined future trends in first- and last-mile transportation, including autonomous delivery systems, electric micromobility, Mobility-as-a-Service (MaaS), and smart logistics technologies. These emerging systems were analyzed to better understand how transportation agencies and cities may need to adapt their infrastructure and transportation policies to meet changing mobility demands.

Overall, this methodology combines transportation engineering analysis, international comparisons, logistics research, and localized planning strategies to better understand how first- and last-mile transportation systems can become more efficient, accessible, and sustainable.

3. Case Study 1: China

China has established itself as the global leader in solutions for the last-mile problem. China's large population size has made this a crucial problem to solve within the country. China has put many different things in place to address this problem, including decentralized service centers, micro-delivery vehicles, and parcel lockers. There have also been many third-party logistics providers that have stepped up to help facilitate different methods of delivery. Tracking technology has been implemented for the convenience of users to be able to find where their package has gone in order to streamline delivery and pickup. Overall, China's approach to the last-mile problem positions it ahead of most nations, as the following sections highlight.

One of the solutions that has been put in place by China is decentralized service centers. This is where there are many small distribution centers and places for people to pick up their packages, rather than one giant warehouse where everything is taken directly to someone's door. The use of convenience stores for this has been a big thing in China. The owners of small convenience stores and other businesses have been allowing their stores to be used as distribution centers, in return for per-parcel subsidies and other bonuses. This allows drivers to only deliver to one place rather than many different locations, which saves gas and labor costs and is still close enough to people's homes to be convenient for pickup.

The next solution implemented in China is the use of micro-delivery vehicles. In practice, micro-delivery in China includes both drone and robot delivery systems. Instead of having truck drivers deliver packages by hand, China has employed the use of drones to drop packages on people's doorsteps. This model reduces labor costs because they are eliminating the need for human drivers. It is also faster, and the only costs are the costs of operating the drones themselves. Another related innovation is the use of crowd-delivery formats. In the US, we have services like Uber Eats, where an independent person accepts a delivery and delivers it, rather than using mass delivery through individual restaurants. This has been used in China as a delivery system for packages. This has taken a lot of pressure off of delivery drivers and has allowed another form of income for a lot of Chinese people who are available to deliver packages.

Finally, there is the use of parcel lockers. Parcel lockers have popped up in many places in the US, mostly for Amazon, but they are much more common and mainstream in China. There are parcel lockers everywhere, in local stores, community centers, and more. People find these parcel lockers very convenient because they can choose which locker they want their package to be delivered to, and they can incorporate picking it up into their daily schedule as they do other things. The lockers allow delivery drivers to make much fewer stops, leading to lower costs. These are also super useful in rural and agricultural areas where individual delivery is a logistical nightmare. China's newly integrated smart locker infrastructure has grown significantly, with Hive Box alone operating over 1 million lockers nationwide. It is estimated that smart lockers handle 15% to 20% of urban e-commerce deliveries in major Chinese cities. The adoption of smart lockers in major cities is predicted to reach 25% in the coming years [3].

Another major factor in China's last-mile system is its network of logistics companies. Yunda, ZTO, and STO are express delivery carriers; they physically deliver the parcels generated by e-commerce marketplaces such as Taobao, JD.com, and Pinduoduo. Together, these carriers make up the majority of China's delivery infrastructure. Software platforms like Cainiao are used to control this volume and assist established companies in streamlining their deliveries. Companies like Kuaidi provide additional delivery and logistics services. The combination of these companies handles the high volume from e-commerce demand, with over 174.5 billion parcels delivered in 2024, representing a 21% year-over-year increase [4].

China's parcel delivery market has seen a fall in prices to roughly 7.5 to 8 yuan (approximately \$1.05 to \$1.10) per parcel as of 2024-2025, driven by competition among carriers and cost efficiencies from locker-based delivery [5]. For comparison, a 2026 survey found that the average U.S. grocery retailer's last-mile delivery cost is roughly \$10.10 per order; however, Amazon's cost is only \$4 per package [6]. Even though these figures cannot be compared directly, they highlight a substantial cost gap that displays the need for further country-specific research.

With its logistics companies, parcel stations, decentralized stations, and micro-delivery vehicles, China has built one of the world's highest-volume last-mile delivery systems, handling over 174 billion parcels in 2024 alone. This has been made possible by a high urban population and a highly developed locker infrastructure that reduces the number of delivery stops. The delivery services in China are top-notch, along with their lower per-parcel costs. The specific mechanisms from China, such as its locker system and logistics systems, offer many ways for other international systems to learn from its systems, including U.S. cities.

4. Case Study 2: Amazon

One of the most advanced first- and last-mile logistics systems currently operating in the United States is Amazon's integrated freight and delivery network. As e-commerce demand has grown substantially over the past decade, Amazon has continuously expanded its transportation infrastructure to deliver to customers faster and more reliably. Unlike traditional supply chains that rely heavily on third-party carriers, Amazon has developed a highly coordinated system that integrates fulfillment centers, regional distribution hubs, transportation fleets, and last-mile delivery operations into a single network. Amazon's logistics system operates through three major stages: fulfillment, distribution, and final delivery. Fulfillment centers are strategically located near major population centers to reduce transportation distances, improve responsiveness to customer demand, and support same-day and next-day delivery. Packages are then transferred through regional distribution facilities before reaching local delivery stations, which handle the final stage of delivery to customers. This integrated structure allows Amazon to manage extremely large package volumes while maintaining fast delivery schedules and reducing operational inefficiencies throughout the supply chain.

A major reason for Amazon's success is its heavy use of technology, data analytics, and advanced routing systems. The company uses artificial intelligence, machine learning, and real-time logistics data to improve delivery efficiency and reduce transportation costs. Rather than relying on fixed delivery routes or manual planning systems, Amazon continuously analyzes roadway congestion, package locations, customer demand, travel times, and delivery density to optimize delivery operations. Research has shown that last-mile delivery is one of the most expensive and operationally difficult portions of the supply chain due to fragmented delivery patterns, low drop density, and increasing congestion within urban environments [7]. To address these challenges, Amazon Web Services developed the Dynamic Delivery Planner, a routing system that can make real-time route adjustments based on changing roadway and delivery conditions. This technology improves delivery flexibility while maximizing driver productivity and reducing delays. Amazon also uses flexible delivery methods such as third-party logistics providers and crowdsourced drivers through programs like Amazon Flex, allowing the company to quickly respond to periods of high delivery demand without relying entirely on permanent fleets. In addition, Amazon has invested heavily in automation and robotics within fulfillment operations to increase processing speed and reduce human error.

Amazon's performance data showed real results due to the newly integrated approach. In 2025, Amazon delivered over 13 billion items globally from its same-day or next-day shipping, with 8 billion being from the United States. This represents a 30% year-over-year increase and the fastest delivery speeds Amazon has ever recorded [8]. The same-day delivery grid has expanded by 60% to 140+ metro areas, which has been driven by the use of AI, robots, and other emerging technologies that have reduced shipping distances by 10% [9]. Amazon invested around $4 billion in 2025 to increase its next-day and same-day deliveries to 4000 smaller cities, towns, and rural communities, greatly increasing Amazon's coverage [10]. Amazon is also scaling its Prime Air drone program, intending to reach 30 million customers by the end of 2026 and 500 million packages annually by the end of the decade in under 30 minutes [11]. These figures show that the future of last-mile delivery will be faster than we can imagine.

Overall, Amazon's logistics network demonstrates how integrated infrastructure planning, advanced technology, and data-driven operations can significantly improve modern freight transportation systems while highlighting the growing importance of efficient last-mile delivery within urban transportation networks.

5. Solutions for a Local Community

To effectively address the FMLM challenges within a localized context, a comprehensive strategy has been developed for Wilmington, Delaware. Unique FMLM solutions must be proposed for Wilmington due to its regional freight hub status and large transportation gaps. More than 68 million tons of freight move through Delaware annually [12], with the Port of Wilmington being a key aspect of the cargo distribution. This freight intensity places a large amount of pressure on Wilmington's transportation, contributing to road congestion and overall FMLM inefficiencies that the proposed solutions address. A fundamental aspect of this strategic alignment is ensuring that all project goals align with the 2026 Delaware State Freight Plan Update, which was created by DelDOT in partnership with WILMAPCO on July 1, 2025, and the plan is expected to be completed by December 2026 [13]. This plan was developed alongside the Infrastructure and Jobs Act requirements under 49 U.S.C. §70202. By anchoring the localized FMLM solutions within this statewide framework, the proposed interventions can deliver scalable, sustainable improvements for the community.

5.1. Micro-Mobility and Freight Mitigation

The first set of solutions focuses on micro-mobility and freight mitigation, specifically targeting the Riverfront District. Drafting has been initiated for the placement of Micro-mobility Hubs situated at the Wilmington Riverfront. The primary objective of these hubs is to address the last-mile gap experienced by commuters who arrive via the Wilmington Transit Center. By providing accessible micro-mobility options directly at transit terminals, commuters can seamlessly complete the final leg of their journey.

Furthermore, the mitigation of freight-related congestion is being addressed through a developing proposal for Smart-Locker Delivery Systems. These systems are intended to centralize parcel drops in highly trafficked areas. The implementation of centralized lockers aims to reduce the total volume of delivery vans operating in the area, thereby curbing local street congestion. To ensure these systems are placed optimally, the WILMAPCO Congestion Management Process will be used as a reference to supply necessary data on current regional congestion hotspots [14]. This placement strategy is highly backed by research, finding that high-density and mixed-use areas have the best parcel locker performance in terms of utilization and convenience [15].

5.2. Infrastructure and Geometric Design

Physical infrastructure improvements are required to support these multimodal shifts, bringing the focus of infrastructure and geometric design to Walnut and

King Streets. The proposed changes involve applying the AASHTO Green Book (Chapter 3) standards to design Complete Street modifications. These modifications will specifically focus on the integration of protected bike lanes alongside pedestrian refuge islands to enhance safety for non-motorized users.

A critical technical detail of this redesign is the implementation of pedestrian refuge islands with a minimum width of 6 feet. Ideally, these refuge islands should be expanded to 8 to 10 feet to adequately accommodate bicycles and scooters [16]. Adhering to these dimensions, as per AASHTO and ADA guidelines, is essential to ensure safe multi-stage crossings for all pedestrians and micro-mobility users. To guide the practical application of these designs, the DelDOT Washington Street Separated Bike Lane Project will be utilized as a local benchmark for separate bike facility implementation [17].

5.3. On-Demand Transit Integration

The final component of the local community strategy involves integrating on-demand transit. This requires analyzing the scalability of the existing DART Connect on-demand micro-transit model specifically for Wilmington's urban core. The DART Connect pilot has already successfully demonstrated the utility of 16-passenger vehicles for providing flexible, app-based routing throughout lower-density areas of Delaware [18]. Microtransit will continue to consistently reduce passenger wait times compared to fixed-route services.

Drawing on the success of that model, the overarching goal is to propose a similar pilot program for Wilmington. This localized pilot would serve to bridge the persistent gap between fixed-route bus stops and the final residential destinations of transit users. To structure this proposal effectively, the DART Connect Microtransit Launch Details will be referenced as a foundational guide for deployment.

6. Comparison of International Suggestions

In comparison to many international transportation systems (**Figure 1**), the United States remains heavily automobile-dependent. Roadway geometric design standards frequently prioritize high-speed vehicle travel and roadway capacity over multimodal accessibility. Wide travel lanes, large curb radii, expansive parking facilities, and low-density land use patterns often create barriers for pedestrians, cyclists, and transit users. Many U.S. transit systems additionally struggle with disconnected street networks and poor pedestrian infrastructure. Sidewalk gaps, unsafe intersections, and limited bicycle facilities reduce the practicality of walking or cycling to transit stations. As a result, transit users frequently rely on park-and-ride systems or personal vehicles to complete their FMLM trips.

International transportation systems demonstrate that improving multimodal accessibility requires coordinated infrastructure planning rather than isolated transportation projects. Countries such as the Netherlands and Japan integrate transportation planning with land use policy to reduce travel distances and encourage alternative transportation modes. Similarly, China and Singapore demonstrate how technology and logistics innovation can improve transportation efficiency. Another major difference is the prioritization of vulnerable roadway users. International roadway designs often emphasize pedestrian safety through narrower lanes, lower design speeds, protected bicycle facilities, and improved crossing infrastructure. In contrast, many U.S. roadways continue to prioritize vehicle throughput even in urban environments with significant pedestrian activity. The United States has begun adopting some international transportation practices through Complete Streets policies, protected bicycle lanes, and transit-oriented development initiatives. Organizations such as NACTO and the Federal Highway Administration have also promoted multimodal design guidance that more closely aligns with international standards. However, implementation remains inconsistent across many communities.

	China	Amazon (U.S)	Netherlands/Japan/Singapore
FMLM Focus	Freight	Freight	Passenger
Mechanisms	Decentralized parcel lockers, micro-delivery vehicles, logistics networks	AI route optimization, delivery planning, investments into drones and robots	Bike infrastructure, transit land use, curbside management
Delivery/Ridership	174.5 billion parcels in 2024, 21% year-over-year increase [4]	13 billion same/next-day items in 2025, 30% year-over-year increase [8]	N/A, passenger FMLM not freight
Locker Pickup Points	Lockers handle 15% - 20% of urban e-commerce deliveries, projected to reach 25% [3]	N/A, no comparable locker figure	N/A
Same-Day Coverage	No comparison in selected sources	Same-day delivery grid expanded 60%, covering 140+ metro areas [9]	N/A
Costs	Average parcel price is 7.5 - 8 yuan ($1.11 - $1.18) in 2024-2025 [5]	US average last-mile cost is $10/package; however, Amazon pays roughly $4/package [6]	Cost data not collected in sources
Land-Use	High, very dense urban areas makes locker density viable	Low, already working within a low-density delivery network	High, requires heavy land-use integration, not just infrastructure
U.S Feasibility	High for overall use of lockers	Already operating in the U.S	Moderate, would require many policy and zoning changes to make possible, not just infrastructure changes

Note: The China and U.S cost figures are not directly comparable. The China figure represents the average price per parcel, while the U.S figure represents the delivery costs of Amazon. Both figures are included to show pricing.

Figure 1. Comparison table.

A significant difference between international transportation systems and those in the United States is the relationship between land use planning and transportation infrastructure. In many international cities, transportation systems are designed alongside compact mixed-use developments that reduce travel distances and encourage walking, cycling, and transit use. Residential areas, employment centers, retail spaces, and public services are often clustered around major transit stations. This integrated planning approach creates transportation systems where FMLM trips are shorter, safer, and easier to complete without relying on personal vehicles. In contrast, many suburban communities within the United States are characterized by urban sprawl, segregated land uses, and disconnected roadway networks. Large residential subdivisions are frequently separated from employment centers, schools, and shopping areas by high-speed arterial roadways that are difficult for pedestrians and cyclists to navigate safely. As a result, even short-distance trips often require automobile travel. This development pattern creates substantial challenges for implementing effective FMLM transportation systems.

Another major distinction involves roadway geometric design philosophy. International transportation systems increasingly adopt context-sensitive roadway design principles that prioritize safety, accessibility, and multimodal balance rather than maximizing vehicle capacity alone. Narrower lane widths, lower design speeds, raised intersections, traffic calming measures, and protected multimodal infrastructure are commonly used to create safer transportation environments. By comparison, many roadway corridors within the United States continue to emphasize wider lanes, larger curb radii, and higher operating speeds. While these features may improve vehicle throughput in certain contexts, they can negatively impact pedestrian crossing safety, bicycle accessibility, and transit usability. Large intersections with wide crossing distances often discourage walking and increase crash exposure for vulnerable roadway users.

The treatment of curbside space also differs significantly between international systems and many U.S. cities. International urban environments increasingly recognize curb space as a critical transportation asset that must support deliveries, passenger loading, transit access, bicycle parking, and pedestrian movement. Dynamic curbside allocation systems are often used to balance competing transportation demands throughout the day. Within the United States, curbside management is still evolving. Many urban corridors experience operational problems caused by ride-sharing vehicles, delivery trucks, and unauthorized stopping activities blocking travel lanes or bicycle facilities. As e-commerce demand and ride-hailing usage continue to increase, effective curbside management will become increasingly important for maintaining roadway efficiency and safety.

Technology integration is another area where several international systems currently outperform the United States. Singapore and China have invested heavily in real-time mobility platforms, autonomous delivery technologies, and smart logistics systems that improve operational efficiency. Integrated transportation applications allow users to coordinate multiple transportation modes within a single platform, simplifying multimodal trip planning and improving user convenience. The United States has made progress in this area through app-based microtransit systems and ride-sharing services; however, transportation systems often remain fragmented between agencies, operators, and service providers. Greater integration between public transportation, shared mobility services, and logistics operations may significantly improve FMLM connectivity in both urban and suburban environments.

Environmental sustainability also plays a much larger role in many international transportation systems. Countries with advanced multimodal infrastructure often prioritize reducing greenhouse gas emissions, limiting vehicle dependency, and improving air quality through transportation policy. Investments in cycling infrastructure, public transit, and electric delivery systems support broader sustainability goals while simultaneously improving transportation accessibility. The United States continues to face challenges in balancing transportation demand with sustainability objectives. Automobile dependency contributes to roadway congestion, environmental impacts, and increasing infrastructure maintenance costs. International examples demonstrate that multimodal transportation systems can improve mobility while also supporting long-term environmental and economic sustainability.

Ultimately, the comparison between international systems and the United States highlights the importance of coordinated transportation planning, context-sensitive roadway design, multimodal infrastructure integration, and technology-driven mobility solutions. While direct replication may not always be possible due to differences in geography and development patterns, international case studies provide valuable insights into strategies to improve FMLM accessibility and overall transportation system performance.

6.1. Recommendations for the United States

Based on international case studies, several recommendations can be proposed to improve FMLM connectivity within the United States.

One of the most important recommendations for the United States is the adoption of more context-sensitive roadway geometric design standards. Many current roadway design practices prioritize high-speed vehicle operations even in urban environments where pedestrian activity and multimodal transportation demand are significant. Transportation agencies should place greater emphasis on roadway designs that balance mobility, accessibility, and safety for all roadway users.

Reducing excessive lane widths in urban corridors can improve pedestrian crossing safety while naturally lowering vehicle operating speeds. Narrower roadway profiles also create opportunities to incorporate protected bicycle lanes, wider sidewalks, transit lanes, and landscaped pedestrian buffers without requiring substantial right-of-way expansion. International examples demonstrate that these design adjustments can improve multimodal accessibility while maintaining efficient transportation operations.

Protected intersections should also become more common within U.S. roadway networks. International case studies from the Netherlands show that protected intersections significantly reduce conflict points between bicycles and turning vehicles. These designs improve safety for vulnerable roadway users while increasing comfort for cyclists and pedestrians. Implementing protected intersection designs near schools, transit hubs, and commercial districts could improve FMLM accessibility in many American communities.

Another recommendation involves improving transit station accessibility through multimodal integration. Many U.S. transit stations remain heavily automobile-oriented and are surrounded by large parking facilities rather than walkable mixed-use developments. Transportation agencies and local governments should prioritize station-area redevelopment projects that support walking, cycling, and transit connectivity. This may include constructing pedestrian pathways, bicycle parking facilities, micro-mobility hubs, and dedicated curbside pickup areas surrounding transit stations. Integrating commercial and residential development near transit centers would additionally reduce travel distances and support greater transit ridership.

The United States should also expand the use of centralized parcel locker systems and smart logistics hubs to improve urban freight operations. As e-commerce activity continues to increase, traditional door-to-door delivery systems are placing significant pressure on roadway networks and curbside infrastructure. Centralized delivery systems similar to those used in China could reduce neighborhood delivery traffic and improve operational efficiency.

In addition, transportation agencies should begin planning roadway infrastructure that can support emerging delivery technologies such as autonomous delivery robots and electric micro-delivery vehicles. These systems may become increasingly important within dense urban areas where congestion and curbside competition continue to intensify. Curbside management should become a larger priority within transportation planning efforts. International examples demonstrate that curb space can no longer function solely as static parking infrastructure. Instead, curbside areas must support a wide range of transportation activities, including passenger loading, freight deliveries, ride-sharing, transit access, and bicycle parking. Dynamic curbside management systems using real-time monitoring and flexible allocation strategies may significantly improve urban transportation operations. Designating delivery windows, ride-share loading areas, and freight zones would reduce operational conflicts while improving traffic flow and safety.

Another major recommendation is increased investment in pedestrian infrastructure. In many U.S. communities, incomplete sidewalk networks and unsafe crossings discourage walking as a practical FMLM transportation mode. Transportation agencies should prioritize continuous sidewalks, accessible curb ramps, pedestrian refuge islands, and high-visibility crosswalks in areas surrounding schools, transit stations, and commercial centers. Lower urban design speeds should also be considered in areas with high pedestrian activity. International transportation systems consistently demonstrate that lower vehicle speeds improve pedestrian safety and encourage multimodal transportation usage. Traffic calming strategies such as raised intersections, curb extensions, and narrowed travel lanes can significantly improve roadway safety while maintaining acceptable traffic operations.

Technology integration should additionally become a central focus of future transportation planning in the United States. Integrated mobility applications that combine public transit, ride-sharing, bike-sharing, and microtransit services within a single platform would simplify multimodal trip planning for users. Real-time transportation information and payment integration could improve convenience while increasing multimodal transportation usage.

Finally, improving FMLM connectivity within the United States will require stronger coordination between transportation agencies, local governments, land developers, and private mobility providers. International transportation systems often succeed because transportation planning, land use policy, and infrastructure investment are closely coordinated. Adopting similar planning approaches within the United States would improve transportation accessibility, operational efficiency, and long-term sustainability.

6.2. Environmental and Sustainability Benefits of International FMLM Systems

One of the strongest arguments supporting international FMLM systems is their ability to improve environmental sustainability and public health outcomes. According to the European Environment Agency reports, transportation remains one of the largest contributors to greenhouse gas emissions, air pollution, and urban congestion throughout Europe. The report emphasizes that improving FMLM connectivity is essential for reducing automobile dependency and encouraging greater use of public transportation, walking, and cycling. The study further explains that cities with strong multimodal transportation systems experience lower congestion levels, improved air quality, and increased transportation efficiency.

The report highlights that public transportation systems are only effective when users can conveniently access them. As a result, successful international systems focus heavily on reducing the generalized cost of transportation, which includes both financial cost and the time or inconvenience associated with transfers and waiting. International transportation agencies recognize that travelers value seamless, reliable, and comfortable transportation experiences. Therefore, improving FMLM infrastructure, such as protected bike lanes, pedestrian corridors, and microtransit systems, directly improves public transit attractiveness [19].

The European Environment Agency also emphasizes that active transportation modes such as walking and cycling provide the greatest societal benefits. Walking and cycling not only reduce greenhouse gas emissions but also improve public health by increasing physical activity and reducing vehicle-related pollution exposure. Several European cities have demonstrated that bicycle commuting can become one of the dominant modes of transportation when roadway infrastructure safely accommodates cyclists. Additionally, integrating FMLM systems into public transportation networks significantly extends the service area of transit systems. Better pedestrian pathways, bike-share systems, and multimodal station access increase the number of people who can efficiently reach transit stops without using personal vehicles. This improves overall transportation efficiency while reducing the need for expansive parking infrastructure.

The European case studies included in the report further demonstrate how multimodal transportation systems can improve freight operations. Urban consolidation centers, micro-hubs, and cargo-bike delivery systems reduce the number of heavy delivery vehicles operating within city centers. This decreases congestion, lowers emissions, and improves roadway safety for pedestrians and cyclists. Many European cities have successfully implemented these systems by creating designated freight zones and integrating logistics operations into urban planning strategies.

The report also highlights the importance of integrating technology with transportation policy. Mobility-as-a-Service (MaaS) systems, shared mobility platforms, and app-based transportation coordination improve user convenience while increasing the efficiency of multimodal transportation. Rather than treating transportation modes in isolation, successful international systems increasingly integrate public transit, bike-sharing, ride-sharing, and microtransit into unified mobility networks.

Another important point emphasized in the report is that transportation policy alone cannot solve FMLM problems without supportive land use planning. Compact development patterns, mixed-use zoning, and transit-oriented development significantly improve the practicality of walking, cycling, and public transit use. In contrast, low-density suburban development patterns increase travel distances and make sustainable transportation systems less effective.

The report clearly warns that new transportation technologies are not automatically sustainable simply because they are innovative. Technologies such as electric scooters, autonomous delivery robots, and shared mobility systems only provide environmental benefits when they replace automobile trips rather than walking or cycling. This highlights the importance of designing transportation systems that encourage sustainable transportation choices rather than simply increasing mobility options.

These findings are highly relevant for the United States as transportation agencies attempt to modernize infrastructure and reduce congestion. International examples demonstrate that transportation systems become more sustainable when FMLM infrastructure is prioritized alongside public transportation investments. Without strong multimodal access, public transportation systems may continue struggling with low ridership and automobile dependency.

6.3. Future Trends in International First-Mile/Last-Mile Transportation

As transportation systems continue evolving, many international cities are investing heavily in emerging FMLM technologies and mobility concepts. One of the most important future trends is the expansion of integrated multimodal transportation systems supported by real-time digital platforms. Countries throughout Europe and Asia are increasingly using centralized mobility applications that combine public transit, bike-sharing, ride-sharing, and microtransit services into a single user interface.

These integrated systems simplify multimodal trip planning and improve transportation convenience for users. Rather than purchasing separate tickets and navigating disconnected systems, travelers can coordinate entire trips through a single application. This improves system efficiency while encouraging greater use of public transportation and active mobility modes.

Another major trend is the expansion of electric mobility systems. Electric bicycles, electric scooters, and electric delivery vehicles are becoming increasingly common in dense urban environments. These vehicles reduce emissions while improving operational flexibility for short-distance transportation. Several international cities are already redesigning roadway infrastructure to better support electric micro-mobility systems.

In 2025, the broader market for demand-responsive transit systems, which includes microtransit, paratransit, dial-a-ride, and other transit systems, was valued at $28.4 billion globally. By 2034, the market is projected to reach a value of $102.6 billion, growing at a compound annual growth rate of 15.3% [20]. This growth projection shows the increasing investment in transit alternatives and the accelerating integration of these transit services.

Research also suggests that autonomous transportation technologies may play a growing role in future FMLM systems. Autonomous shuttles, autonomous delivery robots, and automated logistics systems are currently being tested in multiple international cities. These technologies have the potential to improve transportation efficiency while reducing labor costs and operational delays.

However, the successful implementation of autonomous systems will require substantial infrastructure adjustments. Autonomous delivery robots require safe pedestrian pathways and low-speed environments, while autonomous shuttles may require dedicated curbside loading zones and advanced traffic management systems. International case studies demonstrate that roadway geometry and urban design strongly influence the effectiveness of these technologies [21].

The World Economic Forum report on future last-mile delivery systems highlights the growing importance of urban freight innovation. As e-commerce demand increases globally, cities must develop more sustainable delivery systems to reduce congestion and emissions. The report explains that freight consolidation centers, electric cargo bikes, parcel lockers, and shared logistics hubs are becoming increasingly important components of urban transportation systems.

Several international cities are also exploring the use of drones and robotic delivery systems for lightweight deliveries. While these technologies remain in early development stages, they demonstrate how transportation systems may continue shifting toward more automated and decentralized logistics operations.

Climate change and sustainability goals will also continue shaping future transportation systems. Many international governments are implementing policies focused on reducing greenhouse gas emissions, limiting automobile dependency, and improving public transportation accessibility. These sustainability objectives are accelerating investments in multimodal infrastructure and alternative transportation technologies.

For the United States, these trends highlight the need for proactive transportation planning and infrastructure modernization. Transportation agencies will increasingly need to design roadway systems that support multimodal mobility, electric transportation, shared mobility services, and smart logistics systems. Failure to adapt infrastructure to changing mobility patterns may lead to increasing congestion, operational inefficiencies, and reduced transportation accessibility.

Ultimately, the future of FMLM transportation will likely depend on the successful integration of infrastructure, technology, and policy. International case studies demonstrate that transportation systems perform best when multimodal infrastructure, land use planning, and technology investments are coordinated to improve accessibility, efficiency, and sustainability.

7. Conclusions

The first- and last-mile problem has become one of the most important challenges facing modern cities and transportation systems. As e-commerce demand continues to grow and urban populations become increasingly dependent on efficient mobility networks, transportation agencies and private logistics companies are under increasing pressure to improve accessibility, reduce congestion, and create more sustainable transportation systems. The research conducted throughout this study demonstrates that successful first- and last-mile solutions require more than simply improving delivery speed or adding new transportation technology. Effective systems depend on coordinated infrastructure planning, multimodal transportation integration, roadway design improvements, and advanced logistics operations working together as a unified network.

The international case studies analyzed in this paper show that many countries have already made significant progress toward solving first- and last-mile transportation issues. China has developed one of the most advanced urban logistics systems in the world through decentralized parcel distribution centers, parcel locker systems, crowdsourced delivery networks, and emerging autonomous delivery technologies. These systems have allowed China to handle extremely high parcel volumes while reducing delivery inefficiencies and operational costs. Similarly, international transportation systems in countries such as the Netherlands, Singapore, Japan, and the United Kingdom demonstrate that multimodal infrastructure, integrated land-use planning, and context-sensitive roadway design can significantly improve transportation accessibility and overall mobility.

In comparison, many transportation systems throughout the United States remain heavily automobile-oriented. Wide roadways, disconnected land-use patterns, incomplete pedestrian infrastructure, and limited multimodal connectivity continue to create major barriers to efficient first- and last-mile transportation.

While many American cities have begun implementing Complete Streets policies, protected bicycle facilities, and transit-oriented development strategies, progress remains inconsistent. The research presented in this study shows that improving first- and last-mile connectivity in the United States will require transportation agencies to move beyond traditional roadway expansion approaches and instead focus on creating more balanced, multimodal transportation networks. The analysis of Amazon's logistics system further demonstrates how technology and data-driven operations are reshaping modern freight movement. Advanced route optimization, artificial intelligence, predictive analytics, and strategically located fulfillment centers have enabled companies such as Amazon to significantly improve delivery efficiency while meeting increasing customer expectations for rapid delivery. However, the research also shows that technology alone cannot solve first- and last-mile challenges without supportive infrastructure and coordinated transportation planning.

The localized recommendations developed for Wilmington, Delaware, highlight how many of these international and technological strategies can be realistically adapted at the community level. Proposed improvements such as smart parcel locker systems, micro-mobility hubs, protected bicycle lanes, pedestrian refuge islands, and expanded on-demand microtransit services demonstrate how smaller American cities can begin addressing transportation inefficiencies while improving accessibility and sustainability. By aligning these recommendations with AASHTO design guidance, the Delaware State Freight Plan, and existing regional transportation initiatives, the study shows that localized first- and last-mile improvements can support both mobility and long-term economic development.

Another major finding of this research is the growing importance of sustainability within transportation planning. International systems consistently demonstrate that investments in public transit, cycling infrastructure, pedestrian accessibility, and electric delivery technologies can reduce congestion, lower greenhouse gas emissions, and improve public health outcomes. As concerns related to climate change, energy consumption, and roadway congestion continue to grow, transportation agencies will likely face greater pressure to develop systems that balance efficiency and environmental responsibility.

The research also highlights the importance of future transportation technologies and emerging mobility systems. Autonomous delivery vehicles, electric micro-mobility, Mobility-as-a-Service platforms, smart logistics systems, and real-time transportation applications will likely continue transforming how people and goods move through urban areas. However, the effectiveness of these technologies will depend heavily on infrastructure readiness, roadway design, policy coordination, and public acceptance. Cities that proactively invest in adaptable multimodal infrastructure will likely be better prepared to accommodate future transportation demands.

Ultimately, the FMLM problem is not simply a freight issue or a transit issue. It is a broader transportation systems challenge that directly affects mobility, accessibility, economic productivity, sustainability, and quality of life. The findings of this study demonstrate that successful first- and last-mile systems require a combination of smart technology, coordinated infrastructure planning, multimodal transportation integration, and context-sensitive roadway design. While differences in geography, population density, and transportation culture may prevent the direct replication of international systems within the United States, many of the strategies examined throughout this research offer valuable insights into how American cities can improve transportation efficiency moving forward. As transportation systems continue to evolve, the ability of cities and transportation agencies to successfully address first- and last-mile connectivity will play a major role in shaping the future of urban mobility. Communities that invest in integrated, flexible, and sustainable transportation systems will likely experience improved accessibility, reduced congestion, stronger economic performance, and higher overall quality of life in the years ahead.

Author Contributions

All authors contributed equally.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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