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TRADE-OFFS IN LAST-MILE LOGISTICS: LINKING DELIVERY MODELS TO KEY PERFORMANCE METRICS AND SUSTAINABILITY

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Purpose: Although extensive research has addressed operational efficiency and emissions in urban last-mile logistics, there is a lack of systematic analysis integrating financial costs, environmental sustainability, and other factors influencing delivery model selection. This paper aims to fill this gap by providing a comprehensive perspective on last-mile logistics, highlighting key factors that affect delivery model choice, and examining trade-offs among service efficiency, economic viability, and ecological impact in both urban and rural contexts.
Design/methodology/approach: The study is based on a literature review. Leading last-mile delivery models are presented, and key decision factors are identified and categorized as internal, external, or mixed. Based on this analysis, a Comparative Matrix of Last-Mile Delivery Models and Key Decision Factors is proposed, along with guidelines for its practical application**.**
Findings: The Comparative Matrix synthesizes the positive and negative effects of each last-mile delivery model with respect to nine decision factors. By illustrating the potential of different solutions, the matrix serves as a practical decision-support tool for selecting an optimal last-mile delivery model.
Practical implications: The matrix can guide companies in the decision-making process when choosing a last-mile delivery model.
Social implications: The tool may influence corporate social responsibility and promote environmentally sustainable practices in last-mile logistics.
Originality/value: This paper distinguishes itself by adopting a broad, systemic approach. It analyzes the main factors influencing last-mile delivery model choice, differentiates between urban and rural contexts, and considers both financial and environmental impacts. The resulting comparative matrix offers a practical, evidence-based framework for decision-making.
Keywords: last-mile delivery model, choice, matrix.
Category of the paper: research and viewpoint paper.

1. Introduction

The rapid expansion of e-commerce has fundamentally transformed global retail and logistics systems. Between 2016 and 2022, business-to-business (B2B) and business-to-consumer (B2C) e-commerce sales across economies representing approximately three quarters of global GDP increased by nearly 60%, reaching USD 27 trillion (UNCTAD, 2024). This growth has intensified pressure on logistics networks, particularly on last-mile logistics—the final stage of delivery from a local distribution node to the end customer. In e-commerce supply chains, last-mile delivery has become the most complex, cost-intensive, and environmentally burdensome segment, accounting for over half of total shipping costs and a disproportionate share of urban transport emissions (WEF, 2024a, 2024b). Rising customer expectations regarding delivery speed, reliability, and flexibility further exacerbate these challenges, while labor shortages, congestion, and regulatory constraints limit efficiency gains.

Against this background, companies are confronted with an expanding range of last-mile delivery models, including traditional home delivery, pick-up and drop-off (PUDO) points, click-and-collect, microhubs, crowdshipping, and autonomous or green delivery solutions. Each model entails distinct trade-offs in terms of cost, service quality, environmental impact, technological requirements, and regulatory feasibility. The purpose of this paper is to develop a structured and systematic framework to support decision-making in the selection of last-mile delivery models in e-commerce. Specifically, the study identifies key internal and external decision factors and synthesizes them into a comparative matrix that enables the evaluation of alternative last-mile solutions, with particular emphasis on financial and environmental outcomes.

Although the literature on last-mile logistics is extensive, existing studies tend to focus on individual delivery models, technologies, or isolated decision criteria. This fragmentation limits their usefulness for practitioners who must simultaneously consider multiple, interdependent factors under varying strategic and regional conditions. There is therefore a need for an integrative and flexible decision-support tool that captures the multidimensional nature of last-mile delivery choices. By consolidating insights from the literature into a holistic comparative matrix, this paper addresses this gap and provides a practical instrument that can be adapted to different company strategies, product characteristics, and regulatory environments. In doing so, the study contributes to both academic debate and managerial practice by bridging the divide between conceptual analyses and operational decision-making in last-mile logistics.

2. Literature grounding

The logistics definition presented by the Council of Logistics Management focuses on the processes of planning, implementation, and control, which aim to ensure the efficient and economically justified flow of materials and finished products. This approach captures the role of logistics as a discipline that significantly contributes to the optimization of economic processes (Council of Supply Chain Management Professionals [CSCMP], 2013).

The traditional delivery model operating within the business-to-business (B2B) structure has for years been the foundation of logistics, focusing on cooperation between producers and large retail units. This process relied on transporting goods from manufacturing plants to extensive distribution centers, from where products were shipped to retail stores. Individual customers could only purchase goods at physical sales points, which required them to visit stores in person (Christopher, 2016).

With the dynamic growth of e-commerce, a revolution in logistics has taken place. The introduction of the business-to-customer (B2C) model significantly simplified the logistics process by eliminating intermediaries such as retail stores and enabling the direct shipment of goods from producers or warehouses to end customers. This change accelerated the delivery process but also created new logistical challenges related to the need for faster responses to growing customer expectations (Hübner, Kuhn, Wollenburg, 2016).

Three fundamental stages are distinguished in the logistics of product distribution to the customer. The first stage of this process, First Mile Delivery, involves moving goods from the place of production to warehouses or distribution centers, where they are properly prepared for further transportation. Often, this is the stage where the product takes its final form, especially if it requires assembly from various components or the addition of supplementary elements. The importance of this stage highlights the decisive role of inventory management and warehouse logistics in ensuring smooth product flow. Warehouse space must be planned with optimization in mind, which allows for the quick location of individual goods and their seamless movement for the next stage. The intermediate stage, Middle Mile Delivery, covers the transportation of goods from central warehouses or main logistics hubs to regional and local distribution points, where products await the final stage of the journey (Lacy, Dahan, Erera, 2023). The last stage, Last Mile Delivery, is the delivery of the product to the end consumer, which for many customers represents the most tangible and decisive moment of the entire process (Schiffer, Schneider, 2020; Boysen, Fedtke, Schwerdfeger, 2020). The last mile delivery stage is considered the most demanding part of the entire logistics process, as it involves delivering products directly to the customer and requires coordination with local distribution centers and transport partners. In the context of e-commerce, this stage plays a dual role: on the one hand, it represents the technical conclusion of the logistics process, while on the other, it is a key element in building brand image and customer relationships (Plazier, Rauws, Neef, Buijs, 2024).

The way a company manages this stage directly affects how its reliability and quality of service are perceived. This part of the delivery process is particularly complex, as it requires precise planning, rapid execution, and the integration of growing consumer expectations. Increasingly, customers perceive speed and convenience of delivery as decisive factors in their purchasing decisions. The last mile is also associated with the highest environmental costs in the entire distribution process.

2.1. Main Last-mile delivery models

There are many options for organizing last-mile delivery.

According to the literature, the last mile delivery (LMD) process can be structured according to several models. The most well-known models are listed below, along with a brief description of each.

Home Delivery (Traditional Model)

- Goods are delivered directly to the customer's doorstep.
- Still the most widely used approach, but also the most expensive due to fragmented routes, low vehicle utilization, and high labor costs.
- It strongly impacts customer satisfaction but raises sustainability concerns (Trapp et al., 2021; Yılmaz, Aktaş, Demirel, 2022).

Pick-up and Drop-off (PUDO) Points

- Customers collect parcels from parcel lockers, convenience stores, or partner retail outlets.
- This model reduces failed deliveries, lowers costs, and consolidates delivery routes, which contributes to lower CO_2 emissions (Zhang, Demir, 2025).

Click-and-Collect (In-store Pickup)

- Customers order online but collect products directly from the retailer's physical store or a designated collection point.
- Provides convenience for customers who want to save shipping costs or combine shopping trips (Hübner et al., 2016).

Crowdshipping

- Involves using freelance couriers or private individuals (e.g., via apps) to perform deliveries.
- Offers flexibility and scalability but raises concerns about reliability, quality control, and labor rights (Gatta et al., 2019; Le Pira et al., 2021).

Autonomous and Innovative Delivery Models

- Drones and autonomous ground vehicles are being piloted to increase efficiency in urban areas.
- Though not yet widespread, they represent future-oriented solutions that could reduce costs and emissions while speeding up deliveries (Levkovych, Saraceni, 2023; Shaklab et al., 2023).

Microhubs Model

- Involves the use of small, decentralized urban warehouses or transfer points located close to customers.
- Goods are transported in bulk to microhubs and then distributed via environmentally friendly vehicles (e.g., cargo bikes, e-vans).
- This model helps reduce congestion, lower emissions, and improve delivery speed in dense urban areas (Novotná, Švadlenka, Jovčić, Simić, 2022).

Green Delivery Models

- Focus on environmentally sustainable solutions, such as bicycle couriers, electric vans, or cargo bikes in dense urban areas.
- Increasingly adopted to reduce the environmental footprint of logistics (Liu, Zhou, Yuen, Wang, 2024).

The choice of last-mile distribution model depends on many factors. Therefore, the decision regarding the selection of a specific last-mile distribution model should result from a thorough multi-factor analysis and take into account the interrelations between the considered factors.

3. Methods

3.1. Main factors determining last-mile delivery model

A review of the literature on logistics and last-mile delivery enables the identification of several key factors that determine the choice of an appropriate model. In the author's opinion, the most important ones include the listed below. They can be grouped into external and internal factors, i.e., those depending on the microenvironment and the company's internal conditions and capabilities. Stakeholders involved in the design and financing of solutions and available technologies have been consiedred as both external and interal (mixed) factors. This is because stakeholder engagement stems both from the company's involvement and from cultural, business, and legislative conditions. Available technologies, in turn, depend not only on current technological capabilities but also on the company's ability to finance such solutions.

The following nine key decision factors were identified.

- firm strategy (internal factor),
- cost considerations (internal factor),
- the level of customer service and compliance with the Service Level Agreement (SLA) (internal factor),
- environmental impact (external factor),
- stakeholders involved in the design and financing of solutions (external/ internal factor),
- available technologies (e.g., route optimization algorithms, sorting systems, drones, parcel lockers) (external/internal factor),
- product characteristics (internal factor),
- regulatory framework (external factor),
- location (urban versus rural areas) (external factor),
- regional context (global/national), as it influences legal and environmental regulations, customer expectations, and the feasibility of financing delivery solutions (external factor),

Each of the listed factors has a significant impact on the others and should contribute to the selection of the optimal solution. Therefore, a systemic and holistic approach to this issue is essential. This study focuses primarily on costs and environmental aspects. However, to make an optimal decision regarding the last-mile model, all nine factors must be taken into account, as the remaining seven strongly influence both financial and environmental costs. The key factors influencing the choice of the last-mile model are discussed in greater detail below.

3.1.1. Internal factors

Product Characteristics in last-mile delivery

The design of last-mile logistics solutions is strongly influenced by the characteristics of the products being delivered. Different types of goods require distinct logistical approaches to ensure efficiency, security, and customer satisfaction. For example, perishable goods such as food and pharmaceuticals, demand strict temperature control, timely delivery, and compliance with safety regulations. This often requires specialized infrastructure such as refrigerated vehicles, insulated packaging, and monitoring systems that guarantee product integrity throughout the delivery process (Accorsi, Manzini, Ferrari, 2014; Soysal, Bloemhof-Ruwaard, Haijema, van der Vorst, 2018). In contrast, the delivery of durable goods such as consumer electronics focuses more on minimizing the risk of damage and theft, often requiring secure packaging, insurance coverage, and in some cases, proof of delivery (Allen, Browne, Woodburn, Leonardi, 2012).

Product size and weight are also decisive factors in shaping delivery strategies. Large or bulky items, such as furniture or household appliances, cannot be accommodated by parcel lockers or compact vehicles, and therefore rely on specialized fleets offering home delivery and installation services (Mangiaracina, Perego, Seghezzi, Tumino, 2019). On the other hand, lightweight and compact products are better suited for automated delivery options, including parcel lockers and drones, which increase flexibility and reduce costs in dense urban environments (Boysen, Briskorn, Schwerdfeger, Weidinger, 2021).

Product value adds another dimension to last-mile logistics decisions. High-value items require enhanced security measures, such as real-time tracking, restricted delivery windows, or in-person verification at the point of delivery (Vakulenko, Hellström, Hjort, 2018). In contrast, low-value goods can be efficiently managed through unattended delivery systems, which increase convenience and reduce operational costs.

Taken together, these factors: product type, size, weight, and value shape the selection of last-mile delivery models and technologies. As e-commerce continues to expand, tailoring logistics systems to product-specific requirements will remain a critical challenge for operators aiming to balance efficiency, sustainability, and customer expectations.

Unlike product characteristics - an independent variable - the firm's strategy constitutes a dependent variable, determined by the objectives set by the company's management.

Firm strategy

The choice of a last-mile delivery model should align with the company's overall strategy. If the strategic goal is to increase market share, special attention should be paid to the level of customer service in logistics, as it directly influences customer acquisition. Shorter and more reliable delivery times increase customer satisfaction, and the choice of last-mile model has a significant impact on this parameter.

Empirical evidence indicates that superior service generates substantial tangible benefits, whereas inadequate performance entails considerable costs. A detailed examination of consumers satisfied with last-mile delivery highlights several positive outcomes: increased customer loyalty resulting from access to faster delivery options, a greater willingness to pay for enhanced delivery speed, higher monthly expenditure, and more frequent purchasing behavior. Specifically, 74% of satisfied customers intend to increase their purchase levels by 12% with their preferred retailer, and 53% express willingness to subscribe to paid delivery memberships. Conversely, 48% of dissatisfied customers plan to cease purchasing from poorly performing retailers, while those who continue to buy from them expect to reduce their spending by approximately 45% (Cap Gemini, 2019a; Ko, Cho, Lee, 2018).

When cost reduction lies at the core of a company's strategy, it significantly influences the choice of the last-mile delivery model. Expensive solutions, such as courier deliveries, are likely to be eliminated in such cases. However, as evidenced by the CapGemini study cited above, a strong cost-reduction orientation may ultimately result in lower revenues due to the loss of dissatisfied customers.

Financial coniderations and service level shaping Last-mile delivery model decision are resulting from firm strategy.

The level of customer service

In last mile delivery the customer service level is one of the most critical performance indicators, as it directly influences customer satisfaction, loyalty, and brand perception. Key elements include delivery speed, reliability, flexibility in delivery options, and transparency through real-time tracking (Li, Li, 2018).

To ensure consistent service quality, companies often define a Service Level Agreement (SLA**)**, which specifies measurable performance standards such as on-time delivery rates, maximum delivery times, acceptable error margins, and customer support response times. In the context of e-commerce, SLAs serve as a contractual framework that aligns customer expectations with operational capabilities, while also supporting continuous improvement and accountability in last mile operations (Buldeo Rai et al., 2023).

Customer preferences play very important role while shaping the last mile delivery strategy. The findings of Nogueira, Rangel, and Shimoda (2021) indicate that sociodemographic factors shape consumer attitudes toward sustainable last-mile delivery, with clear behavioral differences among groups. Female consumers were more inclined to prioritize sustainability over delivery speed and cost, which contrasts with Deliana and Rum (2019), who reported no gender difference in green consumption. Age also played a role: respondents under 24 and over 49 were more willing to accept slower deliveries in favor of sustainability, showing some alignment with earlier studies but also highlighting greater green potential among older consumers. Education level further influenced flexibility, as highly educated respondents were more likely to accept longer delivery times to reduce environmental impact (Rai et al., 2019). Income, however, did not significantly alter time or cost flexibility, though higher-earning individuals tended to be less sustainable in their choices—opposite to what previous research suggested (Chuanmin et al., 2014). Overall, only a minority of respondents were willing to adjust delivery preferences to support more sustainable last-mile solutions.

SLA and costs are closely interrelated. Managers must align service level agreements (SLAs) with the company's financial capacity and the profitability of individual customers. The more profitable the customer, the higher the SLA offered. In turn, the SLA level directly affects last-mile delivery solutions: the higher the SLA, the more flexible the delivery conditions and the shorter the delivery Times -consequently leading to higher costs.

Financial Considerations in last-mile delivery

Last-mile delivery is estimated to account for 40-55% of overall logistics costs due to fragmented routes, high labor intensity, and congestion in urban environments (Capgemini Research Institute, 2019). Labor cost driver are driver wages and benefits and they can account for 50-60% of last mile delivery costs in traditional (door-to door) model.

Autonomous vehicles and drones promise to reduce these costs by lowering labor expenditures, increasing delivery density, and improving route optimization. However, significant capital investments are required for infrastructure, vehicle acquisition, and compliance with regulatory standards.

Autonomous delivery robots and drones can reduce operational costs in dense metropolitan areas by exploiting economies of scale. For example, route optimization and automation can cut delivery expenses by up to 20-30% compared to conventional vans (Liu et al., 2023). Nonetheless, these savings are offset by high research, development, and certification costs, as well as insurance premiums reflecting liability uncertainties (Rodrigues, Lemos, 2021). Furthermore, deployment in dense urban areas often requires additional investments in micro-hubs and charging infrastructure, which can be costly for smaller operators.

In rural areas, financial challenges are even more pronounced. Long travel distances, low parcel density, and limited charging or landing infrastructure make traditional van deliveries economically inefficient, with costs per package up to three times higher than in urban zones (Allen et al., 2018). Drones and hybrid models, while offering potential efficiency gains, require high upfront expenditures in technology and regulatory approvals. Public subsidies or partnerships are often necessary to make such investments viable, particularly in developing economies (Clarke, Hinchliffe, 2020).

From a long-term perspective, financial viability also depends on environmental regulation. Carbon pricing, low-emission zones, and EU Green Deal objectives create financial incentives for low-emission technologies by penalizing fossil-fuel-based deliveries (European Commission, 2020). Thus, financial and environmental considerations are increasingly intertwined: while autonomous and electric last-mile solutions may be costly to implement initially, they can reduce long-term expenses by avoiding environmental penalties and accessing green subsidies.

3.1.2. External factors affecting Last-mile delivery model choice

Legal and environmental regulations in last-mile logistics

Regulation of last-mile logistics increasingly targets autonomous vehicles, including ground robots and delivery drones. In the European Union (EU), drones are governed by Regulation (EU) 2018/1139 and EASA rules, which classify operations into categories (“open”, “specific”, “certified”) depending on risk and impose requirements for operator registration, risk assessment, and certification (European Union, 2018). Road vehicles fall under the General Safety Regulation (EU) 2019/2144, which introduces advanced driver-assistance obligations and paves the way for automated driving systems (European Union, 2019). UNECE regulations on cybersecurity and software updates further shape technical compliance (Xu, Wei, Mi, Chen, 2025).

Liability remains a central issue. Autonomous delivery accidents raise questions about whether manufacturers, operators, or software providers bear responsibility. Current EU law combines product liability and national tort law, but harmonization is incomplete (Alatawneh et al., 2025a). Data protection under the General Data Protection Regulation [GDPR] (European Union, 2016) and cybersecurity regulations, such as UNECE R-155 (UNECE, 2020), also apply, given the extensive collection of geolocation and sensor data.

Environmental concerns strongly influence legal frameworks. While autonomous electric vehicles and drones reduce local emissions, broader assessments include lifecycle impacts of batteries and energy sources (Alatawneh et al., 2025). The EU pursues stricter emission standards and promotes zero-emission logistics to meet climate goals. Drones can shorten routes and reduce congestion but raise issues of noise, energy efficiency, and wildlife disturbance.

Future regulations are expected to integrate the EU AI Act, which will classify many AI systems used in autonomous logistics as “high-risk,” requiring transparency and safety controls. Policymakers are urged to clarify liability, enforce lifecycle environmental assessments, and harmonize cross-border standards to ensure safe and sustainable last-mile logistics.

Regional Diversity in Last-Mile Logistics Regulations

Regulatory and technological conditions for last-mile logistics vary significantly across regions, reflecting differences in economic development, technological capacity, and environmental policy. In the European Union (EU), harmonized rules for drones and autonomous road vehicles aim to ensure safety and cross-border compatibility. Strong environmental frameworks, such as the European Green Deal and emission reduction targets, accelerate the adoption of low-carbon last-mile solutions, including electric vans, drones, and micro-mobility robots.

By contrast, the United States follows a fragmented regulatory approach. The Federal Aviation Administration (FAA) governs drone use, but states and municipalities impose additional restrictions on airspace and sidewalk delivery robots. While the U.S. is a leader in technological experimentation, especially in urban drone trials, inconsistent rules across jurisdictions often slow large-scale deployment (Rodrigues, Lemos, 2021).

In emerging economies, last-mile logistics often faces challenges of limited infrastructure, high urban density, and weaker regulatory enforcement. Countries in Sub-Saharan Africa and South Asia, for example, experiment with drone deliveries for medical supplies, supported by international organizations, but broader commercialization is constrained by limited legal frameworks and high costs (Clarke, Hinchliffe, 2020). In contrast, China has rapidly integrated drones and autonomous vehicles into urban logistics ecosystems. China is gradually building a comprehensive legal and regulatory framework for data security in autonomous driving, combining legislation, technical standards, and policy measures to ensure compliance (Xu, Wei, Mi, Chen, 2025).

Environmental regulations also differ widely. While the EU imposes strict emission standards and lifecycle assessments, many developing countries prioritize economic efficiency over sustainability. However, cities like Dubai adopt proactive smart mobility strategies, blending regulatory support for automation with environmental planning (Chaudhry, Masoumi, Dienel, 2025).

This diversity underscores the need for adaptive legal frameworks. Policymakers must balance technological innovation, safety, and environmental protection in line with local economic and institutional capacities. Without regional harmonization, global logistics operators face regulatory fragmentation, which may limit the efficiency and sustainability of last-mile delivery systems.

Environmental impact

In some large urban areas (like eg. Paris), freight transport accounts for only 10-15% of total traffic - dominated primarily by private cars - yet it generates about a quarter of CO_2 emissions and significantly contributes to NOx and particulate matter pollution (Dablanc, Diziain, Levifve, 2011). Beyond environmental concerns, last-mile logistics often conflicts with urban policy goals of creating safe, livable, and attractive public spaces. At the same time, its critical role in ensuring the functioning and prosperity of cities makes its elimination impossible, reinforcing the urgent need to shift towards sustainable solutions (European Commission, 2021; Haarstad, Rosales, Shrestha, 2024). Globally, transport is responsible for nearly one quarter of CO_2 emissions, with road freight alone contributing 29.4% of transport-related emissions (Ritchie, 2020).

The challenges of last-mile logistics are intensified by urban densification, the rapid growth of e-commerce, and the expansion of the on-demand economy, which together increase both the necessity of efficient delivery systems and their negative externalities Scholars consistently highlight that strict service-level requirements, fragmented order sizes, frequent deliveries, and dispersed drop-off points make last-mile logistics the least efficient stage of the supply chain and a major contributor to congestion and air pollution (Mommens, Brusselaers, Van Lier, Macharis, 2019).

Consequently, there is growing recognition among stakeholders that last-mile logistics must become more sustainable (Gonzalez, Garrido, Vassallo, 2023). This shift is reflected in rising citizen expectations for cleaner air, safer streets, and higher-quality public spaces in local authorities enforcing stricter regulations on freight flows and their impacts, and in logistics operators increasingly adopting advanced technologies and experimenting with collaborative delivery models (Le Pira et al., 2024).

Rural and Metropolitan Contexts in Last-Mile Logistics

The design of last-mile logistics solutions differs substantially between rural and metropolitan areas, reflecting population density, infrastructure availability, and regulatory considerations. Urban agglomerations face high delivery volumes, traffic congestion, and stricter environmental regulations. Consequently, solutions in large cities increasingly rely on micro-hubs, cargo bikes, sidewalk delivery robots, and short-range drones to reduce emissions and mitigate congestion (Liu et al., 2023b). Municipal governments often support these innovations through low-emission zones, restrictions on heavy vehicles, and subsidies for zero-emission fleets (European Commission, 2020).

In contrast, rural areas present the challenge of sparse populations, long travel distances, and limited infrastructure for electric vehicles. Autonomous drones and mobile parcel lockers are often more cost-effective than traditional truck deliveries in such contexts, particularly for healthcare supplies and time-sensitive goods (Clarke, Hinchliffe, 2020c). However, legal frameworks for beyond-visual-line-of-sight (BVLOS) drone operations remain a bottleneck in many jurisdictions (FAA, 2023).

Environmental considerations also differ. In metropolitan areas, last-mile emissions contribute significantly to local air pollution and noise, prompting strict regulation. Rural areas face less regulatory pressure but must address economic sustainability of low-volume deliveries, where the environmental cost per package may be higher due to longer routes (Allen et al., 2018b). Hybrid models - combining centralized truck deliveries with autonomous drones or lockers - are increasingly explored as a compromise.

Ultimately, last-mile logistics must be adapted to spatial context: dense agglomerations favor short-range, low-emission, high-frequency deliveries, while rural regions require flexible, long-range solutions leveraging autonomy and shared infrastructure. Legal and regulatory systems should reflect these differences to ensure both efficiency and sustainability.

3.1.3. Internal and external (mixed) factors afecting Last-mile delivery model choice

Stakeholder Participation in Last-Mile Logistics

The rapid growth of e-commerce has fragmented last-mile deliveries, making cooperation among stakeholders essential for achieving sustainable Logistics (Kiba-Janiak, Marcinkowski, Jagoda, Skowrońska, 2021) Stakeholders cooperate for reasons such as cost savings, efficiency gains, knowledge exchange, or regulatory compliance.

Collaboration can take different forms. Vertical cooperation aligns supply chain partners to improve responsiveness, while horizontal cooperation between logistics providers reduces costs, empty mileage, and inefficiencies (Gansterer, Hartl, 2018). Public-private partnerships also play a critical role, as cities cannot address last-mile challenges without private actors Such partnerships facilitate infrastructure improvements, knowledge sharing, and route optimisation but raise issues of data ownership and trust.

Local authorities are particularly important in balancing stakeholders' needs. Through urban logistics plans, regulations, and infrastructure investments, they aim to reduce emissions, maintain urban attractiveness, and enhance quality of life (European Commission, 2021). While cooperation involves trade-offs, it is key to mitigating conflicts and advancing sustainable last-mile solutions (Plazier, Rauws, Neef, Buijs, 2024).

Available/required technology

Rapid technological progress is reshaping last-mile delivery, offering solutions that improve efficiency and reduce environmental impact (Le Pira et al., 2024). A major challenge is decarbonising fleets, with regulations and low-emission zones driving adoption of electric, hybrid, and fuel-cell vehicles (Bosona, 2020). Non-motorised modes, such as e-cargo bikes, offer low-cost and flexible alternatives in congested areas. Automation is also emerging, with drones, robots, and autonomous vehicles set to transform deliveries, though raising new concerns about safety and regulation. Technology further enables new delivery models. Parcel lockers, unattended delivery, and consolidation centers increase efficiency and sustainability. Micro hubs help optimise freight flows, though location constraints and limited volumes often require government support). Finally, digitalisation and new entrants—from start-ups to tech giants—are reshaping logistics through innovative, data-driven business models. Collectively, these innovations highlight technology's central role in building sustainable last-mile logistics.

3.2. Comparative Matrix of Last-Mile Delivery Models and Key Decision Factors

The result of the literature analysis on the selection of the last-mile delivery model is the Comparative Matrix of Last-Mile Delivery Models and Key Decision Factors (table 1). This matrix presents the positive and negative effects of applying a specific last-mile distribution model in light of the nine decision factors discussed above. By synthetically illustrating the potential of each solution, the matrix can serve as a useful tool to support the decision-making process related to the selection of an optimal last-mile delivery model.

Table 1.

Comparative Matrix of Last-Mile Delivery Models and Key Decision Factors

	Decision factors							Supporting decision factors	
Last-Mile Delivery Model	Firm Strategy	Financial Considerations	Customer Service & SLA	Environmental Impact	Product Specificity	Regulatory Framework	Urban vs. Rural/Regional Context	Stakeholders & Financing	Available/ required Technologies
Home Delivery (Traditional Model)	(+) Fits customer-centric growth strategies; enhances loyalty and repeat purchases through convenience and reliability. (-) Cost-oriented strategies may avoid this model due to high expenses	(+) High revenue potential via customer preference. (-) Accounts for 40-55% of logistics costs; high labor and fuel costs	(+) Maximizes satisfaction through door delivery. (-) High SLA costs; risk of failed deliveries	(-) High CO_2, congestion, and noise emissions	(+) Suitable for valuable, perishable, or bulky goods requiring secure handling	(-) Subject to vehicle emission limits, driver work-time rules, and low-emission zone restrictions	(-) Urban: costly and congested. (-) Rural: longer routes, up to 3× higher cost per package	Retailers, couriers, customers; funded via delivery fees or subsidies	Route planning, telematics, real-time tracking
Pick-up & Drop-off (PUDO) Points	(+) Supports cost-efficiency strategies and sustainability-oriented approaches by consolidating deliveries	(+) Lower operational costs through route consolidation. (-) Requires infrastructure investment	(+) Reduces failed deliveries; ensures SLA reliability. (-) Less convenient for door-oriented consumers	(+) Lower emissions via consolidated routing	(+) Standardized parcels. (-) Unsuitable for large, fragile, or temperature-sensitive items	(-) Must comply with data and security standards (GDPR for smart lockers)	(+) Urban: efficient and eco-friendly. (-) Rural: limited locker density, accessibility issues	Retailers, locker operators, logistics providers, local governments	Parcel lockers, RFID, route optimization systems
Click-and-Collect (In-store Pickup)	(+) Aligns with omnichannel retail strategies aiming to integrate e-commerce with physical stores.	(+) Eliminates delivery costs. (-) Requires in-store staffing and storage	(+) Flexible for customers; integrates with shopping trips. (-) SLA limited by store hours.	(±) Reduces delivery emissions but customer trips may offset benefits	(+) Best for non-perishable, low-value, or impulse-buy products	(-) Subject to retail operational and consumer safety regulations	(+) Urban: convenient near dense retail zones. (-) Rural: limited due to sparse retail networks	Retailers finance infrastructure; logistics providers minimally involved	Order management and inventory systems, in-store scanning

Cont. table 1.

Crowdshipping	(+) Fits asset-light, flexible business strategies; enables market entry with minimal capital	(+) Low entry costs, scalable. (-) Surge pricing and quality variability	(+) Fast and flexible service. (-) SLA reliability risks due to variable workforce	(±) Mixed impact: small vehicles can reduce emissions, but fragmented routing may raise them	(+) Small, urgent, low-value goods. (-) Not suitable for high-value or bulky items	(-) Subject to labor laws, platform regulation, and insurance liabilities	(+) Urban: effective for food and parcels. (-) Rural: low density limits feasibility	Platforms, freelancers, customers; shared financing	Mobile apps, GPS, algorithmic matching
Autonomous & Innovative Models (Drones, AGVs, Robots)	Supports innovation-driven strategies and green transformation goals; aligns with long-term sustainability and cost reduction	(+) 20-30% cost savings potential. (-) High upfront capital, R&D, and compliance costs	(+) High SLA potential—fast and reliable. (-) Limited payload and weather constraints	(+) Zero local emissions. (−) Battery lifecycle, noise, and wildlife impacts	(+) Lightweight, urgent, or high-value items (e.g., medical goods)	(±) Regulated under EU 2018/1139, EASA, and national aviation rules; liability and cybersecurity under GDPR & UNECE R155	(+) Urban: efficient for dense areas. (±) Rural: long-range drones viable but costly and legally constrained	Tech firms, logistics providers, governments (PPP models)	Drones, AGVs, AI route planning, IoT monitoring, charging stations
Microhubs & Urban Consolidation Centers	Ideal for sustainability-focused and efficiency-oriented strategies in dense cities	(+) Economies of scale reduce delivery costs. (-) Requires costly urban real estate	(+) Improves SLA reliability and delivery speed	(+) Major emission reduction via EVs and e-cargo bikes	(+) FMCG, groceries, e-commerce parcels	(±) Governed by urban mobility plans, low-emission zone regulations	(+) Urban: highly effective. (-) Rural: low density limits viability	Municipalities, real estate investors, logistics operators	Routing software, EV fleets, consolidation systems
Mobile Parcel Lockers / Hybrid Drone Models	Fits innovation and cost-control hybrid strategies, especially in low-density regions	(±) High initial costs but lower per-parcel costs over time	(+) Reliable SLA; 24/7 availability	(+) Reduces repeated delivery attempts and emissions	(+) Non-perishable, small, standardized items	(-) Must comply with airspace and data protection regulations	(+) Urban: supports flexible service. (+)Rural: improves accessibility where traditional routes fail	Governments, e-commerce platforms, logistics providers	Drones, IoT-enabled lockers, route optimization

Source: own work.

To facilitate the decision-making process for users of the matrix, the assessment of the suitability of a given last-mile distribution model can be quantified by assigning numerical values to individual cells of the matrix. Each positive effect ("+" in the matrix) is assigned a value of 1, while each negative effect ("–") is assigned a value of –1. This approach enables a straightforward evaluation of the overall value of a particular solution.

Given that the significance of individual decision factors will vary depending on the company's adopted strategy, operational characteristics, and broader context (such as regional regulations, technological capabilities, or stakeholder collaboration), it is reasonable to assign differentiated weights to these factors. The total sum of these weights should equal 1.

By multiplying the value obtained in a given cell by the weight assigned to the corresponding decision factor, one obtains the final quantified value for each cell in the matrix.

This allows for a clear and straightforward comparison of the results obtained by the individual last-mile models.

4. Discussion and limitations

In the matrix, the factor: „regional diversity in Last-Mile logistics regulations has been omitted. This results from the impossibility of assigning a specific last-mile delivery model to this factor. However, this factor may be incorporated into the matrix in the form of a weighting coefficient assigned to other decision factors.

Decision factors such as stakeholders & financing and available/required technologies serve a supporting role within the matrix but are not quantifiable. This is justified by the fact that the ability to secure financing for certain solutions through stakeholder involvement increases the likelihood of their implementation. However, stakeholder engagement depends on multiple factors, including existing regulations—which, for example, may encourage collaboration to develop environmentally friendly solutions—or the presence of best practices in partnership management. Consequently, this factor is difficult to quantify.

Possession of the required technologies is a necessary condition for the implementation of specific last-mile delivery models, but the ability to finance them depends on the company's situation and strategy, as well as the potential for co-financing by stakeholders. Therefore, quantification of this factor is also not feasible.

As a result, quantifiability applies to 7 of the 9 decision factors discussed.

The key to the effective application of this tool lies in the selection of appropriate decision criteria and the assignment of contextually adequate weights to them.

Depending on the company's operational profile and macro-environmental conditions, the number of decision factors may be adjusted to specific needs or contextual requirements.

In the existing literature, there is a substantial body of work on last-mile delivery models. Each model could serve as the basis for extensive, dedicated studies. The same applies to the decision-making factors discussed; each could be explored in considerable depth in individual studies. The present paper is synthetic in nature, aiming to provide a comprehensive and systematic overview. However, it certainly does not examine all topics in as much detail as specialized studies devoted to a single aspect of the discussion.

The matrix presented in this paper is illustrative and must be adapted to the specific requirements of the company applying it. Not all potential advantages and disadvantages associated with the implementation of a particular last-mile delivery model are listed in the matrix. The matrix requires careful contextualization with respect to the conditions of the specific company and its product.

The assessment of the potential of the presented matrix requires its practical application in companies facing the choice of a last-mile delivery model.

5. Summary

Despite extensive research on operational efficiency and emissions in urban last-mile logistics, there remains a notable gap in the literature regarding the integration of economic, environmental, and operational considerations in delivery model selection. Existing studies often focus on a single dimension—such as cost optimization, service performance, or carbon emissions - without systematically evaluating how these dimensions interact or considering the full range of factors that influence the choice of last-mile delivery models. This paper addresses this gap by providing a comprehensive, multi-dimensional perspective on last-mile logistics, with a particular focus on the trade-offs between service efficiency, economic viability, and ecological impact in both urban and rural contexts.

A literature review was conducted, synthesizing current research on leading last-mile delivery models, including traditional carrier-based systems, crowd-sourced and gig-economy solutions, locker-based networks, and emerging green logistics practices. Through this process, the study identifies and categorizes the primary decision factors affecting delivery model selection into three groups: **internal factors** related to organizational resources, capabilities, and operational processes; **external factors** including regulatory requirements, market demand, and environmental constraints; and **mixed factors**, which represent interactions between internal capabilities and external conditions.

Building on this analysis, the paper proposes a **Comparative Matrix of Last-Mile Delivery Models and Key Decision Factors**, designed to illustrate the positive and negative impacts of each delivery model against nine critical decision criteria, including cost efficiency, service quality, environmental footprint, flexibility, scalability, resource utilization, and regulatory compliance. The matrix provides a structured, practical tool for logistics managers, enabling informed decision-making by highlighting potential trade-offs and synergies among different delivery models.

The study further discusses how this framework can be applied in practice, both in urban centers with high population density and complex traffic patterns, and in rural areas where delivery distances, infrastructure, and cost structures pose distinct challenges. By integrating operational, financial, and ecological perspectives, the research contributes to the literature on sustainable logistics management and offers actionable guidance for companies seeking to optimize last-mile operations while advancing environmental sustainability.

Ultimately, the paper emphasizes the necessity of a **holistic, context-sensitive approach** to last-mile logistics decision-making, where strategic choices in delivery models must carefully balance competing objectives, including service performance, cost minimization, and ecological responsibility. The proposed framework supports both academic understanding and practical implementation, offering a versatile tool for future research and managerial decision-making in evolving logistics landscapes.

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