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Diversity in the evolution of last-mile deliveries: Interactions between e-commerce growth, urban development, planning, and the delivery service market

Takanori Sakai [a,*], Bram Kin [b], Heleen Buldeo Rai [c], Alison Conway [d], Lynette Cheah [e], Giacomo Dalla Chiara [f], Walther Ploos van Amstel [g]

[a] Department of Logistics and Information Engineering, Tokyo University of Marine Science and Technology, 2-1-6 Etchujima, Koto-ku, Tokyo 135-8533, Japan
[b] Research Group Logistics in a Vital Society, HAN University of Applied Sciences, Ruitenberglaan 31, 6826 CC Arnhem, the Netherlands
[c] Mobilise Research Group, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Elsene, Brussels, Belgium
[d] Department of Civil Engineering, The City College of New York, 160 Convent Ave, New York, NY 10031, United States
[e] School of Science, Technology and Engineering, University of the Sunshine Coast, 90 Sippy Downs Drive, Sippy Downs, QLD 4556, Australia
[f] Department of Civil and Environmental Engineering, University of Washington, 3760 E. Stevens Way NE, Seattle, WA 98195, United States
[g] Centre of Expertise City Net Zero, Amsterdam University of Applied Sciences, Tweede Boerhaavestraat, 1091 GH Amsterdam, the Netherlands

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ABSTRACT

E-commerce is transforming urban freight systems and creating challenges for last-mile delivery due to fragmented demand, high stop density, and diverse delivery models. This study examines last-mile e-commerce delivery in five cities, primarily focusing on parcel deliveries, and analyzes how the state of practice of last-mile delivery systems is influenced by local contexts, including urban development, planning and policy, and market structures. Case studies of Brussels, Amsterdam, Singapore, Tokyo, and New York illustrate how last-mile delivery processes differ across cities and identify the key contextual factors that explain these variations. A cross-case comparison shows that differences in demand density, the size of urban agglomeration, the built environment, zoning restrictions, building codes, market structure, and zero-emission policies shape the last-mile delivery modes and solutions. Furthermore, several common strategies from a public-sector perspective are observed across cities. These include enhancing market cooperation and coordination, promoting non-home and unattended handovers, establishing regulatory frameworks for non-automobile delivery modes, developing logistics spaces, and exploring intermodal systems that use non-road transportation modes. However, specific implementation approaches remain unique to each local context. Finally, based on these findings, a set of key questions is proposed to help planners and policymakers assess their local contexts, define their vision for last-mile delivery systems, and select appropriate strategies and implementation approaches.

1. Introduction

The e-commerce market continues to grow in cities worldwide and last-mile deliveries are becoming increasingly challenging across the world. The share of e-commerce in retailing sales increased from about 8% to 16% between 2016–2025 in the US (U.S. Census Bureau, 2025), and from about 4% to 10% between 2014–2024 in Japan (Ministry of Economy, Trade and Industry, Japan, 2025). In Europe the share of companies that had e-sales grew from 17 to almost 24% between 2013 and 2023, with their turnover coming from e-commerce having grown from 14 to 19% (Eurostat, n.d.). In Singapore, e-commerce revenue increased from 6.6% to 7.9% of the total services sector operating revenue between 2016–2023 (Singapore Department of Statistics, 2024). E-commerce-driven deliveries that are designated to end-consumers are characterized by fragmentation with a low drop density but an extremely high stop density (Allen et al., 2018; Kin et al., 2018). The increase in stop demand by delivery vehicles adds more burden on limited urban curbside and parking spaces.

On the supply side, the delivery models (e.g., quick commerce/instant delivery and crowd-sourced deliveries) have been diversifying

* Corresponding author.
E-mail addresses: tsakai2@kaiyodai.ac.jp (T. Sakai), bram.kin@han.nl (B. Kin), Heleen.Buldeo.Rai@vub.be (H. Buldeo Rai), aconway@ccny.cuny.edu (A. Conway), lcheah@usc.edu.au (L. Cheah), giacomod@uw.edu (G. Dalla Chiara), w.ploos.van.amstel@hva.nl (W. Ploos van Amstel).

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and complicating last-mile delivery transport systems. Currently in cities around the world, goods are delivered by a multitude of service providers (Buldeo Rai et al., 2023; Dablanc et al., 2017; Kin & Quak, 2025) and novel solutions such as parcel lockers, mobile hubs, and e-cargo bikes have been more widely adopted over the past few decades. The rise of e-commerce also impacts land use, driven by the needs of carriers for promoting their distribution strategies (Janjevic and Winkenbach, 2020). More logistics facilities have been developed in the close proximity to urbanized areas to realize quality services for e-commerce driven delivery demand (Buldeo Rai et al., 2022).

Cities worldwide have been affected by rapid e-commerce growth, but differences in local context have created diverse last-mile delivery challenges. Delivery service markets have also evolved in distinct ways (Janjevic and Winkenbach, 2020). Understanding how local contexts shape last-mile delivery systems is essential for explaining variations in challenges, strategies, and outcomes. Assuming that universally transferable "better approaches" exist is unproductive without recognizing the processes and contextual factors underlying these developments, highlighting the need for context-sensitive research.

In this study, we focus on e-commerce driven last-mile deliveries. As for the last-mile delivery, we follow the definition used in Boysen et al. (2021): "… last-mile delivery starts once a shipment has reached a starting point in an urban area, e.g., a central depot after long-haul transportation, and ends once the shipment has successfully reached the final customer's preferred destination point." Our hypothesis is that differences in last-mile delivery systems can be largely explained by variations in urban development (i.e. the built environment and transport systems), urban planning and policy frameworks, and the structure of the delivery service market. Through studying five cities around the world, we attempt to answer the following research question: How do the contexts of development, planning and policy, and market interact with the development of existing last-mile delivery systems? We investigate the state-of-practice of last-mile delivery processes together with the contextual factors that may explain it.

The remainder of the paper is organized as follows. Section 2 reviews the literature on last-mile delivery concepts, urban freight initiatives, and contextual factors. Section 3 outlines the case cities and methodology. Section 4 analyzes city-specific practices and policy contexts. Section 5 presents a cross-case comparison and the observed common strategies for last-mile delivery systems, and Section 6 proposes a set of key questions about local contexts to be used for planning last-mile delivery systems and then provides the conclusion.

2. Literature review

While numerous studies have identified existing last-mile delivery concepts and documented their processes and operations, they have generally analyzed these concepts in isolation from the local contexts that shape their evolution. For example, Boysen et al. (2021) review state-of-the-art last-mile delivery concepts—including human-driven vans, cargo bikes, and self-service options—as well as emerging approaches such as drones, autonomous delivery robots, crowdshipping, and alternative handover methods. They focus primarily on their implications for operations research. Similarly, Lyons and McDonald (2023) identify 22 last-mile delivery strategies through a systematic literature review and classify them into four categories: innovative vehicles, urban goods consolidation, technological and routing advancements, and emerging planning tools and policies. They note that planning tools and policies remain underrepresented in the literature. Other reviews also catalog last-mile delivery concepts but similarly emphasize typologies over contextual analysis (e.g., Bosona, 2020; Kiba-Janiak et al., 2021; Zhu et al., 2023).

Parallel to this stream, a substantial body of research has examined public-sector responses to the transformation of urban freight systems driven by innovative last-mile distribution models. Browne et al. (2012) identify 26 policy measures aimed at mitigating negative urban freight impacts and document initiatives across four countries: the United Kingdom, Japan, the Netherlands, and France. Holguín-Veras et al. (2020a, 2020b) extend this work through a global assessment of 48 freight initiatives, categorized into supply-side and demand-logistics measures, based on expert surveys covering 56 cities in 32 countries. While these studies provide valuable insights into the range and perceived effectiveness of policy interventions, they do not examine the contextual factors that led to the adoption of specific initiatives. Focusing on the United States, Maxner et al. (2025) identify common urban freight strategies through stakeholder interviews, but similarly offer limited discussion of how local contexts shape system evolution.

A smaller number of studies explicitly address last-mile delivery practices within specific urban contexts. Allen et al. (2018) examine last-mile delivery operations in London and highlight conflicts between freight activity and policies prioritizing walking, cycling, and public transport. However, their analysis remains largely descriptive and does not deeply explore the contextual drivers of these conflicts. Other studies focus on logistics space as a key contextual factor. Kin et al. (2024) compare logistics space policies in Paris and Rotterdam, illustrating how different policy-making contexts shape facility allocation. Buldeo Rai et al. (2022) introduce the concept of "proximity logistics" to describe logistics facilities in high-density urban areas and examine supporting trends across New York, Paris, Seoul, Shanghai, and Tokyo.

Closest in scope to the present research is Janjevic and Winkenbach (2020), who develop a conceptual framework linking firms' last-mile distribution strategies—such as network design, transport modes, and facility location—to external contextual factors, including demand characteristics, urban form, infrastructure, and regulatory environments. Their analysis, however, primarily adopts a business-oriented perspective and focuses on large or major firms.

Despite more than a decade of growth in e-commerce delivery, relatively few studies examine how last-mile delivery systems differ across cities or how they evolve within specific urban contexts. Public-sector actors often seek to transfer policies and practices across cities, yet without sufficient understanding of the conditions under which such initiatives emerge, there is a risk of inappropriate policy transfer. This paper addresses this gap by examining the evolution of last-mile delivery systems through case studies of five urban areas across three continents.

3. Methodology

3.1. Cases: Metropolitan areas

We conducted case studies of five cities, including surrounding areas where appropriate, across three continents: Brussels-Capital Region (Belgium), Amsterdam (the Netherlands), Singapore, Tokyo 23 wards (Japan), and New York City (United States) (Fig. 1). In all five cases, rapid growth in e-commerce has led to a substantial increase in last-mile deliveries, which is widely recognized as a social and an environmental issue. The selected cities vary in scale: Brussels-Capital Region and Amsterdam represent medium-sized cities, while Singapore is a large city state. Tokyo 23 wards and New York City are core cities within two of the world's largest metropolitan areas. They also differ in historical development trajectories, with the European cities emerging as major urban centers earlier than the Asian and North American cases. Urban form and transportation systems vary significantly across the five cities, reflecting differences in zoning and building regulations, transport market governance, and the roles of the public sector at different administrative levels. While contrasts are most pronounced between Europe, Asia, and North America, notable differences also exist within each region. These cities were selected in part because expert knowledge was available to support a robust international comparative analysis. Table 1 provides the size and key infrastructure characteristics of the case cities and Fig. 2 shows their administrative boundaries. Brief profiles of each case city are presented below.

Fig. 1. Case cities.

Table 1
The size and key infrastructure characteristics of case cities.

City	Population(within administrative boundary) (2025)	Area (km^2)	People per km^2	Population of Urban Agglomeration (2025) [a]	Key infrastructure characteristics
Brussels-Capital Region	1.3 million	161	7700	1.4 million	Narrow streets, central canal, high bike lane density
Amsterdam	935,000	219	4270	1.2 million	Narrow streets, dense canal network, high bike lane density
Singapore	6.1 million	736	8300	5.0 million	Modern transport infrastructure (passenger rail, road, and parking lots), limited bike lanes, port city (island)
Tokyo 23 wards	9.7 million	628	15,400	33.4 million	Extensive passenger rail network, port city but limited waterway transport
New York City (Manhattan)	8.5 million(1.6 million)	789 (59)	10,900 (27,000)	13.9 million	Multi-modal street network with expanding bicycle and dedicated bus infrastructure, extensive passenger rail network, access to urban core constrained by limited water crossings

[a] United Nations Department of Economic and Social Affairs, Population Division (2025).

Fig. 2. Administrative boundary of case cities.

3.1.1. Brussels-capital region

The Brussels-Capital Region is the largest metropolitan area in Belgium and the 13th largest in Europe. It has a population of about 1.3 million people within 161 km^2, corresponding to a density of approximately 7700 people per km^2. It is a monocentric city, with nearly three-quarters of its territory covered by buildings. The Brussels-Capital Region hosts the Belgian capital of Brussels and the headquarters of the European Union. The north–south canal running through the central area enables river transport, while most regional logistics facilities are located outside the region and close to the waterfront. Many Belgian cities are characterized by their extensive bicycle lane networks, and Brussels is one of them.

3.1.2. Amsterdam

Amsterdam, the largest city in the Netherlands, has about 935,000 inhabitants and 1.2 million inhabitants in the urban agglomeration. The city itself has a population density of about 4270 people per km^2. Amsterdam is a historic port city, characterized by its dense canal network, narrow streets, and numerous bridges within a relatively small city boundary (219 km^2). It forms part of the Randstad, a polycentric urban region that also includes Rotterdam, The Hague, and Utrecht, with a total population of around 8 million.

3.1.3. Singapore

Singapore, a tropical island city-state, is home to 6.1 million people within an area of 735.7 km^2, resulting in a population density of around 8300 people per km^2. The city is highly advanced in Transit-Oriented Development (TOD), with a well-developed public transport system and an extensive highway network. About 76% of residents live in high-rise public housing apartments (called HDB). Singapore also hosts a major global trading port and operates busy sea and airports, with most goods being imported.

3.1.4. Tokyo 23 wards

The Tokyo 23 wards constitute the central part of the Tokyo Metropolitan Area (TMA). This area has one of the highest residential densities in the world (15,400 people/km^2). Around 33.4 million people live in the monocentric urban agglomeration centered on this area. The cityscape is diverse: residential skyscrapers, mainly concentrated in coastal areas, house between 1,000 and 2,000 households, while older residential areas are characterized by apartments and single-family homes. Public transportation, particularly urban rail, is highly developed and the modal share of automobiles is only about 10% in the Tokyo 23 wards.

3.1.5. New York city

New York, the most populous city in the United States, has about 8.5 million residents with an average population density of 10,900 people per km^2, though densities vary greatly across the city. The highest densities are found on Manhattan Island, which is considered the city's core. New York City also has the largest metropolitan economy in the world. It is the most public-transportation-dependent city in North America, with public transit accounting for more than 50% of the modal share, carried largely by the city's extensive subway system and buses. While the metropolitan region is home to the largest port complex on the east coast of the United States, the city itself is heavily dependent on truck transport for goods movement due to limited freight rail crossings and waterfront freight infrastructure.

3.2. What to compare?

Each case study comprises two analytical components. The first component, "state of practice," examines current last-mile delivery systems, including delivery modes (e.g., vans, bicycles, and handcarts), delivery and pickup methods (attended and unattended), and supporting infrastructure such as lockers, pickup points, and delivery hubs. It also reviews delivery market structures and emerging innovations that are not yet widely adopted. The second component, "context and policy roles," analyzes how broader factors—such as urban development history, planning practices, market regulation, and public policies—have shaped existing last-mile delivery systems and helps explain observed practices. As no standardized global method exists for collecting last-mile delivery data, this study relies on document analysis, site visits, semi-structured interviews and others. Despite efforts to ensure consistency, differences in data availability limit direct comparability across cities. Major data sources for case studies are summarized in Table 2.

4. Case studies on last-mile delivery processes

4.1. Brussels-Capital Region

4.1.1. State-of-practice

With the development of e-commerce, the number of delivery vehicles is increasing, and the sector is switching to smaller vehicles: +33% between 2005 and 2015 for vans compared to −5% for trucks (Brussels Mobility, 2021). In the Brussels-Capital Region, as in the rest of Belgium, about a dozen companies operate in the last-mile parcel delivery sector. The most important company is Belgian postal operator bpost, holding 30 to 40% of the volume (Belgian Institute for Postal Services and Telecommunications, 2025). Others include international parcel companies linked to postal operators elsewhere in Europe (including DPD, DHL, PostNL, and GLS) and American companies (such as UPS and FedEx). Amazon controls less than 5% of the parcel volume (Belgian Institute for Postal Services and Telecommunications, 2025). The majority of parcels are delivered in Brussels by van, conventional as well as electric, although cargo bicycles are gradually gaining importance. According to the Belgian Cycle Logistics Federation (2024), 5% of parcels are currently delivered by bike in the Belgian capital. Six companies specializing in bicycle deliveries are active there (Brussels Mobility, 2019).

Logistics real estate is concentrated in the historic industrial area of the region around the canal. The sorting and distribution centers of parcel delivery companies have however been located on or just outside the Brussels periphery (Strale et al., 2015). Some new distribution centers, such as that of bpost in Evere and that of DPD in Vilvoorde, confirm this trend. Others in the middle of the city occupy only a few hundred square meters (de Voghel et al., 2018). As a result of the modal shift to cycling, Brussels is experiencing an increase in urban logistics facilities. This is visible in the form of micro and mobile hubs in otherwise underused urban spaces, such as a car park for Urbeez, former storage locations for Urbike, and transformed industrial space for Cargo Velo (the so-called "Circularium"). Furthermore, the Brussels-Capital Region recently launched a project implementing a network of so-called nanohubs through its Brussels Mobility agency, with their 5 m^2 even smaller than a typical microhub. The first was launched on the campus of the Vrije Universiteit Brussel in Elsene, the idea being that different bicycle delivery companies can share the nanohub via a dedicated mobile application. Fig. 3 shows some of the facilities mentioned.

So far, most bicycle delivery activities in Brussels are organized in and around the center, also called the Pentagon, where the population is most dense and apartment buildings and terraced housing are prevalent. These activities are less present toward the peripheries of the Brussel-Capital Region, where the density is lower and people also reside in detached houses. Most of these deliveries are still brought to consumers' homes, of which about 16% fails at the first attempt (Brussels Mobility, 2019). In response, Brussels Mobility, which is responsible for transport policy and management in the Brussels-Capital Region, launched a public campaign to showcase the environmental and societal advantages of collection points and encourage their use. Fig. 4 illustrates some of the last-mile parcel delivery processes.

Table 2
Major data sources.

City	Document analysis	Site visits (during 2024–2026)	Semi-structured interviews / meetings (during 2024–2026)
Brussels-capital region	References cited in Section 4	- Urbeez car park microhub (January 2024) - Brussels Mobility nanohub (February 2025)	- Interviews with Brussels Mobility (Feb 2024) - Interviews with the Brussels Green Deal on Urban Logistics (Feb 2025) - Interviews with the advisory board of the Belgian Cycle Logistics Federation (Nov 2024; June 2025; Sep 2025) - Interviews with retail and logistics organizations (monthly)
Amsterdam	References cited in Section 4	- Site visits to logistics hubs, pilot projects, and policy initiatives (including Sustainable Neighborhood Logistics, April 2024; Amsterdam Makes Space, June 2024; CTPark hub opening, Dec 2024; CityHub, June 2025; waterborne transport initiatives, Jul 2025)	- Participation in stakeholder workshops, conferences, and policy events (including "meet & match" event on hub facilitation, June 2024; zero emission event, Nov 2024; Mobility discussion session, Feb 2025; Closing conference of the Urban Logistics Programme, Nov 2025)
Singapore	References cited in Section 4	- Site visits to multiple locations, including commercial and residential neighborhoods.	- Meetings with the Land Transport Authority (LTA), Urban Redevelopment Authority (URA), academic researchers in freight and logistics.
Tokyo 23 wards	References cited in Section 4	- Field survey (on-street observations) of last-mile deliveries (Mar-Aug 2025; 788 delivery observations)	- Interviews with members of the Tokyo Metropolitan Planning Commission (monthly) - Interview with a staff member of a major delivery service provider (December 2025) - Interviews with academic researchers in freight and logistics (irregular)
New York City	References cited in Section 4	- Field visit to curbside microhub	- Participation in stakeholder workshops, conferences, and policy events (APA Transportation Committee Curb Management Panel Apr 2024, NYC Industrial Plan Public Realm Design Charrette June 2025, Research on the Road Conference Nov 2025) - Participation in NYC DOT Freight Advisory Committee meetings (quarterly)

4.1.2. *Context and policy roles*

The Brussels-Capital Region stands out for its ambitious mobility policies, guided by the regional mobility plan for 2020–2030, called Good Move. This plan has regulatory value and aligns with existing land use planning policies. Regarding goods transportation, Good Move explicitly aims to improve last-mile delivery efficiency. Strategies include developing local logistics real estate (e.g., expanding the nano-hub network, promoting mixed zoning), strengthening regional logistics hubs, leveraging parking management tools, and introducing a quality label for the delivery sector (Brussels Mobility, 2021). These actions build on two specific measures already in effect: the low emission zone for cars and vans (since 2018; to be extended to a zero emission zone by 2035) and the kilometer charge based on the Euro emission standard for trucks (since 2016). By combining existing and upcoming initiatives, the region aims to support vehicle electrification and bicycle deliveries (Leefmilieu Brussel, 2022), which Good Move cites as a priority (Brussels Mobility, 2021). Nevertheless, following the 2024 elections and the ultimate 2026 coalition agreement, Good Move faces potential revisions.

Furthermore, in 2023, the Brussels-Capital Region launched the Green Deal for low emission urban logistics, a public–private alliance that aims to accelerate the transition towards less polluting transportation in the last-mile delivery sector. Each of the participating organizations commits to at least one concrete action to be implemented over the next two years (Leefmilieu Brussel, 2025).

Despite the historical absence of urban logistics facilities due to restrictions, the strong emphasis on active mobility, particularly the development of cycling infrastructure, which began before the 2000 s, supports the recent focus on using cargo bikes for last-mile deliveries. The potential for bicycle deliveries is significant: 25% of all goods and 50% of light goods can be delivered by bike (Belgian Cycle Logistics Federation, 2024), which includes most e-commerce parcels.

4.2. *Amsterdam*

4.2.1. *State-of-practice*

In the coming decade, vehicle movements related to urban logistics in the Netherlands are expected to grow by approximately 19% (Kin et al., 2026). Out of these movements, an estimated 5% of all light commercial vehicles are related to parcel deliveries. The Dutch parcel delivery market is highly concentrated, with PostNL and DHL accounting for more than 90% of the market (Authority for Consumers and Markets, 2023). Other operators include Amazon, FedEx, UPS, GLS, DPD, Trunkrs, and Ampere. Most parcels (over 95%) are still delivered using small to large vans, although cycling infrastructure has existed for decades and cargo bike companies have been operating in most Dutch cities, including Amsterdam, for years. The transition toward cleaner delivery vehicles is accelerating, partly in response to the planned introduction of zero-emission zones in 30 to 40 Dutch cities from 2025 onward. By mid-2025, more than 5% of all light commercial vehicles in the Netherlands were electric (RVO, 2025), with a higher proportion of electric vans found in the parcel delivery sector compared to other sectors such as construction and retail. Light electric freight vehicles, including cargo bikes, are increasingly deployed in dense urban districts, driven mainly by access restrictions and, to a lesser extent, emission regulations (van Duin et al., 2022; van Duin et al., 2026). Larger parcel

Fig. 3. Facilities supporting last-mile deliveries in Brussels. Top: TIR center along the canal in the Brussels center (Urban Brussels, 2024), bottom left: nanohub at the Vrije Universiteit Brussel campus in Elsene (photo taken by the authors), bottom middle: Urbeez in the Royal car park in the Brussels center (photo taken by the authors), bottom right: Urbike microhub in Anderlecht (photo taken by the authors).

Fig. 4. Last-mile parcel delivery processes in the Brussels-Capital Region. (Photos taken by the authors).

operators have also experimented with alternative, more sustainable distribution modes. For example, PostNL tested an initiative using barges to move parcels into the city center, from where they were transferred to smaller, zero-emission vehicles for last-mile distribution. The role of microhubs, mobile hubs, and on-pavement sorting in Amsterdam's parcel logistics remains limited. Compared to larger metropolitan areas, Amsterdam is relatively compact, which reduces the need for extensive intermediate facilities.

The number of pick-up points, both manned service counters and parcel lockers, is increasing, although grocery click-and-collect services remain limited and relatively unpopular in the Netherlands. Information on failed deliveries is scarce, but sector estimates suggest that only 2–4% of deliveries are unsuccessful. This relatively low rate is partly explained by the common Dutch practice of delivering to neighbors when recipients are not at home. Pick-up points represent an alternative option: approximately 11% of parcels are delivered to such points, the majority by consumer choice rather than delivery failure. These pick-up points are usually manned service counters, although there is a rapid expansion of automated parcel lockers in supermarkets, DIY stores, public transport hubs, universities, and residential complexes. Initiatives such as MyPup, a parcel logistics company based in Amsterdam, support this trend by integrating parcel lockers into apartment and office buildings. The pace of innovation in the parcel delivery sector is constrained by market dynamics. Still, several incremental innovations are being implemented. These include the shared use of parcel locker infrastructure by competitors (e.g., GLS and PostNL). See Fig. 5 for some e-commerce delivery practices in Amsterdam.

4.2.2. *Context and policy roles*

In terms of urban planning and policy, Amsterdam has paid relatively limited attention to e-commerce deliveries as a distinct category of urban logistics. Instead, such flows are subsumed under broader policies targeting urban logistics vehicles. The most significant measure is the introduction of a zero-emission zone, which gradually took effect from January 1, 2025. Under this scheme, all conventional vans will be phased out in the city center by 2025, and all trucks by 2030. Notably, the parcel delivery sector itself is among the frontrunners in electrification and the deployment of light electric freight vehicles, including cargo bikes. However, the actual use of cargo bikes in Amsterdam for home deliveries is limited.

Furthermore, Amsterdam has begun to address the nuisance and disruption associated with light electric freight vehicles through regulation, experimentation, and infrastructure measures. A core intervention has been the reduction of speed limits to 30 km/h across most of the city's street network, with the aim of calming traffic and reducing conflicts between motor vehicles, cyclists, pedestrians, and light electric freight vehicles. In parallel, the municipality, in cooperation with the national government, is developing a clearer regulatory framework for

Fig. 5. Last mile delivery practices for e-commerce in Amsterdam. (Photos taken by the authors). Top left: Parcel delivery vans in the city center, top right: e-tailer Coolblue delivering with a cargobike, bottom left: e-grocer Picnic delivering, bottom right: DHL pick-up point.

light electric freight vehicles. This includes efforts to classify vehicles by speed category, define their positioning within the road hierarchy, and improve safety standards for e-bikes, cargo bikes, and fat bikes. On the other hand, the city has announced that parcel lockers are not permitted in public space, and, while new or redeveloped neighborhoods include loading and unloading zones, these are not designated for high-density parcel deliveries.

Finally, Amsterdam has taken strong regulatory action against quick-commerce companies such as Flink and Getir, whose rapid expansion of "dark stores" raised concerns about noise, traffic disruption, and neighborhood livability. The city introduced zoning restrictions banning such facilities in residential and mixed-use areas and limiting their presence to business or industrial zones. Several outlets were ordered to close, and noncompliance triggered financial penalties. (Gemeente Amsterdam, 2020, 2022, 2023a, 2023b; Frolova, 2024; Ministerie van Infrastructuur en Waterstaat. 2021).

4.3. Singapore

4.3.1. State-of-practice

In Singapore, the last-mile delivery market is fragmented without dominant players. The main delivery companies include SingPost, Ninja Van, DHL Express, and Grab Express (Mordor Intelligence, 2025). For parcels, white goods, and grocery orders, the delivery process is similar. These are usually delivered from a warehouse or distribution center directly to doorsteps. Deliveries are fulfilled by two- or three-wheelers, cars, vans, or trucks (Fig. 6). There is a strong push by the government to encourage vehicle electrification. As of 2024, 1 out of 4 light and heavy goods vehicles sold are electric or hybrid electric (Land Transport Authority of Singapore, 2024). Meal deliveries are typically delivered by individual contractors on motorcycles, e-bikes or bicycles.

Approximately 76% of residents in Singapore live in high-rise public housing estates (known as HDB estates), which are typically accompanied by large adjacent parking areas (Housing Development Board of Singapore, 2024). This characteristic has significant implications for how last-mile deliveries are conducted. Unattended parcel or goods deliveries are generally rare due to shared corridors. On the other hand, automated parcel lockers are widely deployed near residential estates, community clubs, and transport nodes, mostly in public spaces. A government-initiated federated parcel locker system brings together an alliance of locker operators, so that a nationwide network of lockers can be shared among e-commerce and logistics providers. Aside from parcel lockers, consumers can also pick up parcels at convenience stores and small retail outlets, which are designated pick up/drop off (PUDO) points. For instance, Ninja Van has established a nationwide network of 800 businesses to serve as PUDO points, including the popular convenience store chain 7-Eleven (Ninja Van, 2025).

In Singapore, creative transportation solutions for both passengers

Fig. 6. Common last-mile delivery modes in Singapore. Left: three-wheeler (Singapore Post Limited, 2021); right: delivery van and truck (Ninja Van).

and freight have been actively explored. ERP 2.0, the road congestion pricing system using the Global Navigation Satellite System (GNSS), is one such example. In the area of last-mile logistics, a Courier Hub Scheme was launched in 2024 by government agencies, permitting logistics providers to use public parking lots in housing estates during business hours (9:00am to 6:00 pm) to sort and handle parcels (see Fig. 7, bottom left). Integrated passenger-freight transport was trialed when SingPost partnered with the urban rail operator to collect mail and parcels using the rail network (see Fig. 7, top). Automation is being explored with the use of sidewalk delivery robots by OTSAW (see Fig. 7, bottom right).

4.3.2. Context and policy roles

In the compact and dense island-city state, many urban logistics innovations and initiatives are driven by high-rise living, shared urban spaces, as well as a push for automation amidst a shrinking and ageing workforce. Street and parking spaces are tightly regulated, and creative solutions to optimize their use are explored. These solutions are mainly led by the government or industry players. Since much of the city was developed after 1970, it is well designed with modern transportation considerations in mind, including motor vehicles and mass rapid transit. Singapore is often cited as one of the most successful examples of TOD (Cervero, 1998). The city has effectively preserved large areas for public spaces and surface road transportation, which has significant implications for last-mile logistics. As mentioned earlier, most of the population lives in HDB estates or, otherwise, private condominiums, both of which are typically high-rise buildings. Fig. 8 shows the typical city scape in Singapore. Furthermore, the Urban Redevelopment Authority (URA) sets standards and requirements for parking provision (Urban Redevelopment Authority, 2025) for residential and commercial developments.

Fig. 8. Typical city scape in Singapore. (Photo taken by the authors).

Together with car ownership controls, the imbalance between parking demand and supply is not a major concern in many parts of the city, although in retail districts, a shortage of loading/unloading bays at shopping malls during peak-hours has been identified as an issue (Mepparambath et al., 2023; Dalla Chiara and Cheah, 2017). This unique situation in Singapore makes the large-scale implementation of cargo bike and handcart deliveries—and the development of microhubs to support these delivery modes—less necessary than in other cities.

Fig. 7. Urban logistics innovation and initiatives in Singapore. Top: Freight-on-transit trial by SingPost (© SingPost, 2024. Reprinted with permission.); bottom left: Permitted use of public parking lots within a residential estate as a courier hub (© Urban Redevelopment Authority. All rights reserved.); bottom right: Deployment of an autonomous delivery robot in a residential neighbourhood (© OTSAW, 2021. Reprinted with permission.).

4.4. Tokyo 23 wards

4.4.1. State-of-practice

In Tokyo, the parcel delivery system has evolved around three major service providers (Yamato Transport, Sagawa Express, and Japan Post) that have dominated the market for decades, although the market for small professional subcontractors conducing parcel deliveries, such as those working with Amazon Japan, has been recently growing. In central business districts (CBDs) in Tokyo 23 wards, like Shinjuku and Ueno, trolley deliveries by companies like Yamato or Sagawa account for the majority of parcel distribution. In these areas, trolleys, sometimes with delivery staff and sometimes unattended, can be seen throughout the streets during the day (Fig. 9, top left and top middle). These trolleys typically operate out of microhubs (known as "Eigyo-sho", which vary in size and can be as small as 50–150 m^2 in CBDs) (Fig. 9, top right). In the TMA, there are approximately 1,300 microhubs (Sakai et al., 2024); in Ueno, for example, Yamato's microhubs are spaced just 400 to 500 m apart. Even in CBDs, deliveries to high-rise apartment buildings are conducted using vans and trucks, as off-street parking lots are available on the premises of these buildings. In CBDs, Amazon also often subcontracts deliveries to Yamato and Sagawa.

In other urban areas outside of CBDs (Fig. 9 bottom), approximately 30–50% of delivery vehicles are small vans operated by small businesses subcontracted by Amazon. These vans are often difficult to identify as delivery vehicles unless they are carrying boxes with the Amazon logo. These vehicles, along with trucks from Sagawa and other companies with smaller market shares, are frequently parked on roadsides or pedestrian walkways. In such areas, Yamato often uses small trucks to access neighborhoods, with last-mile deliveries carried out using trolleys and cargo bikes, treating the truck as a mobile hub. A similar situation can be observed in suburban areas, although delivery service providers there tend to rely more heavily on vehicles that deliver directly to recipients' premises.

Regarding parcel receiving methods, only 2% of households receive parcels away from home (e.g., using public PUDO lockers). In contrast, 97% receive parcels at home, including 26% through unattended delivery (12% leave-at-door and 14% is using residential/apartment parcel lockers) (Kanto Regional Development Bureau, 2025). Failed deliveries have decreased from 16.0% in 2019 to 10.4% in 2022 (Ministry of Land, Infrastructure, Transport and Tourism, Japan, 2023), partially due to the increase in unattended deliveries. Most delivery vehicles run on diesel fuel.

4.4.2. Context and policy roles

One of the most distinctive features of the Tokyo case is that parcel deliveries in CBDs rely heavily on trolley deliveries originating from microhubs. Several factors contribute to this situation. First, the parcel delivery market is dominated by a small number of major carriers. Their high delivery demand density makes non-automobile-based delivery methods economically feasible. This structure is partly a result of national-level regulation: companies wishing to operate as freight carriers must obtain permission from the Minister of Land, Infrastructure, Transport and Tourism (MLITT) under the Motor Truck Transportation Business Law stipulated in 1989. This regulatory framework has also limited the expansion of the gig economy in the freight sector, with the notable exception of ready-to-eat meal deliveries using bicycles or motorcycles. Second, zoning regulations permit parcel delivery providers to establish microhubs even in historic or densely developed CBDs. Consequently, microhubs are often located on the ground floors of commercial or residential buildings. Third, strict parking regulations and enforcement make the use of vans and trucks for deliveries in CBDs difficult. Repeated illegal parking can result in driver's license suspension under the Road Traffic Law, and the introduction of a privatized parking inspection system in 2006 has further increased enforcement intensity. While growing e-commerce demand, such as that generated by Amazon, is increasingly served by small-scale local carriers holding freight business licenses and operating commercial vehicles, such vehicles are more prevalent outside CBDs. In CBDs, traditional major carriers maintain an advantage through established logistics systems. Outside CBDs, the oversupply of passenger car parking—stemming from long-standing national parking space obligations in building codes—facilitates transloading from vehicles to trolleys or cargo bikes.

Thus, the key component of the state-of-the-practice can be explained by long-lasting legal frameworks, while there are some short-term factors. The shortage of the labor force in the parcel delivery service industry is widely recognized among the public in 2017–2018 when the three giant parcel delivery service providers increased delivery fee to suppress the demand. Such crisis in parcel delivery service, named "Takuhai Crisis", was identified as a social issue and further motivated the public sector at the national level to promote the subsidy for

Fig. 9. Last-mile deliveries in Tokyo. (Photo taken by the authors). Top row: Deliveries in central business districts (left: delivery staff with handcarts; middle: handcart temporarily placed on a pedestrian path during delivery; right: a microhub). Bottom row: Deliveries in non-CBD urban areas (left: delivery van at curbside; middle: truck-to-handcart transfer in a parking lot; right: cargo bike in front of an apartment building).

reducing failed deliveries and advancing technological innovations. As mentioned earlier, the failed delivery has decreased to 10%, which is partially due to the efforts of governmental agencies, such as the subsidy for installing receiving boxes.

4.5. New York city

4.5.1. State-of-practice

Parcel deliveries are predominantly conducted by four major companies – Amazon, FedEx, the US Postal Service, and United Parcel Service (UPS). In 2024, these four entities accounted for more than 90 percent of parcel volume nationally (Kulisch, 2025), with Amazon volumes increasing. While the other three companies directly employ operators, Amazon's last mile deliveries are primarily conducted by its delivery service providers, private entities contracted to provide delivery services. These include a large number of companies operating trucks and vans, as well as companies such as DutchX and NetZero logistics who operate small vans and cargo cycles. Amazon also directly employs operators within its Amazon Logistics network, as well as utilizes independent drivers as part of its Amazon Flex program.

In New York, more than 90 percent of goods are moved by trucks. Given the city's relatively wide range of population densities across its five boroughs – from more than 28,000 residents per km^2 in Manhattan to only a little more than 3,000 residents per km^2 in Staten Island (New York State Department of Health, 2022), a variety of vehicle types are used for moving parcels via different distribution strategies (Fig. 10). In the city's less dense neighborhoods, sprinter vans are commonly used for delivery from last mile distribution facilities. In more densely populated areas, vehicles range from large box trucks (which often serve as a mobile hub for handcart deliveries performed by porters), to step vans, to cargo cycles and e-bikes. While detailed vehicle type statistics are not available at the city scale, trends indicate a recent shift toward smaller vehicles. A NYC Department of Transportation (DOT) study investigating vehicles entering NYC found that between 2015 and 2018, truck traffic grew by 21% (vs. 12% for all vehicles), and that 50% of this increase was due to small, single-unit two-axle trucks (NYC Department of Transportation, 2021). Currently, micro-distribution in dense neighborhoods is primarily conducted informally from vehicles parked in curb spaces and double parking on travel lanes, where goods are transferred to trolleys and handcarts for final delivery (Fig. 10, top left). Most permanent parcel distribution facilities are large and are located within the city's Industrial Business Zones (IBZs) in all five boroughs, but primarily concentrated in Brooklyn, Queens, and the Bronx (NYC Department of City Planning, 2025). About half of these are in locations close to residential zones. The city is also served from warehouse facilities in neighboring states of New Jersey and Pennsylvania.

As detailed in the *Delivering Green* report jointly published by the NYC DOT and the NYC Economic Development Corporation (EDC), the city aims to shift goods to non-truck modes, both by increasing the share of goods distributed by the city's waterways and by moving goods onto smaller, greener vehicles such as cargo bikes (Fig. 10, bottom row). NYC DOT has recently launched a number of related pilot programs, including a commercial cargo cycle pilot program (2019); LockerNYC, a publicly-accessible common carrier parcel locker pilot program (2024) (Fig. 10, top right), a micro-hub pilot program (2025); and Blue Highways (in collaboration with NYC EDC), a program that aims to shift goods to maritime modes connected with green delivery vehicles for final distribution (NYC Department of Transportation, 2025a).

In 2021, Rensselaer Polytechnic Institute's Center of Excellence for Sustainable Urban Freight Systems estimated that New York residents were receiving more than 2.3 million packages per day (Deffenbaugh and Eisenpress, 2021). According to NYC DOT's Citywide Mobility Survey, of the 35% of New Yorkers who received a package on a typical day, 32% received a delivery to home, 1% a delivery to work, and 2% a delivery to another location such as a locker or pick-up point (NYC Department of Transportation, 2024). In very large buildings, goods are often delivered to attended desks, with packages managed via computerized package management systems (Fig. 11.) In smaller buildings, packages are typically left in a building lobby or a package storage room (more common in newer buildings). At single or multi-family homes, packages are typically left outside on a porch or doorstep.

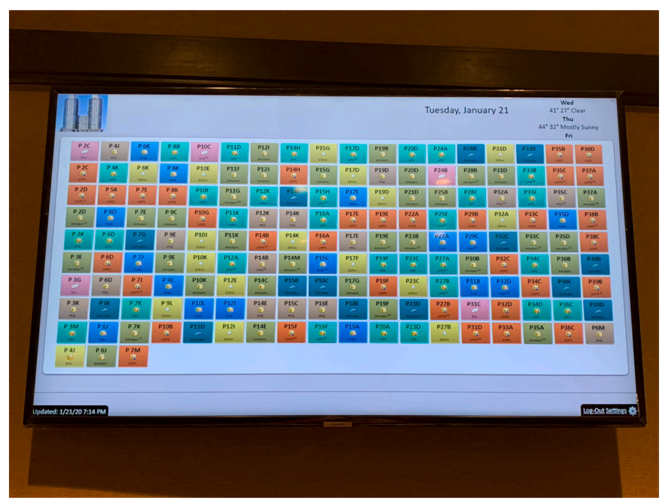

Fig. 11. Computerized package management system in a residential building. (Photo taken by the authors).

Fig. 10. Last-mile deliveries in New York. (Photo taken by the authors). Top left: curbside sortation; top middle: handcart delivery; top right: parcel locker; bottom left: sprinter van; bottom middle: e-cargo bike; bottom right: cargo bike parked at curbside.

4.5.2. Context and policy roles

Historically, distribution in NYC has primarily been via truck or van from warehouse facilities located outside of the city or in areas of the city zoned for industrial and manufacturing land uses, where warehouses and distribution facilities could be developed as of right (Conway, 2024). Informal micro-distribution from unauthorized parking spaces has been spurred by a general culture of non-compliance, as well as by the existence of the city's stipulated fine program, which allows delivery companies to pay a reduced fine for parking violations if they waive their right to a hearing (City of New York, 2025).

However, the City of Yes, New York's first major update to its zoning code in more than 50 years approved in 2024, included a number of provisions expected to encourage development of smaller distribution facilities located closer to commercial and residential customers. Updates include allowing development of micro-distribution facilities up to 232 m^2 in neighborhood commercial districts in Manhattan and up to 464 m^2 on the ground floor and 928 m^2 above the ground floor in destination and regional retail districts in all boroughs (NYC Department of City Planning, 2024b). Updated zoning also allows spaces in commercial parking garages to be used for micro-distribution activities (NYC Department of City Planning, 2024a). Micro-distribution by cargo bike and e-bike was also previously inhibited by unclear vehicle regulations at the city and state level. However, in recent years, the city issued clear guidance on what vehicle types, with what types of electric motor characteristics, could be operated on city streets (NYC Department of Transportation, 2025b). In 2024, the city issued specific regulations defining commercial cargo bikes, and establishing speeds limits, prohibiting sidewalk parking, and defining size and weight regulations for these vehicles (NYC Department of Citywide Administrative Services, 2024).

A number of other local policies may encourage further implementation of micro-distribution strategies. In January 2025, the city implemented congestion pricing in midtown and downtown Manhattan, with tolls ranging from $14.40 to $21.60 for peak-hour entry by trucks (Metropolitan Transportation Authority, 2025). Small vans pay the passenger vehicle toll of $9 per day, while cargo bikes are not required to pay any toll. In addition, both the City of New York (The New York City, 2024) and the State of New York (New York State, 2025) are considering indirect source rules similar to regulations recently implemented in California (Legiscan, n.d.). These rules would require warehouse facility operators to earn credits by implementing sustainable vehicle or warehouse operations or face financial penalties. Aligning with the goals outlined in the *Delivering Green* plan, the NYC DOT and NYC EDC are continuing to pursue the pilot programs detailed earlier. NYC DOT also recently received a $5.6 millon grant from the US Department of Transportation to establish an urban freight innovation hub (City of New York, 2024).

5. Discussion across cases

5.1. Cross-case comparison: What contextual factors influence existing last-mile delivery systems, and how?

The above case studies demonstrate that last-mile delivery systems have evolved differently across cities in response to their local contexts. The results of the cross-case comparison of contextual factors and last-mile delivery practices are summarized in Table 3. Seven key contextual factors are identified. *Demand density*, the *size of the urban agglomeration*, and the *built environment* characterize the physical context of the cities. *Zoning regulations* and *building codes* significantly influence the

Table 3
Cross-case comparison of contextual factors and last-mile delivery practices.

City	Contextual Factors							State-of-Practice
	Demand Density	Urban Agglomeration	Built Environment	Zoning Restrictions on Logistics-Related Land Use (High-Density Areas)	Building Code on Parking Provision	Zero Emission Policies (As of April 2026)	Delivery Service Provider Market	
Brussels-capital region	Relatively high	Medium	Dense historic core; limited space; high bike lane density; mixed housing types	Restrictive (but becoming less so)	No strict parking supply controls (on-street overnight parking is common)	LEZ based on Euro emission standards (applies to the entire Brussels-Capital Region)	Relatively fragmented (bpost is most dominant)	Vans; limited but growing use of cargo bikes; direct deliveries from regional hubs
Amsterdam	Relatively high	Medium	Dense historic core; limited space; high bike lane density; mixed housing types	Restrictive	No strict parking supply controls (on-street overnight parking is common)	ZEZ in the center since 2025 (all vans and trucks must be zero-emission gradually)	Highly concentrated (i. e., PostNL, DHL)	Vans; limited use of cargo bikes; direct deliveries from regional hubs
Singapore	High (concentrated in high-rise estates)	Large	High-rise housing with ample planned parking; modern infrastructure	Restrictive	Parking supply controlled through building codes	No LEZ/ZEZ (nationwide emission policy; congestion pricing implemented)	Fragmented	Mixed (trucks, vans, motorcycles); direct deliveries from regional hubs
Tokyo 23 wards	Very high	Mega-city	Multiple dense CBDs; good off-street parking; mixed housing types	Less restrictive (extensive microhub network)	Parking supply controlled through building codes	No LEZ/ZEZ (nationwide emission policy)	Highly concentrated (Yamato, Sagawa, Japan Post)	Mixed (trucks, vans, cargo bikes, trolleys); transloading at microhubs/ mobile hubs
New York	Very high (especially in Manhattan)	Mega-city	Dense historic core; large buildings (often with attended desks); constrained curb space	Restrictive (but becoming less so)	Parking supply controlled through building codes for some uses; on −street parking is also common	No LEZ/ZEZ (statewide emission policy; congestion pricing implemented)	Highly concentrated (Amazon, UPS, FedEx, USPS)	Mixed (trucks, vans, cargo bikes, handcarts); transloading at curb spaces

availability of key infrastructure, particularly logistics facilities and off-street parking. *Zero-emission policies* have significant impacts on delivery modes and fleet composition, particularly in European cities. Finally, the structure of the *delivery service provider market* affects the consolidation or fragmentation of delivery demand, as well as the presence of specialized or unconventional operators. How each identified contextual factor shapes last-mile delivery practices is discussed below.

Demand density. Demand density significantly affects the feasibility of different delivery modes. Higher demand density results in a smaller delivery area per delivery tour. At the highest density levels, trolleys (in combination with trucks that transport parcels to nearby transfer points, such as curbside spaces, microhubs, or temporary loading/unloading areas) become highly feasible (e.g., central areas of Tokyo 23 wards and New York City). At medium levels of demand density, where delivery locations are more spatially dispersed, cargo bikes may become a competitive option (e.g., their use in the Pentagon area of Brussels). Non-motorized modes such as trolleys and cargo bikes are also advantageous in congested areas, pedestrianized zones, and/or areas with limited parking availability, which are typical characteristics of high-density urban environments.

Size of urban agglomeration. In the largest urban agglomerations, deliveries to the densest neighborhoods typically require transshipment from trucks to trolleys or other smaller delivery modes (e.g., Tokyo and New York). In these cities, accessibility from regional logistics hubs to final delivery locations is often limited due to heavy congestion and the long distances between urban cores and logistics facilities. In contrast, in medium-sized cities such as Brussels, Amsterdam, and Singapore, direct deliveries from large warehouses and/or distribution centers located outside city centers using small- to medium-sized goods vehicles (often vans) are more common.

Built environment. The built environment, including local road networks, parking availability and housing types, strongly influences last-mile delivery systems. Many cities have seen an increase in small-sized goods vehicles, particularly in Brussels, Amsterdam, and New York, where urban cores are characterized by narrow streets and limited parking for larger freight vehicles. In Brussels, the extensive bike lane network makes cargo bikes a viable delivery mode. By contrast, Singapore's well-developed surface road network and car parks reduces reliance on cargo bikes and trolleys. Safety, neighborhood and building management characteristics also shape delivery practices. In Amsterdam, neighbors often receive parcels on behalf of absent recipients, while in New York, centralized parcel facilities are common in high-rise buildings, whereas unattended doorstep deliveries prevail in low-density areas.

Zoning restrictions. In many European and U.S. cities, including Brussels, Amsterdam, and New York, neighborhood-scale logistics activities such as sorting and transloading are not explicitly recognized in zoning codes and are often prohibited in residential and commercial zones. The limited recognition of neighborhood logistics in zoning regulations has encouraged informal use of curbs and sidewalks for sorting and transloading, a practice that is particularly evident in Manhattan (New York City), the densest part of the mega-city, and has constrained the expansion of non-motorized delivery systems, such as cargo-bike operations in Brussels. In response, cities including New York and Brussels have begun revising zoning codes to allow neighborhood logistics uses in underutilized urban spaces, such as parking facilities, or mixed developments combined with housing. Singapore has also recently permitted the use of parking facilities in residential areas for sorting parcels, enabling flexible use of shared urban spaces and encouraging parcel walkers to complete last-mile deliveries. In contrast, microhubs have historically been permitted within urbanized areas in Tokyo, reducing the reliance on curbside space and limiting the obstructive use of streets and sidewalks for transloading from trucks to trolleys and cargo bikes.

During the COVID-19 pandemic, private-sector workarounds also emerged: quick-commerce firms expanded through "dark stores," store-like warehouses located in residential and commercial areas (Buldeo Rai et al., 2023). These facilities are now often considered non-compliant with zoning regulations and face increasing restrictions. Public parcel lockers may also be viewed as visual obstructions in cities that prioritize streetscape and landscape preservation, particularly in European contexts such as Amsterdam.

Building codes on parking provision. Building codes, together with norms regarding street use, vary across cities and shape last-mile delivery practices. In Singapore and Tokyo, large buildings are typically required to provide loading/unloading bays or off-street parking, allowing goods vehicles to access high-rise buildings more easily. The required parking provision would scale with the size of the development. In New York, many large office buildings and industrial facilities are required to provide off-street loading docks, but for lower density and residential uses, operators commonly rely on on-street spaces. By contrast, in Singapore, parking supply and demand are tightly managed through vehicle ownership controls. In Tokyo, an oversupply of passenger car parking, driven by building code requirements, has become a concern in central areas but also provides off-street space for goods handling.

In both Asian cities, strict enforcement and severe penalties for illegal parking discourage on-street parkings and effectively necessitate off-street goods handling. By contrast, on-street delivery stops are widespread in New York, often informal and subject to fines, with sidewalks and roadways used for sorting and transloading. As a result, managing curbside space sharing is a major planning challenge (NYC Department of Transportation, 2023).

Zero-emission policies. Policies aimed at reducing emissions are having a significant impact on the freight transportation sector in Europe. In Amsterdam, progressive zero-emission zone policies are driving ongoing changes in last-mile delivery systems, particularly through the electrification of delivery vans (from 2025) and trucks (from 2030 onwards). In Brussels, although the current low-emission zone policy restricts only high-emission vehicles (below Euro 4), the region aims to implement more stringent emission regulations in the future. While in Singapore and New York City congestion pricing schemes have been adopted, their impact on commercial fleet is still not well understood.

Delivery service provider market. The comparison of case cities indicates that the existence of dominant delivery service providers and/or small-scale specialized operators plays an important role in shaping last-mile delivery practices. In Tokyo, the concentration of delivery demand among a small number of major carriers makes microhub-based trolley delivery feasible in CBDs, as high demand justifies the cost of operating microhubs in high-rent areas. Strong regulatory barriers have partially contributed to the formation of this market structure. In contrast, in Brussels, where the market is relatively fragmented, small and emerging firms specializing in bicycle deliveries play a significant role in the growing adoption of cargo bikes. In New York, the strong presence of Amazon and its delivery service network accounts for a large share of last-mile parcel deliveries, contributing to the increasing use of cargo bikes and walking-based delivery routes.

5.2. Observation of common strategies for last-mile delivery system

Comparative analysis of the case cities also enables the identification of common public-sector strategies at a conceptual level, while recognizing variations in how these strategies are implemented in practice. The scope of this study is limited in its ability to evaluate the effects of individual solutions associated with these strategies. However, identifying commonalities provides a useful foundation for developing transferable insights and guiding cities in adapting strategies to their specific local contexts.

Enhancing market cooperation and coordination. Intense competition among numerous small carriers can undermine sustainability by reducing demand density per operator and increasing pressure on public infrastructure. Conversely, excessive market regulation may limit competition and stifle innovation. A middle-ground approach involves creating a level playing field that enables cooperation among carriers in logistics initiatives and shared infrastructure use. This strategy is particularly relevant in contexts where fleets and facilities are otherwise underutilized and/or inefficiently used due to fragmented demand, where knowledge and resources are dispersed across stakeholders despite shared goals (e.g., CO_2 emission reduction), and where shared infrastructure can improve system-wide efficiency.

For example, in Brussels, where the market is relatively fragmented and the public sector has strong low-emission initiatives, cooperation is facilitated through public–private partnerships such as the Green Deal. Furthermore, the presence of numerous small, competing bicycle delivery operators makes the development of shared nanohub systems a viable approach. Carrier-agnostic parcel locker systems are promoted more widely across different contexts, as they help prevent the proliferation and underutilization of lockers that consume urban space, while supporting more environmentally sustainable delivery systems. However, variation is observed in their scale and location, reflecting differences in public-sector involvement, market structure, and the built environment.

Promoting non-home and unattended handovers. Reducing the dispersion of handover locations, through shorter travel distances, reduced delivery time, and fewer failed deliveries, can improve delivery efficiency while reducing pressure on infrastructure and environmental impacts. This provides a strong rationale for the public sector to promote non-home delivery options. The promotion of non-home deliveries is therefore common due to its clear benefits; however, the ways in which it is implemented depend strongly on local context. In Singapore, where high-rise public housing and shared public spaces are prevalent and unattended deliveries are relatively uncommon, the development of carrier-neutral locker systems in community spaces is a practical approach to increasing delivery efficiency and reducing failed deliveries. In New York, where space is constrained, population density is high, and curbside space is heavily utilized, the LockerNYC pilot program tests the potential of shared parcel lockers located in small public spaces to reduce pressure on infrastructure, particularly curb space.

In contrast, in Tokyo, where parcel lockers are less widely used, supporting unattended handovers through the installation of receiving boxes at residential buildings and homes represents a more appropriate approach than promoting non-home handovers. In Tokyo, unattended handovers are promoted as a response to labor shortages, as reducing repeated delivery attempts helps alleviate workforce constraints.

Establishing regulatory frameworks for non-automobile delivery modes. Last-mile operations are increasingly shifting from conventional truck-based deliveries toward lighter, low- and zero-emission modes. This trend is widely observed across cities, including the case cities examined in this study. However, the absence of clear regulatory frameworks for these emerging modes can create legal uncertainty and lead to disorganized delivery practices. As new delivery modes continue to grow, public authorities increasingly recognize the need to establish regulatory frameworks that are aligned with local delivery practices and urban conditions. In Amsterdam, where strong policies promoting vehicle electrification are in place, efforts focus on defining clear hierarchies among transport modes, including vehicle classification and speed limits, to enable the safe integration of relatively new delivery modes into an already dense transport system with narrow streets. Similarly, in New York, cargo e-bikes, which were previously not clearly regulated, have been incorporated into the city's e-bike regulations in response to the rapid growth of cargo-bike deliveries. This strategy typically emerges in contexts where the increasing use of non-automobile delivery modes risks exacerbating safety, regulatory, or spatial conflicts, and where clearer rules are needed to both manage these challenges and support the further adoption of sustainable delivery modes.

Cultivating logistics spaces. Lighter, non-automobile delivery modes offer advantages in dense urban areas, particularly in their ability to operate in narrow spaces and reduce congestion and emissions. However, these modes have limited range and capacity, and therefore require transloading from larger motor vehicles. In Tokyo, zoning regulations have historically permitted the establishment of microhubs in central areas, enabling private operators to adopt handcart and cargo-bike deliveries. In contrast, cities with traditionally strict restrictions on logistics land use in dense urban centers face growing pressure to secure space for goods handling and transloading. As a result, several cities have put forward policies that enable logistics activities in underutilized or shared urban spaces. In Singapore, where parking facilities in residential estates are well developed, allowing logistics service providers to use these spaces under the Courier Hub Scheme represents a practical approach. In New York City, where carriers often rely on curb space to organize walking delivery routes, the public sector has moved to formalize transloading at designated curbside locations. In Brussels, where some underutilized industrial spaces remain in urban areas, these spaces are repurposed to support goods handling for cargo-bike logistics networks. Among the case cities, both New York City and Brussels have gone further by updating zoning codes to permit certain logistics activities in mixed-use areas, partially converging toward a regulatory environment that has long existed in Tokyo.

Exploring intermodal systems beyond road transport. Finally, as the capacity of road space is limited, some cities are motivated to reduce its burden by exploring the use of alternative transport systems that already exist. In Amsterdam, a city with a historic canal system, the public sector has enabled private-sector initiatives to use barges for parcel deliveries. In New York City, a port city with a well-developed waterway system, the Blue Highways program has been initiated by the city to promote a modal shift to waterways. In Singapore, one of the most transit-oriented cities, the use of urban rail for mail and parcel deliveries has been tested through freight-on-transit trials.

6. Discussion and conclusion

This study examined e-commerce–driven last-mile delivery systems in five cities with different characteristics around the world, highlighting how local contexts of urban development, planning, and delivery service markets shape the state-of-practice. While the growth of the e-commerce market presents challenges to cities globally, its implications for last-mile logistics are mediated by differences in *demand density*, *size of urban agglomeration*, *built environment* (including parking and road spaces), *zoning restrictions*, *building code*, *zero-emission policies,* and *delivery service provider market*. These contextual factors allow us to understand the prevalence of specific delivery modes with their supporting facilities. The following are suggested key questions for planners and policymakers to assess urban freight transport in their cities, while considering their own vision for last-mile delivery systems and selecting appropriate strategies and strategy adaptation approaches.

- *Demand density*: What is the density and spatial distribution of parcel delivery demand? Does it justify the use of specific delivery modes (e.g., trolleys and cargo bikes)?
- *Urban agglomeration*: Does the size of the urban agglomeration support direct deliveries from large logistics facilities, or does it require transloading to achieve higher efficiency and lower costs?
- *Built environment*: What is the width of local roads, and what is the availability of curb space and parking? Do neighborhood and building types support specific types of receiving methods?
- *Regulatory and policy environment*: What regulations shape delivery options? Do zoning restrictions limit or permit logistics facilities such as microhubs that support specific delivery modes and/or out-of-home delivery infrastructure? Is revising zoning codes a feasible option? Do building codes provide sufficient parking for goods vehicles? Which delivery modes comply with zero-emission policy requirements?

- *Delivery service market*: Is the parcel delivery market fragmented or concentrated among dominant players? To promote sustainable last-mile delivery processes, is it appropriate to support new businesses, encourage dominant players, and/or enhance cooperation and coordination among them?

By assessing these dimensions, cities can better identify challenges and opportunities, and which strategies and implementation approaches are most appropriate for their specific context. Exploring these questions can also guide the development of sustainable urban logistics plans.

The findings underscore the importance of avoiding simplistic transfers of "best practices" from one city to another. Instead, strategies must be interpreted and adapted in light of the contextual factors that structure urban logistics systems. Our observation of common strategies and how they are implemented in case cities indicate that planners and policymakers should recognize both the shared challenges posed by the growth in last-mile delivery demand and the unique local conditions that shape how solutions can be implemented. By framing last-mile delivery systems through the dual lens of contextual differences and common strategies, this study contributes to a more nuanced understanding of urban logistics.

Despite these contributions, this study has several limitations. The comparative analysis relies largely on secondary data from diverse sources, which involve temporal inconsistencies in the reported statistics. Furthermore, limited data availability required the use of data at spatial scales that differ from the study area (e.g., national-level statistics). Moreover, related to the above limitations, the analysis remains largely qualitative, as constructing a fully consistent quantitative comparison across case cities was not feasible given the heterogeneity in data availability. While efforts were made to ensure consistency in the interpretation of contextual factors, these limitations should be considered when interpreting the findings.

Future research could extend this comparative approach by investigating additional city cases. The current study considers only five cities, all of which are from developed countries. In particular, including cases from the Global South would provide a more in-depth and generalizable understanding of how contextual factors influence last-mile delivery solutions. Insights from such extended research would help anticipate the future trajectories of last-mile logistics and inform the development of policies that promote greater sustainability. Another research gap is that this study focuses primarily on high- to medium-density areas, while issues in low- to medium-density residential areas are not explored in depth. Discussions of challenges and relevant policies for last-mile deliveries to suburban areas are often overlooked, even though they are becoming increasingly important as the e-commerce market expands and more delivery vehicles operate in these regions. This topic is also left for future studies.

CRediT authorship contribution statement

Takanori Sakai: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Conceptualization. **Bram Kin:** Writing – original draft, Visualization, Validation, Methodology, Investigation. **Heleen Buldeo Rai:** Writing – original draft, Visualization, Validation, Methodology, Investigation. **Alison Conway:** Writing – original draft, Visualization, Validation, Methodology, Investigation. **Lynette Cheah:** Writing – original draft, Visualization, Validation, Methodology, Investigation. **Giacomo Dalla Chiara:** Writing – review & editing, Validation, Methodology. **Walther Ploos van Amstel:** Writing – original draft, Visualization, Validation, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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