UNIVERSITY OF MISKOLC
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DIPLOMA THESIS

Logistics and E-commerce: How Last-Mile Logistics is Transforming the Online Sales Sector: Research into the challenges and logistics solutions for fast delivery, especially in the context of the growth of e-commerce and the new demands of consumers.

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3515 Miskolc-Egyetemváros

MASTER'S DEGREE THESIS ASSIGNMENT

Ramon de Paula Santos
Neptun code: BGUAJU
for candidate Logistics Engineer MSc.

Subject of the design: ***Logistics***

Title of the task: ***Logistics and E-commerce: How Last-Mile Logistics is Transforming the Online Sales Sector:*** *Research into the challenges and logistics solutions for fast delivery, especially in the context of the growth of e-commerce and the new demands of consumers.*

Details of the task:

1. To analyze how last-mile logistics is transforming the online sales sector, identifying key challenges and logistics solutions for fast delivery in the context of e-commerce growth.
2. Qualitative and exploratory study based on literature review, focused on B2C e-commerce last-mile logistics in Europe (2015–2025).
3. A literature review using secondary sources (articles, reports, and specialized publications), with no primary data collection, aimed at identifying patterns and innovations in the sector.
4. It contributes to logistics theory by mapping innovative and practical solutions, and supports companies in formulating efficient, sustainable, and customer-centered logistics strategies.
5. When developing the task, use figures, tables, and the above examinations and analyses, as well as support the development proposals with calculations.

Supervisor: ***Dr. Ákos Cservenák***
Consultant:
Instructor:
Date of publication of the thesis: *10 February 2025*
Deadline for submitting the thesis: *09 May 2025*

Signature of the head of the institute

1. *Modification of the thesis: necessary (the amendment is included in a separate sheet)*

   not necessary (the corresponding part must be underlined)

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DECLARATION OF AUTHENTICITY

Undersigned **Ramon de Paula Santos**, Neptun Code: **BGUAJU**, graduating as **Logistics Engineer MSc** student of the Faculty of Mechanical Engineering and Informatics of the University of Miskolc, I hereby declare under my criminal law and disciplinary responsibility and certify with my signature that **Logistics and E-commerce: How Last-Mile Logistics is Transforming the Online Sales Sector:** Research into the challenges and logistics solutions for fast delivery, especially in the context of the growth of e-commerce and the new demands of consumers, is my own, independent work; the literature referred to in it was used in accordance with the rules of source management.

I acknowledge that in the case of a thesis, it is considered plagiarism:

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Miskolc, May 9, 2025

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Student

Summary

1. Introduction

1.1. Motivation

E-commerce has experienced rapid growth in recent decades, becoming a key component of global retail. In 2022, for example, 68% of consumers in the European Union (aged between 16 and 74) made purchases online (Parcel monitor, 2025), highlighting the massive penetration of e-commerce. The COVID-19 pandemic has further boosted this movement, leading to a significant increase in the volume of parcels in circulation. In this scenario, logistics takes on a strategic role: delivering products efficiently and quickly is crucial, since the delivery experience directly influences customer satisfaction and loyalty.

Within the e-commerce logistics chain, "last mile logistics" - the final stage that takes the product to the end consumer - stands out as one of the biggest challenges. This phase can represent from 41% to more than 50% of the total logistics cost, making it the largest part of the distribution budget (Deloitte, 2022). Factors such as operational inefficiencies, failed delivery attempts, urban congestion and dispersed routes contribute to this high cost and complexity.

These issues make the last mile not only an operational challenge, but also a socio-environmental one, due to the increase in traffic and carbon emissions in urban areas. At the same time, consumer demand has evolved significantly, requiring fast, reliable and often free deliveries. Approximately 60% of global consumers expect to receive their orders within two days, with a growing preference for convenience, such as real-time tracking and alternative delivery options (Raji et al., 2024).

The ability to efficiently manage the last mile has become a critical success factor in e-commerce, differentiating leading companies from the competition. Academically, last-mile logistics is a fertile field for research, with recent studies exploring innovative operating models and the use of new technologies such as autonomous vehicles, drones and advanced data analysis. On a practical level, companies and logistics operators have invested in initiatives such as lockers and crowdshipping, as well as electric fleets and drone deliveries to overcome the challenges identified.

Therefore, investigating "Logistics and E-commerce" with a focus on the last mile is justified by its high contemporary importance, contributing to both logistics theory and practical solutions in the market.

1.2. Objectives

1.2.1 General Objective

This study aims to analyze how the online sales sector (e-commerce) is transforming last-mile logistics, in order to identify the main challenges related to the fast delivery of orders and emerging logistics solutions, considering the continuous growth of e-commerce and the new demands of consumers.

1.2.2 Specific objectives

- Mapping the current e-commerce landscape, describing its recent growth in Europe and globally, and analyzing the implications of this increase in volume on logistics operations, especially distribution to the end consumer.

- Identify and examine the main logistical challenges faced in the last mile, including high costs, operational complexity, urban problems such as traffic and delivery restrictions, as well as difficulties related to failed delivery attempts and environmental sustainability requirements.

- Present and evaluate solutions and innovations applied to the last mile, investigating strategies adopted to improve the efficiency and speed of deliveries, such as emerging technologies (autonomous vehicles, drones, data analytics), alternative delivery models (lockers, collection points, crowdshipping) and best operational practices in Europe and globally.

- To discuss the impacts of these transformations on the online sales sector, analyzing how improvements in the last mile influence the consumer experience, the competitiveness of e-commerce companies and aspects of sustainability, as well as identifying gaps and opportunities for future research in this area.

1.3. Delimiting the topic

This work is characterized as qualitative and exploratory research, conducted by means of a literature review. All the theoretical foundations and the analysis developed are based on secondary sources - mainly scientific articles, academic publications, industry reports and recent studies on logistics and e-commerce - without collecting primary data or conducting field research.

The purpose of a literature review is to compile and summarize existing knowledge on the topic, enabling the identification of patterns, recurring challenges, and solutions proposed in different scenarios.

In terms of scope, the study focuses on last-mile logistics in the context of B2C (business-to-consumer) e-commerce, i.e. the stage of delivering products purchased online to the end consumer. The analysis focuses on distribution operations urban and peri-urban retail orders, and does not cover, in detail, other stages of the logistics chain - such as production, supply or reverse logistics - except when these are directly related to the challenges of the last mile.

The geographic scope favors the European context, while also considering global dynamics for comparison and contextualization purposes, given the transnational nature of e-commerce. With regard to the time frame, priority is given to studies and data produced in the last decade (2015-2025), a period marked by the strong expansion of e-commerce and the emergence of logistical innovations, especially intensified during the COVID-19 pandemic.

It is also recognized that the subject of the last mile involves regulatory and urban infrastructure issues. However, this study is restricted to the operational, logistical and management perspective, addressing aspects of public policy or urban planning only when necessary to contextualize the solutions analyzed.

1.4. Work structure

In order to achieve the objectives outlined, this work is organized into five chapters, in addition to the bibliographical references:

- Introduction: Presents the context of the topic, including the justification, objectives, delimitation of the study and its organizational structure.

- Methodology: details of the procedures adopted in the research, highlighting the choice of bibliographic review, the sources used, the selection criteria and the limitations of the study.

- Literature Review: exposes the relevant theoretical concepts and studies related to last-mile logistics, e-commerce and consumer behavior, based on up-to-date data and specialized publications.

- Analysis of the literature review: presents the main challenges identified in the literature on the last mile and discusses the solutions and strategies proposed or implemented. It also includes practical examples and technological innovations that impact logistics efficiency.

- Final considerations: summarizes the main findings considering the established objectives, highlights the study's contributions and suggests recommendations for business practice and future academic research.

2. Methodology

2.1. Type of research

This study is qualitative and exploratory in nature. The qualitative approach was chosen because it enables an in-depth understanding of the processes related to last-mile logistics, particularly in the complex context of e-commerce. The exploratory nature is justified by the fact that the topic encompasses multiple variables in constant evolution, requiring an open and flexible analysis to identify emerging trends, challenges, and opportunities.

2.2. Methodological Procedures

For the theoretical foundation of this work, a systematic literature review was chosen. This method was selected due to its ability to gather, critically evaluate, and synthesize existing knowledge on the topic. Various secondary sources were analyzed, including indexed scientific articles, academic dissertations, specialized technical books, reports from renowned consultants, and institutional publications from recognized international organizations.

2.3. Source Selection Criteria

Specific criteria were adopted for the selection of bibliographic sources to ensure the relevance and quality of the materials used. These criteria included: the timeframe of publications between 2015 and 2025, ensuring up-to-date information; direct adherence to the central themes of the research (e-commerce and last-mile logistics); a geographic context primarily European and/or international, aiming for a broad and comparative perspective; and the academic and institutional credibility of the selected sources.

2.4. Research limitations

As this is an exclusively bibliographic study, it does not include the collection of primary data or empirical validation through field research. Furthermore, the analyzed information depends directly on the availability and quality of the consulted sources, which may introduce potential biases or regional restrictions. Nevertheless, the diverse and comprehensive use of sources allowed for the development of a critical and consistent analysis of the studied topic.

3. Literature Review

3.1. Modern Logistics: Recent transformations and the European context

Logistics plays a fundamental role in today's economy, permeating practically all productive sectors. Estimates indicate that logistics costs represent between 8% and 15% of global GDP, depending on the economic structure of each country (Apol, 2025). In Europe, renowned for efficient supply chains, the logistics sector has undergone intense transformations in response to global and regional changes. Geopolitical tensions, economic volatility and new regulatory demands expose vulnerabilities in the European supply chain. Recent events, such as the pandemic and international conflicts, have highlighted the importance of resilience and diversification in supply chains, leading companies to seek multiple suppliers and nearshoring strategies to mitigate risks.

At the same time, we are witnessing the digital and green revolutions in the transport and logistics sector, catalyzing a radical transformation in the way goods are moved. Technological advances - such as 5G connectivity, the Internet of Things (IoT), big data and Artificial Intelligence (AI) - are being incorporated into logistics processes, making flows more dynamic and intelligent. Concepts such as Logistics 4.0 are emerging, integrating sensors and automation to improve decision-making and operational efficiency. At the same time, sustainability has become a priority: there is growing pressure to reduce the carbon footprint of freight transport, whether due to increasingly conscious consumer demands or stricter environmental regulations. For example, European policies set modal migration targets, providing for 30% of freight transport over 300 km to migrate from road to rail or water by 2030, aiming for 50% by 2050, as a way of reducing emissions and congestion (Solistica, 2022).

Another driving force behind logistics modernization is the boom in e-commerce. Over the last decade, e-commerce in Europe has grown exponentially, culminating in a turnover of €887 billion in 2023 (European E-commerce report, 2024). This growth has significantly increased home deliveries, creating capacity and service challenges. Increasingly connected consumers demand fast and reliable deliveries: almost 50% of European carriers report that their customers expect delivery times of less than two days (La Haye, 2025). The massive increase in home deliveries and expectations for agile service are putting pressure on operations - just note that markets and consumers are demanding ultra-fast deliveries and impeccable green credentials from logistics companies. In response, the sector has invested

in urban hubs (distribution centers close to customers), larger fleets and new service technologies, to balance speed of delivery with costs and sustainability.
In this context, modern European logistics relies on four key strategic pillars: visibility, integration, technology, and sustainability. These pillars guide companies in adopting best practices to remain competitive in a rapidly changing market. The following sections explore how these pillars shape the current design of logistics, providing the conceptual foundation for understanding trends such as innovations in last-mile logistics

3.2. Evolution of E-commerce in the World and in Europe

E-commerce in Europe has seen consistent growth in recent years, reflecting significant changes in consumer habits and technological advances.

Market growth

In 2024, European e-commerce turnover reached €958 billion, representing an 8% increase on the €887 billion recorded in 2023. This growth marks the first significant expansion since 2021, adjusted for inflation (Reuters, 2024).

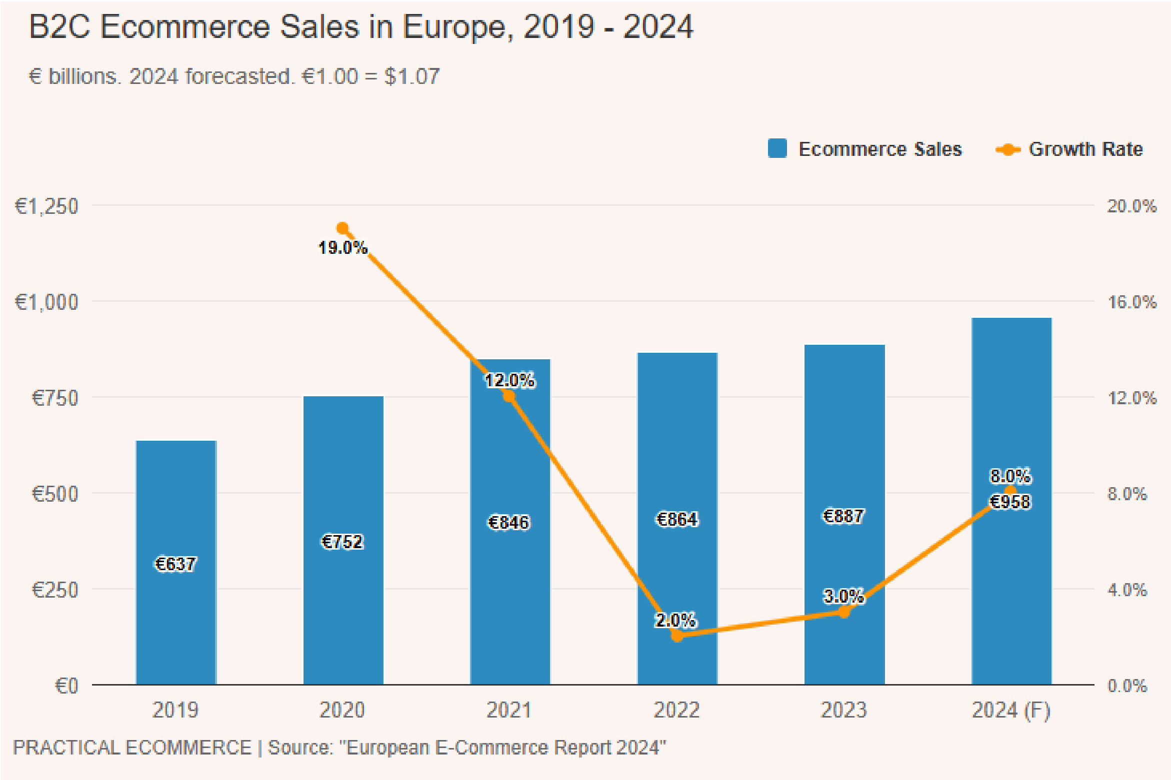

Figure 1 - Business to costumers E-commerce sales in Europe 2019- 2024 (Source: Practical Ecommerce | European E-commerce Report 2024)

Consumer Participation

By 2024, 77% of internet users in the European Union had made online purchases in the previous 12 months, a significant increase on the 59% recorded in 2014.

Age groups between 25-34 and 35-44 were the main contributors to the flow of e-commerce in the EU in 2024, with 89% and 86% of these internet users, respectively, making online purchases. (European Commission, 2024)

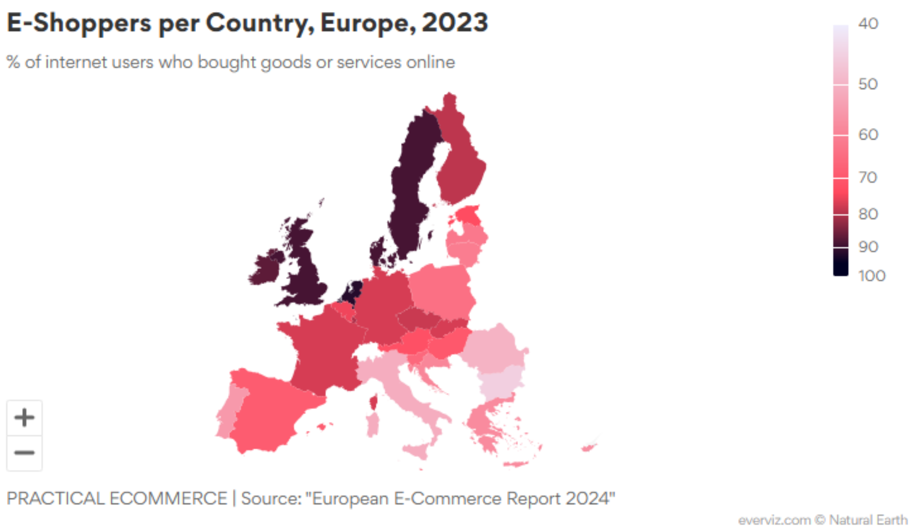

Figure 2 - Eletronic shoppers per country, Europe, 2023 (Source: Practical Ecommerce | European E-commerce Report 2024)

Popular Product Categories

The most popular categories among online shoppers in the EU in 2024 were clothing, footwear and accessories, with 46% of internet users purchasing these items, followed by products from restaurants, fast-food or catering services.

Regional Highlights Examples

Italy stood out with robust growth in e-commerce, reaching €80.6 billion in online sales in 2023, consolidating its position as one of the fastest-growing markets in Europe (E-Commerce News PT, 2024). In Germany, e-commerce sales grew by 1.1% in 2024, also reaching €80.6 billion, driven by greater consumer confidence and rising domestic economies (Reuters, 2024).

Future trends

The number of e-commerce users in Europe is expected to reach 564.4 million by 2025, indicating a growing adoption of online shopping in the region (Hostinger, 2025).

In addition, revenues from the European e-commerce market are projected to reach almost $900 billion by 2028 (Statista, 2024; Mordor Intelligence, 2024).

These figures show the growing importance of e-commerce in Europe, both in terms of consumer participation and economic impact, highlighting the need for efficient logistics strategies to meet the demands of this expanding market.

3.3. Comparing Logistic Models

3.3.1. Logistics models

Logistics models refer to the different ways in which organizations structure their flows of materials, information and services to meet market demand, considering factors such as product type, target market, delivery time, technology, infrastructure and competitive strategy. The main models include:

Integrated Logistics

A model that seeks total coordination between supply, production, storage, distribution, and reverse logistics activities, with the aim of maximizing the level of customer service and minimizing total costs. Integration also encompasses information flows and the intensive use of IT systems.

The choice of a business model involving the concept of total logistics in its processes is a complex and very delicate choice, as it involves determining factors for the success of the business. Defining the business rules very well in the strategic, tactical and operational areas. (Garnbratt & Lindh, 2024)

Some of the main logistics elements for the different planning time horizons:

Strategic: The planning horizon is medium to long-term, where the business's goals and objectives in a more distant future are evaluated, defining the macro objectives. Definition of the business structure and sectors and their hierarchies. Evaluating the financial and political impacts that imply the achievement of the defined objectives. In terms of logistics, taking into account points that make the business viable, such as:

- customer service
- channels of distribution
- supply points
- production locations
- depot configuration
- depot types and number
- location and size of depots transport modal choice
- third party or own account direct
- delivery stock levels

Tactical: It has a characteristic of short to medium-term decision-making. The focus at this stage of planning is in a subsystem manner, within what was defined in the long-term planning, the short-term actions that will ensure the fulfillment of these objectives are defined. The planning must consider the annual financial and cost budgets defined. As well as the definition of goals and objectives that will guide the actions and planning of the operational sectors. At this stage, aspects such as:

Table 1 - Aspects by Operational Sectors (self made)

Transport	Vehicle types/sizes/numbers
	Contract hire
	Primary routes
	Delivery schedules
	Driver resources
	Support facilities
Depot storage	Design and layout
	Space allocation
	Storage media
	Handling methods
	Fork-lift truck types and numbers
	Unit loads
Administration/information	Information support systems
	Monitoring procedures
	Stock location and control
	Order processing documentation

Operational: to fulfill the objectives established by tactical planning, the operational planning must include strategies and day-to-day action plans, with weekly controls and reports, ensuring the efficiency of the goals established in tactical planning, and thus ensuring the long-term objectives, established by strategic planning. Points that the operational planning encompasses:

- goods receipt and checking
- bulk storage
- order picking

- stock replenishment
- order marshalling
- load scheduling returns
- personnel availability
- stock update
- documentation completion
- vehicle maintenance
- vehicle workshop activity

Pull and Push Logistics Model

Pull Logistics

The Pull system, on the other hand, operates based on actual demand. Nothing is produced or moved until there is a customer order. In this model, the supply chain is "pulled" according to need, avoiding unnecessary inventory and focusing on demand-driven production. This provides greater flexibility, less waste, and better adaptation to market variations. However, as everything is done on demand, there may be a longer waiting time for the end customer, and the system needs to be highly efficient and responsive to avoid delays and disruptions. This model is common in made-to-order, customized, or highly variable demand industries. (Rushton et al., 2014)

Push Logistics

The Push system is based on demand forecasts, meaning products are produced in advance and pushed through the logistics chain, from the manufacturer to the consumer, even before a confirmed sale. Production is guided by market estimates and projections, which means products remain in stock until they are sold. This model is widely used in environments with high consumption predictability, such as the durable goods and fast-moving consumer goods sectors. Its main advantages are economies of scale, reduced costs per volume, and immediate availability for the customer. However, it also presents significant risks of excess inventory, product obsolescence, high storage costs, and low flexibility in the face of unexpected demand changes. (Rushton et al., 2014)

Table 2 – Comparison between Pull and Push logistics systems (self made)

Characteristic	**Push System**	**Pull System**
Operational Basis	Demand Forecast	Actual Demand / Confirmed Orders
Production Trigger	Estimates and Planning	Customer Need
Inventory	High, throughout the chain	Low, only as needed
Delivery Time	Short	May be longer
Flexibility	Low	High
Risks	Obsolescence, excess inventory	Lost sales due to delays
Inventory Costs	High	Reduced
Efficiency	Good with stable demand	Good with variable demand
Example of Use	Retail, mass production	Customization, made-to-order

Just in Time (JIT):

Originally developed in the automotive industry, the JIT concept was born with the objective of improving the efficiency of production plants and reducing production costs. Focused on the elimination of waste, especially inventory, the inputs arrive exactly when needed for the production process.

'JIT aims to meet demand instantaneously, with perfect quality and no waste'. (Sarkar, 2014)

The central objective in eliminating waste goes beyond production surpluses, it is the overall evaluation of the system and the identification of process improvements that help improve efficiency as a whole. Main types of waste that should be evaluated in the process: overproduction.

- waiting;
- transporting;
- inappropriate processing;
- unnecessary inventory;
- unnecessary motions;
- defects.

In terms of last-mile, especially in a context of a high number of deliveries, the JIT methodology is very important to ensure the necessary quality, in the best possible efficiency. This model requires high reliability of suppliers, synchronization and predictability.

3.3.2. Logistics Resources Planning and Management

MRP and DRP (Materials Requirements Planning and Distribution Requirements Planning)

MRP is a computerized production planning system that aims to ensure that the right materials are available at the right times. It starts from the dependent demand of the final products to calculate the needs of raw materials and components. Evolving into MRPII, the focus expands to include all the productive resources of a company, integrating material planning with production and supply control. (Rushton et al., 2014)

DRP, on the other hand, applies these same concepts to the distribution system, organizing the flow of materials from the production center to the distribution centers and final customers. It works based on time, ensuring that products flow through the chain and are available in the right place and at the right time. When integrated, both systems reduce freight, storage, and inventory costs, and increase efficiency and customer service levels, being particularly relevant in global and complex logistics chains.

Objectives of MRP and DRP

- MRP: Plan and control the acquisition of raw materials, components, and supplies, ensuring that production occurs at the right time, in the right quantity and quality.
- DRP: Plan and synchronize the distribution of finished products throughout the logistics chain, ensuring availability at distribution centers and points of sale.
- Reduction of excess and obsolete inventories throughout the chain.
- Improvement in the accuracy of demand and replenishment planning.
- Optimization of purchasing and production, with shorter lead times.
- Increased service level.
- Better balancing of supply and demand, with end-to-end visibility.
- Reduction of costs with storage, transportation, and working capital.
- Integration of material and information flows, reducing disruptions.

MRP II (Manufacturing Resource Planning)

MRP II is a variation of MRP, expanding its scope to comprehensively integrate all the productive resources of an organization. In addition to material planning, MRP II includes planning for production capacity, labor, machines, equipment, production time, and other resources necessary to meet demand. Its systemic approach covers everything from order receipt to final product delivery, promoting greater operational efficiency and integration between the production, purchasing, logistics, and finance sectors. In complex and global logistics chains, the use of MRP II provides strategic alignment, waste reduction, and greater precision in tactical and operational planning, being essential to ensure competitiveness and sustainability in the market (Burney et al., 2017; Shorrock & Orlicky, 1978).

Defining the Ideal Inventory Level

In modern e-commerce, especially under the pressure of fast delivery and evolving customer expectations, inventory planning becomes a key enabler of last-mile logistics efficiency. The ideal inventory system must balance product availability with inventory costs, while ensuring proximity to the end consumer for rapid fulfillment.

To achieve this, we integrate the following engineering and logistical concepts:

- Economic Order Quantity (EOQ)
- Reorder Point (ROP)
- Safety Stock
- ABC Classification and the Pareto Principle

EOQ (Economic Order Quantity)

EOQ is a classical inventory model used to determine the optimal quantity of units to order to minimize the total cost of inventory, (Rushton et al., 2014) which includes:

- Ordering Costs (e.g., administrative, handling, shipping)
- Holding Costs (e.g., storage, insurance, depreciation)

EOQ Formula

$$EOQ = \sqrt{\frac{2 \cdot P \cdot D}{U \cdot F}}$$

Where

- P = Cost of placing an order
- D = Annual demand in units
- U = Cost of a unit of inventory
- F = Annual stock-holding cost as a fraction of unit cost
- UF = Cost of holding stock per unit per year

Example

P = €75 = Cost of placing an order

D = 2.400 = Annual demand in units

U = €50 = Cost of a unit of inventory

F = 25% (1/4) = Annual stock-holding cost as a fraction of unit cost

$$EOQ = \sqrt{\frac{2 \cdot 75 \cdot 2.400}{50 \cdot 0{,}25}} = \sqrt{\frac{360.000}{12{,}5}} = 170[units]$$

Reorder Point (ROP)

While EOQ determines how much to order, the Reorder Point tells when to reorder — i.e., the inventory level at which a new order should be placed. It considers the lead time (the time between placing an order and receiving it) and the demand during that lead time.

ROP Formula

$$ROP = d \cdot L + SS$$

Where

- d = Average daily demand
- L = Lead time (days)
- SS = Safety Stock

Safety Stock (SS)

Safety stock acts as a buffer against demand variability and delays in lead time (Rushton et al., 2014). This is crucial in last-mile logistics where customer satisfaction depends heavily on delivery speed and stock availability.

Safety Stock (Greasley's Formula)

$$SS = Z \cdot \sigma d \cdot \sqrt{L}$$

Where

- Z = Z-score for desired service level (e.g., 1.65 for 95%)(based on Z table)
- σd = Standard deviation of daily demand
- L = Lead time in days

Z Table

The Z table, also known as the standard normal distribution table or Z-score table, is a widely used tool for looking up Z-scores and their corresponding probabilities. It's essential for anyone working with statistics who needs to find the probability linked to a specific value in a normal distribution.

In the Z table, values are shown to the left of the mean of the normal distribution. Each entry represents the area under the normal curve to the left of a given Z value. Negative Z-scores indicate values below the mean (Iverson, 2010)

Example

Daily demand: $d = 20\ units$
Standard deviation: $\sigma d = \ 5\ units$
Lead time: $L = 3\ days$
Desired service level: 95% ($Z = 1.65$)

$$ROP = 20 \cdot 3 + 1{,}65 \cdot 5 \cdot \sqrt{3}\ \approx 74{,}3$$

Reorder when inventory reaches ~74 units.

ABC Classification and Pareto Principle (80/20 Rule)

To manage inventory effectively across hundreds or thousands of SKUs, we use the ABC Classification method, based on the Pareto Principle: 20% of products typically account for 80% of revenue or demand.
This segmentation helps prioritize inventory investments and service levels.(Swamidass, 2000) Class A items receive the most attention with tight inventory controls and high service levels, Class B items get intermediate attention, and Class C items have simpler controls with lower service levels. (Kannaiah, 2015)

Direct Product Profitability (DPP)

Direct Product Profitability is an analysis technique that allows attributing all logistics and commercial costs directly to a specific product, instead of distributing them as an average over the entire product line (Rushton et al., 2014). Transportation, storage, handling, and other costs are precisely allocated to each item. This approach offers granular visibility into the actual profitability of a product, being extremely useful for identifying inefficiencies in the overall logistics operation. (Kannaiah, 2015) Applied in an international context, DPP allows understanding how different products perform in specific regional markets, taking into account local logistics costs, such as predominant modes, infrastructure, distances, and regulatory conditions. Furthermore, the methodology serves as a support for pricing, promotion, and marketing positioning strategies, being crucial for business decisions in highly competitive environments such as the globalized e-commerce.

DPP Formula

This metric quantifies the adjusted gross margin, less direct product costs, as:

$$\boldsymbol{Direct\ product\ profitability}\ (\%) = \boldsymbol{Gross\ margin}\ (€) - \boldsymbol{Direct\ product\ costs}\ (€)$$

The basic DPP formula is:

$$\boldsymbol{Sales\ Price}(€) - \boldsymbol{Purchase\ Cost}(€) = \boldsymbol{Gross\ Margin}(€)$$

$$\boldsymbol{Warehouse\ Costs} + \boldsymbol{Transport\ Costs} + \boldsymbol{Store\ Costs} = \boldsymbol{Direct\ Product\ Costs}$$

$$\boldsymbol{Gross\ Margin} - \boldsymbol{Direct\ Product\ Cost} = \boldsymbol{Direct\ Product\ Profit}$$

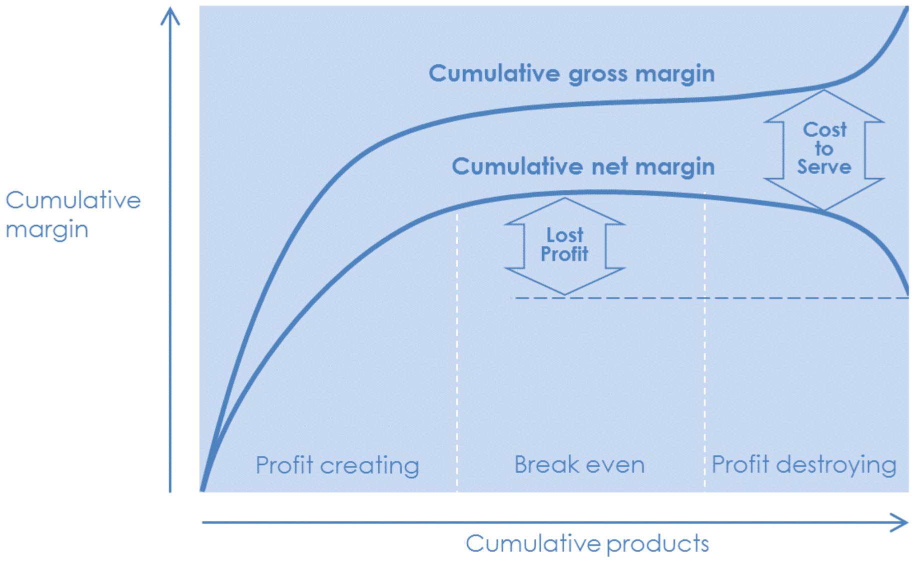

Figure 3 - Cumulative margin per cumulative products (Source: Anaplan, 2025)

Objectives of DPP in Logistics

The implementation of Direct Product Profitability in logistics is a strategic approach aimed at measuring the actual profitability of each product, considering all direct costs associated with its logistics cycle.

- Evaluate the actual unit profitability of each SKU, integrating logistics costs.
- Support portfolio, pricing, and promotion decisions based on net margin per product.
- Reduce cross-subsidies between high and low profitability products.
- Optimize the product mix considering profitability and cost-to-serve. Transparency in profitability by SKU, improving financial control.
- Cost reduction through the elimination of unprofitable items.
- Optimization of replenishment and storage processes, focusing on high-profit products.
- Improvement in the level of customer service with a focus on profitable and high-demand products.
- Support negotiation with suppliers and channels, with more accurate data on the cost-to-serve.
- Alignment between areas based on common profitability indicators

3.3.3. Distribution Structures

Distribution Center-Based Logistics Model

The logistics model based on Distribution Centers is a widely used structure in supply chain management, whose main objective is to centralize or decentralize inventories at strategically located geographic points in order to optimize the flow of products between the supply chain links and serve demand more efficiently. This approach aims to reduce total transportation costs, improve logistics service levels, and reduce delivery times to the end customer.

The design and dimensioning of logistics networks based on DCs involve quantitative methodologies, with a focus on mathematical optimization models, especially those based on Mixed-Integer Linear Programming. The classic formulation of these models seeks to minimize total logistics costs, represented by the following objective function:

$$Min\ Z = \sum_{i \in I} \sum_{j \in J} (Cij \cdot Xij) + \sum_{j \in J} (Fj \cdot Yj)$$

Where

- Cij is the unit transportation cost from origin point i to distribution center j;
- Xij represents the quantity of products transported from i to j;
- Fj corresponds to the fixed operating cost of distribution center j;
- Yj is a binary variable that indicates the activation of the distribution center (Yj =1) or not (Yj = 0)

The decision between centralization or decentralization should consider the trade-off between economies of scale and agility in responding to the market. Centralization allows for greater control and reduction of fixed operational costs, while decentralization favors reduced delivery times and increased responsiveness. Multi-criteria analysis techniques, such as the Analytic Hierarchy Process, can be employed to evaluate alternatives for the location and structure of the distribution center network based on multiple strategic and operational criteria.

From an operational standpoint, the logistics flows in a distribution center-based model involve three macro-processes:

inbound logistics: encompasses the receipt and transportation of products from suppliers or production facilities to the distribution centers;

Warehousing and inventory control: includes inventory policies, such as economic order quantity, reorder point, and accuracy management;

outbound logistics: refers to the distribution of the products stored in the distribution centers to points of sale, end customers, or consumption centers, generally with the support of routing algorithms, such as those of the Vehicle Routing Problem type.

Furthermore, the use of decision support technologies, such as WMS and TMS systems, integrated with ERP platforms, is essential to ensure the efficiency and traceability of logistics processes in distributed networks.

This model, when properly planned and implemented, contributes significantly to the achievement of sustainable competitive advantages, by aligning logistics objectives with the organization's corporate strategy.

Micro-fulfillment: Using local hubs for quick delivery

Micro-fulfillment refers to the strategic use of small, automated or semi-automated warehouses located close to end consumers to accelerate order processing and last mile delivery. Positioned within urban areas or densely populated regions, micro-fulfillment centers (MFCs) aim to bridge the gap between growing consumer expectations for rapid delivery and the logistical constraints of centralized distribution models.

Unlike traditional large-scale fulfillment centers located on city outskirts, MFCs are designed to store high-demand, fast-moving items and enable same-day or next-day delivery within a narrow geographic radius. This proximity drastically reduces delivery lead times and allows for efficient batch picking and route optimization. Micro-fulfillment thus plays a vital role in supporting e-commerce models such as quick commerce (q-commerce) and on-demand delivery, particularly for grocery, pharmaceuticals, and consumer goods sectors.

In the European context, micro-fulfillment has gained traction as a response to urban delivery challenges, including congestion, environmental regulation (e.g., low-emission zones), and increasing labor costs. Retailers and e-commerce players across countries such as the UK, Germany, and the Netherlands are adopting hybrid models that combine in-store picking with dedicated urban MFCs to enhance service levels without overextending supply chain costs.

Technologies such as warehouse robotics, AI-driven inventory management, and integration with delivery management platforms are essential to the micro-fulfillment concept. These tools support high-throughput operations within limited urban footprints and enable dynamic stock replenishment based on real-time demand signals.

Nevertheless, micro-fulfillment entails significant CAPEX, space constraints, and the complexity of maintaining synchronized inventory across a decentralized network. Despite these challenges, the model is increasingly viewed as a competitive differentiator for e-commerce operations focused on speed, flexibility, and customer-centricity in last mile logistics.

3.3.4. Last-Mile Delivery Models

Direct Delivery: Traditional delivery to the customer's door.

Direct delivery, also known as home delivery, is the classical distribution model in which the product is transported directly from a distribution center or consolidation point to the customer's address. Widely adopted across the European e-commerce landscape, this model represents the final and most critical link in the logistics chain — the so-called last mile, a stage that plays a decisive role in customer satisfaction and online retail competitiveness.

Direct delivery stands out for offering maximum convenience to the consumer, eliminating the need to travel to pickup points or lockers. However, it also presents significant logistical challenges such as fragmented routing, high operational costs, low delivery density per route, limited delivery time windows, and rising expectations for fast, trackable shipments.

In Europe, advancements in Industry 4.0 technologies have helped mitigate these challenges, with the implementation of electric delivery vehicles and intelligent routing algorithms aimed at supporting the continent's environmental agenda, reducing costs, and increasing efficiency in densely populated urban areas.

Success stories from companies such as Amazon and JD Logistics illustrate the positive impact of the direct delivery model, especially when supported by strategically located urban fulfillment centers, advanced fleet management systems, and automation in picking and sorting processes.

Although direct delivery offers a clear competitive advantage — particularly in markets with high digital penetration and mature infrastructure — its economic viability depends on balancing service level with delivery density. As a result, many European e-commerce players combine this model with hybrid alternatives such as PUDO (Pick-Up and Drop-Off) points and automated lockers to optimize logistics performance and enhance the overall customer experience.

Out-of-Home Delivery

Out-of-home (OOH) delivery refers to last mile logistics models in which online orders are not delivered directly to the consumer's home, but rather to designated collection points such as smart lockers or staffed pickup points. This model has gained substantial traction across Europe as an alternative to traditional home delivery, offering greater flexibility to both carriers and consumers while alleviating common last mile bottlenecks.

Smart lockers, typically located in high-traffic areas (e.g., transit hubs, supermarkets, or residential complexes), allow customers to retrieve parcels 24/7 by entering a digital code or scanning a QR code. Pickup points, often hosted in local shops or service counters, provide a human interface for parcel collection and sometimes returns. These formats reduce failed delivery attempts and optimize delivery density, especially in urban environments where traffic congestion and parking limitations challenge direct-to-door delivery.

From a logistics efficiency standpoint, OOH delivery enables carriers to consolidate multiple deliveries into fewer routes, which translates into reduced fuel consumption, lower emissions, and faster delivery rounds. This aligns closely with the European Union’s environmental goals and supports the broader transition toward green logistics and sustainable last mile solutions.

Consumer adoption of OOH options is also rising due to their convenience and reliability. In countries like France, Germany, and the Nordics, out-of-home delivery networks are well-established and widely used. In Poland and the Baltic region, companies such as InPost and Omniva have pioneered dense locker networks that integrate with mobile apps and real-time tracking technologies, delivering seamless user experiences.

Despite its benefits, OOH delivery requires significant upfront investment in infrastructure, system integration, and maintenance. Additionally, rural deployment may be less economically viable due to low parcel volumes. Nevertheless, the model offers scalable potential in urban areas and is increasingly integrated with omnichannel retail strategies and reverse logistics processes.

Crowdsourced Delivery: Utilizing independent deliverers

In the European e-commerce landscape, crowdsourced delivery has become particularly relevant for urban areas, where delivery time sensitivity, fluctuating order volumes, and cost-efficiency are key concerns. It offers high levels of flexibility, enabling rapid response to peak demand periods and localized fulfillment needs. Furthermore, crowdsourced delivery can reduce fixed logistics costs and facilitate late-night or weekend deliveries that traditional carriers may not support.

The model operates through digital platforms that connect available gig workers with delivery requests in real time. These platforms typically provide route guidance, customer communication tools, and performance tracking features, allowing for relatively seamless integration with the e-commerce or retail company's fulfillment system.

From a logistical standpoint, crowdsourced delivery supports hyperlocal fulfillment and complements other last mile strategies such as micro-fulfillment and out-of-home delivery. However, it introduces variability in service quality, legal risks around labor classification, and challenges in ensuring consistent customer experience. Additionally, it is less suited for large or regulated items, focusing instead on small parcels, food, or same-day essentials.

In Europe, the expansion of this model is influenced by national labor laws, urban mobility infrastructure, and platform regulation frameworks. While cities like Berlin, Barcelona, and Milan have seen rapid adoption, policy scrutiny over gig economy practices—particularly regarding worker protections—may shape its future scalability and legal sustainability.

Autonomous Delivery

Autonomous delivery involves the use of unmanned aerial vehicles (UAVs or drones) and ground-based delivery robots to transport goods directly to consumers without human intervention. As part of the broader digital transformation of last mile logistics, this model holds promise for improving delivery speed, reducing labor dependency, and addressing environmental and urban congestion challenges.

In Europe, pilot programs and regulatory sandboxes have enabled the testing of autonomous delivery solutions in both urban and rural settings. Companies such as Starship Technologies, based in Estonia, have deployed ground delivery robots in several European cities, including Milton Keynes (UK) and Hamburg (Germany), for short-range deliveries of groceries and takeout food. Meanwhile, drones have been tested in countries like

Switzerland and Iceland for medical supplies and time-sensitive deliveries across difficult terrain.
Autonomous delivery technologies relieve a complex integration of sensors, GPS, computer vision, AI-based navigation, and cloud connectivity. Their effectiveness is particularly high in hyperlocal scenarios, university campuses, gated communities, and low-traffic residential areas. These technologies offer potential cost reductions and emission-free operations—aligning with the European Union's environmental and innovation goals.
However, widespread adoption faces several limitations. Regulatory frameworks around airspace use, safety, and data protection vary significantly across EU member states. Infrastructure readiness, reliability in unpredictable weather conditions, and public acceptance are also key challenges. Despite these barriers, autonomous delivery is gaining institutional and private-sector support as a long-term enabler of efficient, sustainable last mile logistics.

3.3.5. Strategic Models

Fourth-Party Logistics (4PL): Integrated Supply Chain Management

Fourth-party logistics (4PL) refers to a logistics model in which an external provider assumes comprehensive responsibility for managing the entire supply chain on behalf of a client company. Unlike third-party logistics (3PL) providers, which focus primarily on executing specific logistics functions (e.g., transportation, warehousing), a 4PL acts as a strategic integrator that oversees and coordinates multiple 3PLs, internal operations, and technology systems.
The core function of a 4PL provider is to deliver end-to-end visibility, optimization, and alignment across all logistics and supply chain activities. This includes strategic planning, network design, procurement, performance management, and the integration of advanced IT platforms such as transportation management systems (TMS) and warehouse management systems (WMS). In this model, the 4PL typically operates as a neutral, asset-light partner, ensuring unbiased coordination across all stakeholders involved.
By centralizing decision-making and leveraging cross-functional expertise, 4PLs help companies achieve greater efficiency, agility, and control over increasingly complex supply chains. This is particularly valuable in globalized and fragmented logistics environments, where seamless orchestration among suppliers, carriers, and service providers is critical to operational success.

Ultimately, the 4PL model enables organizations to focus on core competencies while relying on a single point of contact to drive continuous improvement, cost optimization, and supply chain innovation.

Collaborative Logistics

Collaborative logistics involves companies sharing logistics resources with the objective of increasing efficiency, reducing costs, and minimizing environmental impact. This practice is particularly common among small and medium-sized enterprises that may lack the scale and resources to maintain standalone logistics operations. By pooling transportation assets, warehousing facilities, and delivery networks, SMEs can benefit from economies of scale, improved asset utilization, and reduced carbon footprints. Collaborative logistics models enable these companies to enhance their competitiveness and respond more flexibly to evolving market demands.

The design and implementation of collaborative logistics initiatives necessitate careful consideration of several factors, including trust, communication, and coordination among participants.

Omnichannel Model: Integrated Retail and Logistics Flexibility

The omnichannel model is a retail strategy that integrates physical and digital sales channels to create a unified, seamless customer experience across touchpoints. In this approach, consumers may interact with a brand through physical stores, websites, mobile apps, social platforms, or call centers — and expect consistency and flexibility regardless of channel.

From a logistics perspective, omnichannel fulfillment demands high operational agility and advanced inventory visibility. Logistics systems must support multiple delivery and service options, such as home delivery, buy online and pick up in store (BOPIS), in-store returns of online purchases, and inter-store transfers. This requires real-time synchronization of stock levels across distribution centers, retail outlets, and digital storefronts.

Effective omnichannel logistics hinges on four key capabilities:

- Unified inventory management;
- Dynamic order routing;
- Integrated reverse logistics for cross-channel returns;
- A responsive transport network capable of last mile and store-based fulfillment.

As customer expectations evolve toward speed, personalization, and convenience, the omnichannel model reinforces the need for a customer-centric, data-driven, and supply-chain-integrated logistics framework.

Reverse Logistics

Reverse logistics refers to the process of managing the backward flow of goods from the point of consumption to the point of origin for the purposes of return, repair, refurbishment, recycling, or environmentally responsible disposal. It plays a critical role in modern supply chain strategies, especially in sectors such as e-commerce, electronics, and consumer goods, where product returns and end-of-life management are increasingly frequent and regulated.
As an integral component of green logistics and the circular economy, reverse logistics enables organizations to reduce waste, recover value from used products, and minimize their environmental impact. Typical reverse logistics activities include customer returns, warranty recovery, unsold goods reclamation, and the collection of recyclable packaging or components.
Implementing an effective reverse logistics system involves challenges such as unpredictable return volumes, quality variability of returned items, and the need for efficient inspection, sorting, and reintegration into inventory or disposal streams. Advanced technologies such as barcode/RFID tracking, AI-powered return forecasting, and automated return authorization systems are increasingly used to enhance reverse logistics performance.
Ultimately, reverse logistics not only contributes to sustainability goals but also offers competitive advantages by improving customer satisfaction, reducing costs, and enabling compliance with environmental regulations.

3.3.6. Trends and Sustainability

Green Logistics

Green logistics refers to the design and implementation of logistics strategies that prioritize environmental sustainability throughout the supply chain. It aims to reduce the ecological footprint of logistics activities—such as transportation, warehousing, packaging, and distribution—while maintaining operational efficiency and customer service levels.

Key practices within green logistics include the adoption of low-emission transport modes (e.g., electric vehicles, rail, cargo bikes), route optimization to reduce fuel consumption, the use of recyclable or biodegradable packaging, energy-efficient warehousing, and the implementation of carbon tracking and reduction programs. Additionally, green logistics often intersects with reverse logistics and circular economy principles by promoting reuse, recycling, and responsible disposal of materials.

For companies, investing in green logistics is not only a response to increasing environmental regulations and consumer awareness, but also a path to long-term cost reduction and brand differentiation. Successful execution requires an integrated approach combining technology (such as IoT and AI), cross-functional collaboration, and continuous measurement of sustainability performance indicators such as CO_2 emissions per delivery.

Green logistics transforms traditional supply chains into eco-efficient systems, aligning profitability with environmental responsibility.

Logistics based on Demand-Driven Supply Chain (DDSC)

The Demand-Driven Supply Chain (DDSC) model emphasizes real-time responsiveness and alignment between end-consumer demand and operational decision-making across the supply chain. Rather than relying on forecast-driven push systems, DDSC operates as a pull-based model, where decisions related to procurement, production, and distribution are continuously adjusted based on actual market signals and demand patterns.

This approach relies heavily on real-time data integration, predictive analytics, and advanced technologies such as artificial intelligence (AI) and Big Data to sense demand shifts early and respond rapidly. The goal is to minimize latency between demand fluctuations and supply chain actions—ensuring optimal inventory levels, faster fulfillment, and increased resilience.

DDSC enhances agility and customer-centricity while reducing excess inventory, stockouts, and operational waste. It is particularly valuable in volatile or fast-changing markets such as fashion, electronics, and online retail.

Each of the logistics models described—whether based on home delivery, micro-fulfillment, green logistics, or 4PL—can be adapted or combined with DDSC principles. The correct selection or intelligent hybridization of models, aligned with sector-specific dynamics, regional infrastructure, and technological maturity, is essential to achieving global logistics competitiveness.

Technologies Applied to Last-Mile Delivery

The last-mile delivery segment is undergoing a rapid transformation fueled by advanced technologies designed to overcome its inherent inefficiencies. Traditionally characterized as labor-intensive, unpredictable, and costly, the last mile has become a hotbed of innovation driven by digitalization, automation, and data analytics (Jucha, 2021). This transformation is crucial, as the quality of the last mile can significantly impact customer satisfaction, the likelihood of repeat purchases, and brand reputation. In highly competitive markets, like online retail, the quality of the last mile can define the success or failure of a business model. Late or unsuccessful deliveries cause reputational damage and can undo marketing and sales efforts.

Route Optimization and AI

One of the most significant technological advancements is the implementation of route optimization software. These systems utilize artificial intelligence and advanced algorithms to calculate the most efficient routes, considering real-time traffic conditions, delivery windows, and customer locations (Jucha, 2021). Dynamic route planning reduces fuel consumption and delivery times while increasing vehicle productivity. Advanced routing systems with AI can draw up efficient routes taking into account real-time traffic and preferred delivery windows, increasing vehicle productivity.

Real-Time Tracking and IoT

Real-time tracking technologies, such as GPS and Internet of Things devices, provide end-to-end visibility into the location and status of parcels (Jucha, 2021). This enhances transparency for both logistics operators and customers, enabling accurate estimated time of arrival notifications and proactive issue resolution. IoT sensors can also monitor environmental conditions, which is particularly important for sensitive or perishable goods. The main types of IoT sensors used in last-mile logistics include:

- GPS Sensors: Track the exact location of vehicles and packages in real time, enabling dynamic route optimization and accurate delivery updates.
- RFID Tags and Readers: Facilitate automated identification and tracking of items throughout the supply chain. RFID enhances speed and accuracy in inventory checks and parcel handovers.

- Temperature Sensors: Monitor thermal conditions in refrigerated trucks or containers, essential for pharmaceuticals, fresh food, and other temperature-sensitive items.
- Humidity Sensors: Detect moisture levels to prevent spoilage or damage to goods like electronics, paper products, or textiles during transit.
- Shock and Vibration Sensors: Record impacts or excessive movements that may compromise the integrity of fragile goods.
- Light Sensors: Detect unauthorized openings of packages or containers, increasing security against theft or tampering.
- Proximity and Ultrasonic Sensors: Assist in automated loading/unloading and collision avoidance in warehouses or during last-mile delivery via autonomous vehicles.
- Fuel and Load Sensors: Monitor fuel consumption and payload weight to optimize efficiency and reduce operational costs.

By integrating these sensors into a unified IoT ecosystem, companies can perform predictive analytics, reduce delivery errors, and improve customer satisfaction through actionable data insights (Zhang et al., 2022).

Mobile Applications

Mobile applications play a vital role in last-mile operations. These apps serve as interfaces for delivery drivers, enabling them to receive route instructions, capture electronic proof of delivery, report incidents, and communicate with dispatchers in real time (Jucha, 2021). Customers also benefit from mobile apps, which facilitate scheduling, delivery tracking, and feedback, thereby enhancing service experience and engagement. Communication apps keep the recipient informed and make it easy to reschedule deliveries, reducing failed attempts.

Transportation Management Systems (TMS)

Transportation Management Systems specifically adapted for last-mile operations are central to coordinating deliveries, managing driver performance, and optimizing resource allocation (Jucha, 2021). When integrated with Warehouse Management Systems and Customer Relationship Management platforms, TMS solutions offer a holistic view of the supply chain, enabling data-driven decision-making.

Data Integration and Analytics

Data integration technologies, such as APIs and Webhooks, are essential for achieving interoperability among diverse logistics systems. These technologies allow for real-time communication between platforms, ensuring that inventory updates, order statuses, and delivery events are synchronized across all stakeholders. Moreover, the adoption of big data analytics enables logistics companies to analyze delivery patterns, customer preferences, and operational bottlenecks, thereby identifying areas for improvement. Sophisticated data analytics allows companies to provide accurate delivery windows and accommodate last-minute changes. Technology will enable more accurate demand forecasts, real-time routing, delivery personalization and multi-channel integration, transforming deliveries into operations that are not only agile, but also predictive and adapted to consumer behaviour.

Automation

Automation is making inroads into last-mile logistics through innovations like autonomous delivery robots, drones, and smart lockers. While still emerging, these solutions promise to revolutionize urban logistics by reducing human dependency and enabling 24/7 delivery capabilities. They also align with sustainability goals by minimizing emissions and energy usage. Delivery drones, for example, can speed up deliveries and reach areas that are otherwise hard to service. Pilot projects for delivery drones are also advancing, especially for rural areas that are difficult to access or for emergency deliveries. Although regulatory and infrastructure challenges still exist for large-scale drones, European logistics companies and technology giants continue to experiment with their use, envisioning a future in which part of small parcels can literally "fly" to the customer.

Security and Data Privacy

Security and data privacy technologies are increasingly important as digitalization expands. Blockchain and secure data protocols help ensure the integrity of transactions, especially in high-value or regulated goods deliveries. These technologies contribute to building trust and reliability in last-mile ecosystems.

Micro-fulfillment Centers and Urban Hubs

The creation of micro-fulfillment centers or urban hubs is another approach to last-mile innovation. Instead of a centralized distribution center serving a large region, companies establish small warehouses within cities or neighborhoods, closer to customers, speeding up short-distance deliveries. This decentralization reduces travel distances and allows orders to be fulfilled quickly, even enabling 2-hour or same-day delivery models for items in local stock. The model of microfulfillment and dark stores should also expand in large urban centers. These hubs close to the end consumer enable deliveries within a few hours, reduce logistics costs and increase responsiveness to peaks in demand.

Out-of-Home Delivery

Solutions such as smart lockers and collection points are emerging as alternatives: instead of delivering to the door of each home, parcels can be consolidated in self-service lockers in strategic locations, where the customer can pick them up at a convenient time. Large retailers and logistics operators in Europe have already installed locker networks, reducing last-mile costs and offering additional convenience to the customer. The strengthening of the Out-of-Home Delivery model, such as lockers, pick-up points and hybrid solutions brings greater flexibility to the consumer and reduces failures in delivery attempts, as well as contributing to more efficient urban logistics.

Crowdshipping

Another trend is the use of crowdsourced delivery: platforms that connect independent deliverers to make local deliveries, along the lines of transport apps. Such models increase flexibility and capillarity in the last mile and can reduce costs in certain scenarios.

Sustainability initiatives

In the field of sustainability, the last mile is the target of innovations such as electric delivery fleets and the use of cargo bikes in urban centers. These low-impact vehicles make it possible to comply with environmental restrictions in cities and reduce emissions - at the same time, they are economically advantageous in the long term due to their lower energy costs compared to conventional vehicles. With the advance of environmental regulations and ecological awareness, investment is growing in electric fleets, cargo bikes and delivery consolidation strategies to minimize carbon emissions and congestion.

Standardization in Last Mile Logistics

Standardization in logistics, particularly in the last-mile segment, plays a pivotal role in harmonizing procedures, enhancing interoperability, and ensuring traceability and efficiency across stakeholders. As e-commerce continues to expand globally, standardization is fundamental to integrating systems, reducing costs, and meeting consumer expectations for fast and reliable deliveries.

Standardization refers to the implementation of common technical specifications, data formats, labeling systems, and operational protocols to ensure uniformity and compatibility. In the context of last-mile logistics, which is characterized by fragmented routes, dynamic delivery schedules, and diverse actors, standardization is essential to achieving scalability and service quality.

European regulatory frameworks such as those by the European Committee for Standardization (CEN) and international standards like those from the International Organization for Standardization (ISO) are instrumental.

Key norms include:

- CEN/TC 331: Covers postal services and logistics interoperability.
- ISO 9001: Quality management systems that ensure procedural standardization.
- ISO 15459: Unique identifiers for transport units and assets.
- GS1 Standards: Including barcodes and EPC/RFID specifications, are globally recognized and integrated into European logistics systems.

Tracking Methods and Technologies

Efficient tracking is at the heart of last-mile optimization. Modern systems leverage multiple identification and data capture technologies:

- 1D Barcodes: Linear barcodes (e.g., Code 128, EAN-13) are widely used for package identification. Their limitations include limited data capacity and line-of-sight scanning.
- 2D Barcodes: Formats such as QR Code and Data Matrix encode more data and are readable from multiple angles. They are suitable for small parcels and enable quick scanning during loading and delivery.
- RFID (Radio Frequency Identification): RFID enables non-line-of-sight data capture and simultaneous reading of multiple items. It supports real-time inventory updates and enhances delivery accuracy. In Europe, RFID integration aligns with GS1's EPCglobal standards and is supported by CEN initiatives promoting digitalization.

Areas of Standardization in Last-Mile Operations

Packaging:

- Standardized packaging facilitates easier handling and transportation, reducing errors and damage during transit.

- Consistent labeling and size dimensions streamline loading processes and optimize space utilization within delivery vehicles.
- Delivery Protocols: - Implementing uniform delivery protocols ensures consistent customer experience and operational efficiency.(Garnbratt & Lindh, 2024)
- GS1 barcodes and EPC/RFID tags enhance automation in sorting and tracking.

Delivery Protocols:

- Standardized operational protocols, such as proof-of-delivery procedures, communication templates, and training modules for couriers, ensure uniform service levels, regardless of region or personnel.
- In a fragmented last-mile ecosystem with multiple third-party logistics providers and independent drivers, standardized practices foster interoperability and reliability.
- ISO 23486 and CEN/TS 17091 provide guidance on logistics operations and smart delivery systems.

The adoption of standardized identifiers and tracking methods facilitates seamless integration between Transport Management Systems (TMS), Warehouse Management Systems (WMS), and carrier platforms. Interoperability allows for real-time visibility, automated status updates, and efficient exception handling.

Furthermore, the development of standardized APIs and data exchange formats enables cross-platform coordination, essential in urban logistics environments where multiple carriers and last-mile partners coexist.

3.4. Last Mile Logistics Concept

Last-mile logistics is understood to be the final stage of the supply chain, responsible for the direct delivery of products to the end consumer. This process is widely recognized as one of the main challenges faced by modern companies, especially those linked to e-commerce, due to the significant economic impact it represents, accounting for up to 50% of total logistics costs, in addition to the increasingly stringent demands for speed and efficiency in the service provided (Boyer & Prud'Homme, 2019).

To understand last-mile logistics better, it is necessary to distinguish between the fundamental concepts of logistics and supply chain management. According to Ballou (2006), logistics is defined as the strategic management of the physical flows of materials, information and resources from origin to final destination, focusing especially on specific activities such as transportation, warehousing and inventory control. In contrast, supply chain management (SCM) refers to a broader vision, integrating all logistics activities along the production chain and seeking to optimize strategic interactions between suppliers, manufacturers, distributors, retailers and customers, with the main objective of creating value and obtaining sustainable competitive advantage in the long term.

From this understanding comes the concept of "Total Logistics", which emphasizes the need to strategically manage and integrate all the elements involved in the logistics process, promoting the continuous generation of value for the end customer. Christopher (2016) points out that this approach requires careful consideration of logistics trade-offs, which are the trade-off decisions made between costs, time and quality of service. For example, opting for fast deliveries to the end customer can significantly increase logistics costs due to the intensive use of resources and the need for advanced stock close to the consumer market. On the other hand, centralizing stocks in a few locations reduces storage costs, but can increase delivery times and reduce service flexibility, making the strategic decision to balance cost, service and speed critical.

Table 3 - Some potential trade-offs in logistics, showing how different company functions (Source: Rushton et al., 2014)

Trade-off	Finance	Production	Distribution	Marketing
Longer production runs	Lower production unit costs	Lower production unit costs	More inventory and storage required	Lower prices
Fewer depots	Reduced depot costs (though transport costs likely to increase)	No impact	Less complicated logistics structure	Service reduction due to increased distance of depots from customers
Reducing stocks of nished goods	Reduced inventory costs	Shorter production runs so higher production unit costs	No need to expand storage facilities	Poorer product availability for customers
Reducing raw material & component stocks	Reduced inventory costs	Less efficient production scheduling due to stock unavailability	Lower stock holding requirements	No direct impact
Reducing protective transport packaging	Reduced packaging costs	No impact	Reduced transport modal choice	Increase in damaged deliveries
Reducing warehouse supervision	Cost savings through lower headcount	No impact	Reduced efficiency due to less supervision	Lost sales due to less accurate order picking

Within this operational context, one particularly relevant logistics practice is crossdocking. This model consists of an operation in which products received at a distribution center are quickly transferred to outbound transport vehicles, with virtually no need for prolonged storage (Rushton et al., 2014). This technique proves especially effective in last-mile logistics, as it makes it possible to reduce operating times and significantly improve performance in final delivery to consumers. By reducing the time products spend in intermediate logistics centers, crossdocking allows companies to speed up delivery, minimize operating costs associated with prolonged storage and improve efficiency in customer service, making a decisive contribution to final consumer satisfaction.

Last-mile logistics faces unique challenges due to the geographical dispersion of consumers, unpredictable traffic in urban areas, increasing regulatory restrictions, and the high expectations of modern consumers for fast, transparent, sustainable and traceable deliveries. These challenges require companies to respond operationally and strategically, requiring continuous investment in technology and innovation to overcome them. In this sense, technologies such as advanced routing applications, real-time GPS tracking, autonomous or electric vehicles, as well as the use of drones in congested urban areas, are emerging as practical alternatives to meet the growing and diverse demands of the digital market.

In addition to technological innovation, the effective integration of logistics processes and supply chain management is becoming crucial to meet the challenges of the last mile. Leading companies have adopted advanced integration models, involving intelligent systems based on Artificial Intelligence and Big Data, capable of predicting demand, dynamically adjusting logistics routes and ensuring adequate stock levels close to end consumers, enabling agile and accurate deliveries.

3.5. The Importance of Fast Delivery for the Digital Consumer

With the advance of e-commerce, consumer habits have undergone a significant transformation. The modern digital consumer values not only the price and variety of products, but also the speed and reliability of delivery as an essential part of the shopping experience. The ability to receive products quickly after purchase has become a basic consumer expectation, strongly influenced by the standards set by major global players in the digital market, such as Amazon, Zalando and Alibaba, which offer extremely agile and effective deliveries.

Studies clearly indicate that the expectation of fast deliveries directly affects customer satisfaction, brand loyalty and repurchase intentions. According to McKinsey & Company

(2022), around 60% of global consumers expect to receive their orders within two days of purchase, while more than 30% explicitly prefer companies that offer same-day or next-day delivery. This preference for agility is pushing companies to adapt their logistics models, increasingly investing in advanced technology and optimized logistics infrastructure to speed up delivery times, even in densely populated urban areas or regions with significant logistical challenges.

Fast delivery also has a substantial impact on purchasing decisions and cart abandonment. A PwC study (2023) revealed that approximately 43% of consumers abandon their shopping carts when they perceive that the delivery time is excessively long. On the other hand, positive experiences with agile and reliable deliveries significantly increase the likelihood of customers recommending the brand to other consumers and returning to make new purchases. This behavior further reinforces the strategic importance of fast delivery, not only for immediate purchase, but also for long-term customer retention and loyalty.

This trend, amplified by the logistics practices of leading companies such as Amazon, Alibaba and Zalando, has set new standards of expectation in the digital market, forcing smaller companies and new entrants to quickly adapt their logistics strategies so as not to lose competitiveness. As a result, many companies have adopted strategies such as cross-docking, advanced routing applications, real-time GPS monitoring, drones and autonomous or electric vehicles, in an effort to reduce the time taken for last-mile operations and guarantee fast and efficient deliveries.

As such, last-mile logistics has taken on a strategic role in the e-commerce value chain, being decisive for the perception of value and the consumer experience. Investing in agile and efficient logistics solutions is no longer just a competitive differentiator, but an essential requirement for sustainability and growth in today's digital landscape. Therefore, innovative and efficient logistics strategies are essential not only to satisfy consumers' immediate demands, but also to consolidate companies' competitiveness and success in the long term.

3.6. Challenges of Last Mile Logistics

Urban infrastructure and traffic

Large cities face complex challenges related to urban mobility. Heavy traffic, restricted access zones, time limitations for deliveries and a shortage of parking areas for freight vehicles compromise the efficiency of urban deliveries. These barriers make last-mile operation slow, unpredictable and costly, especially in densely populated urban centers.

Operating costs

Last-mile logistics is widely recognized as the most costly phase of the supply chain. Estimates indicate that it can represent up to 53% of total delivery costs (Capgemini Research Institute, 2019). Factors such as the low density of deliveries per route, failed delivery attempts, the need for redeliveries and fuel and labor costs all contribute to this increase. In addition, the growing demand for express deliveries puts even more pressure on companies' operating costs.

As part of the challenge in defining operational costs, it is essential to evaluate the return on investment across the entire supply chain. Once delivery strategies are defined, taking into account demand patterns, product types, reverse logistics, and environmental impact, all associated operational costs must align with the overall business objectives.

These expenses are classified as operational expenditures, directly influencing the company's financial statements.

Trade-off analyses are key in this process, involving decisions such as the type of vehicle to use, electric or combustion engine, whether to transport large volumes using trucks or to opt for smaller, more agile vehicles like bicycles. The implementation of tracking technologies and automation tools also plays a significant role in shaping these costs.

Therefore, conducting a thorough Return on Investment (ROI) analysis is crucial for making informed, sustainable, and strategic logistics decisions.

Return on Investment (ROI) in Last-Mile Logistics

Return on Investment (ROI) is a financial metric used to assess the profitability or efficiency of an investment. It helps businesses understand how much return they are generating relative to the amount invested.

The formula for ROI is:

$$ROI = \left(\frac{Gain\ from\ Investment - Cost\ of\ Investment}{Cost\ of\ Investment}\right) \cdot 100$$

In the context of logistics, particularly last-mile delivery, ROI plays a crucial role in decision-making. Last-mile logistics refers to the final step of the delivery process, where goods are transported from a distribution hub to the final consumer. It is often the most expensive and complex part of the supply chain due to factors like traffic congestion, urban restrictions, and customer expectations for fast delivery.

To evaluate ROI in last-mile logistics, companies might consider investing in solutions such as electric delivery vehicles, route optimization software, or micro-fulfillment centers. For instance, a company implementing electric cargo bikes combined with delivery scheduling software could experience operational changes. These may include lower fuel costs, fewer delivery delays, and higher customer satisfaction. By comparing the total benefits (e.g., cost savings, improved service levels) against the initial investment (e.g., equipment, software, training), the company can determine whether the initiative is financially viable.

Interpreting ROI in this scenario helps stakeholders decide whether to expand, adjust, or abandon a given strategy. A positive ROI indicates that the investment is generating more value than it costs, while a negative ROI suggests a need for reevaluation.

Key performance indicators (KPIs) used to support ROI analysis in last-mile delivery include:

- **Delivery cost per order:** Measures cost-efficiency.
- **On-Time Delivery Rate (OTD) or On-Time-In-Full (OTIF):** Assesses service reliability.
- **Customer Satisfaction/NPS (Net Promoter Score):** Reflects the end-user experience.
- **Drop density:** Indicates efficiency by measuring the number of deliveries per route.
- **Average delivery time:** Evaluates operational speed.

Tracking these KPIs in combination with ROI provides a comprehensive understanding of both financial and operational performance in last-mile logistics.

Sustainability and emissions

The increase in the volume of deliveries in urban areas has significantly increased CO_2 emissions, noise pollution and energy consumption. Combustion-powered delivery vehicles continue to be the main emitters, making them a significant environmental challenge. The adoption of sustainable alternatives such as electric fleets, cargo bikes and delivery consolidation systems is increasingly necessary, especially in the face of public policies aimed at carbon neutrality in cities (UNCTAD, 2021).

Customer experience

The delivery experience has a direct influence on the perception of the digital consumer. Models such as same-day or next-day delivery have become a benchmark in the sector, raising customer expectations in terms of delivery agility, traceability and flexibility. Delays, miscommunication, lack of tracking options or changes in order status negatively affect brand image. According to a study by PwC (2023), 43% of consumers abandon purchases when delivery times are long, and 60% expect to receive within two days .

3.7. Innovative Last Mile Solutions

The growing complexity and challenges of last-mile logistics have driven the emergence of innovative solutions centered on the use of emerging technologies and new operating models. These solutions aim to increase efficiency, reduce costs, promote sustainability and improve the end customer experience.

3.7.1. Visibility and Traceability in the Supply Chain

One of the most valued pillars in contemporary logistics is end-to-end visibility of operations. Visibility refers to the ability to track, in real time, the status and location of products along the supply chain, from origin to final destination. The lack of this monitoring creates real operational blind spots. Studies show that 94% of supply chain leaders admit to not having complete visibility of their operations, resulting in significant inefficiencies. Without an accurate view of stocks in motion, companies are simultaneously subject to product shortages (stock-outs) and excess inventory, both of which have deleterious effects: stock-outs mean lost sales and customer dissatisfaction, while excess inventory ties up capital and makes storage more expensive (Spruijt, 2025). Real-time traceability, made possible by technologies such as, makes it possible to mitigate these problems. With integrated tracking systems, managers can anticipate delays or deviations in the logistics flow and react proactively. Accurate and up-to-date inventory data reduces waste and losses: it is estimated that a lack of visibility contributes to an annual waste of US$ 163 billion in unused inventory globally (Spruijt, 2025). In this context, logistics control tower solutions - command centers that consolidate information from various links - have gained prominence, offering unified dashboards that monitor deliveries, stock levels and risks throughout the chain.

Visibility also improves the customer experience, as it provides accurate information on the status of the order (e.g. shipment tracking). In today's market, customers and shippers can no longer tolerate a fragmented view of operations, so investing in visibility has become synonymous with logistics efficiency and reliability. In Europe, many companies have adopted collaborative data platforms and systems integration to achieve this operational transparency. In short, total chain visibility - once a differentiator - is now a basic requirement for logistics excellence, reducing costs, preventing disruptions and increasing satisfaction throughout the supply chain.

3.7.2. Integration and collaboration in the logistics chain

Another consolidated foundation of modern logistics is integration - whether internal (between sectors of the company itself) or external (with business partners). Integrated logistics seeks to eliminate organizational silos, unifying processes from supply, production, storage, transport to distribution to the end customer. According to experts, we are moving towards a scenario in which silos will be eliminated and goods will flow multimodally and continuously from point A to point B, enabled by robust digital solutions. This integration brings synchronization between demand and replenishment, greater agility and responsiveness to market changes.

In practice, integration manifests itself in unified systems and close collaboration between companies. For example, the integration of management systems (ERP, WMS, TMS) provides a holistic view of the logistics flow, breaking down barriers between purchasing, inventory and transportation. This reduces information errors and data duplication, as well as optimizing processes and cycle times. Externally, collaboration takes place through strategic partnerships and outsourcing: currently, more than a third of the entire value of the European logistics market is handled by contract logistics operators (3PL), responsible for transportation, assembly or distribution (Solistica, 2022). This reflects companies' reliance on logistics specialists to manage their supply chains in an integrated way, freeing them to focus on their core business.

Integration also strengthens resilience and the ability to react to setbacks. Through closer coordination with suppliers and carriers, companies are able to align production and distribution plans, sharing demand information in real time (horizontal and vertical collaboration in the chain). Tools such as Collaborative Planning, Forecasting and Replenishment (CPFR) exemplify practices in which manufacturers, distributors and retailers plan together, reducing total inventories and increasing service levels. This synchronization even contributes to sustainability objectives - for example, by optimizing loads and avoiding idle journeys.

In short, integration and collaboration are pillars that go hand in hand: modern logistics in Europe seeks integrated operations from end to end, supported by trusting relationships between partners. The result is a more agile, transparent and cohesive supply chain, capable of adapting quickly to market variations and taking advantage of opportunities for continuous improvement in efficiency.

3.7.3. Technology and innovation applied to last mile

The accelerated incorporation of cutting-edge technologies is revolutionizing logistics, making technological innovation a key pillar in the sector's competitiveness. Solutions based on Artificial Intelligence and Machine Learning are already optimizing demand forecasting, vehicle routing and automatic stock management, reducing human error and increasing productivity (APOL, 2025). For example, AI algorithms make it possible to read market trends and adjust logistics plans in real time, while intelligent routing systems reduce kilometers traveled and emissions, even mitigating traffic impacts on deliveries.

In automation, autonomous warehouse robots (AGVs, AMRs) that speed up the sorting and movement of goods stand out, as well as drones that are beginning to be tested for urgent deliveries in remote areas or areas with heavy traffic. Although human labor remains essential, especially in complex operations, logistics automation initiatives are advancing rapidly. Europe is already seeing pilot projects with drones and augmented reality in warehouses in the UK, aimed at tackling urban and productivity challenges (Solistica, 2022). Blockchain is also emerging as a supporting technology, guaranteeing transparency and security in logistics transactions through decentralized records of shipments and contracts (APOL, 2025)

The use of big data and analytics is another contemporary differentiator. Voluminous data generated by operations (orders, deliveries, sensors) can be mined to extract valuable insights - from identifying bottlenecks to optimizing stock levels. However, research shows that there is still room for progress: only 19% of logistics companies in the European Union used solutions based on big data in 2022, although this figure is projected to exceed 38% in the coming year. This expansion could generate huge gains: it is estimated that the widespread adoption of big data in European logistics would bring time and fuel savings equivalent to €450 billion, as well as increasing operational efficiency by 15% and creating new business models. (Solistica, 2022)

Connectivity is another crucial aspect - IoT (Internet of Things) connects vehicles, containers and warehouses in an intelligent network. Sensors in trucks monitor the temperature, vibration and location of cargo in real time, feeding into central systems. This enables proactive interventions (predictive fleet maintenance, for example) and strengthens integration between stages. Europe is also investing in the digital infrastructure of routes: the Federated initiative, supported by the European Commission, seeks a single digital market for transport, integrating data from different modes to improve international logistics coordination.

Finally, it is worth highlighting the innovation in logistics business models: services such as on-demand deliveries via apps, crowdsourcing of delivery drivers and autonomous delivery vehicles are redesigning the way we operate. The platform economy (Uber, Amazon Flex, etc.) has arrived in logistics, increasing capacity flexibility in times of peak demand. In short, technology is bringing speed and intelligence to modern logistics. Companies that adopt these innovations report measurable benefits - cost savings, speed and greater reliability. Continuous technological evolution has thus become an indispensable pillar for ensuring efficiency, scalability and competitive differentiation in today's European logistics.

3.7.4. Sustainability and Green Logistics

Sustainability has become one of the central pillars of modern logistics, especially in Europe where there is a strong commitment to environmental goals. Freight transport has historically contributed significantly to CO_2 emissions and pollutants, so decarbonizing logistics is a strategic and legal imperative. Recent European regulations impose stricter limits on vehicle emissions, encouraging the migration to electric or alternative fuel fleets (La Haye, 2025). Governments have offered incentives for investment in clean energy and infrastructure such as charging stations for electric vehicles and sustainable logistics facilities (e.g. warehouses with solar panels) - measures that are boosting "green logistics".

European consumers also play a crucial role in this agenda: there is a growing demand for environmentally responsible logistics services, putting pressure on companies to adopt more sustainable practices. Many shippers now consider the carbon footprint of their deliveries as a criterion for selecting carriers, seeking partners with non-polluting vehicles or carbon offset programs. In addition, reverse logistics and circular economy practices are gaining ground - efficient returns logistics, reuse of packaging and recycling of materials reduce waste and close the product life cycle (APOL, 2025)

Recent trends include the electrification of freight transport, with the adoption of electric trucks and hybrid vehicles, especially for short-haul urban deliveries. The sustainable last mile has become the goal of many European cities: there are already zero-emission zones where only electric vehicles or cargo bikes can operate for deliveries. Similarly, alternatives such as the increasing use of rail and water transport for long distances - as per the EU target mentioned above - seek to reduce dependence on road transport, which is more polluting.

The expected results of these initiatives are significant. A study by the World Economic Forum projects that, without changes, carbon emissions from urban deliveries will grow by 32% by 2030, due to the increase in e-commerce and congestion (PURI, 2024 (Top last mile delivery statistics to consider | FarEye)). However, actions such as the implementation of urban micro-hubs and local fulfillment centers could reduce last mile emissions by 17% to 26% by 2025, by shortening delivery distances and enabling the use of cleaner modes. Large operators in Europe are already experimenting with alternative fuels (biofuels, green hydrogen) and improvements in fleet energy efficiency (Solistica, 2022), with the aim of aligning their operations with the goals of the Paris Agreement and sustainable development objectives.

In short, logistical sustainability is no longer an accessory issue, but a strategic pillar. Companies that innovate in favor of the environment reap not only ecological benefits, but also competitive advantages: they reduce fuel costs in the long term, avoid regulatory penalties and strengthen their image with a public that is increasingly aware of social and environmental responsibility. Modern European logistics is therefore based on the search for a balance between operational efficiency and sustainable commitment, understanding that the future of the sector depends on cleaner, smarter operations that are integrated into the global effort to combat climate change.

3.8. The Last Mile and its Strategic Role in the Supply Chain

In the context of modern logistics, the concept of the "last mile" deserves special mention. This term refers to the final stage of the delivery process, in which the product is transported from the nearest distribution center to the customer's destination (be it a final consumer or point of sale). Although it constitutes the final stretch of a long supply chain, the last mile is often the most critical and challenging phase of the entire logistics operation. Several factors contribute to this criticality: in urban deliveries, for example, there is heavy traffic, access restrictions, parking difficulties and the need to consolidate small, geographically dispersed deliveries. In residential areas, couriers deal with address errors, recipient absences and multiple delivery attempts, all of which make the operation more expensive and complicated. From a financial point of view, the last mile is recognized as the most costly part of logistics, it alone accounts for around 50% of all transport costs in e-commerce (PURI, 2024 (Top last mile delivery statistics to consider | FarEye)). This disproportion occurs because, unlike the previous stages (consolidated in batches or closed loads), the last mile is dominated by fractional, low-volume deliveries with a high number of stops. The result is a high unit cost per delivery, with lower economies of scale. One express delivery company noted that the cost of the last mile can exceed half the total cost of shipping an item (KORAYIM, 2021 apud PYMNTS (50% of Delivery Costs Occur in Last Mile, Putting Pressure on Transport Providers | PYMNTS.com)). In addition, consumer pressure for "free" shipping transfers these costs to retailers, squeezing margins and making efficiency in the last mile a strategic differentiator for profitability.

The operational challenges are equally important. The geographical dispersion of deliveries makes it difficult to make the most of the vehicles' capacity; often, a truck or van goes out on routes with dozens of parcels, each to a different address, implying complex routings. Adverse conditions, such as weather (heavy rain, snow) or security problems (cargo theft in transit), also disproportionately affect the last mile, requiring companies to have robust contingency plans. Add to this the growing demand for fast deliveries - same-day or next-day orders - which reduces the windows for planning and optimizing routes. In 2022, for example, it was estimated that 30% of consumers would expect same-day delivery options for their online purchases (PURI, 2024 (Top last mile delivery statistics to consider | FarEye)).

In the midst of these challenges, the last mile has emerged as a strategic element for competitiveness and customer satisfaction. Its effective execution can become a valuable service differentiator. Companies that offer reliable, fast and convenient deliveries (e.g. the possibility of scheduling or rescheduling) win consumer preference. Research indicates that 84% of consumers would not buy from a retailer again after a negative delivery experience, highlighting the direct impact of the last mile on loyalty (PURI, 2024 (Top last mile delivery statistics to consider FarEye) (Top last mile delivery statistics to consider | FarEye)). On the other hand, successful and on-time deliveries increase satisfaction and the likelihood of repurchases. In highly competitive markets - such as online retail - the quality of the last mile can define the success or failure of a business model. Late or unsuccessful deliveries cause reputational damage and can undo the marketing and sales efforts that led the customer to close the order.

Aware of this, the logistics sector has been promoting last-mile innovations to balance the cost-service-sustainability equation. One approach is the creation of micro-fulfillment centers or urban hubs: instead of a centralized distribution center serving a large region, companies establish small warehouses within cities or neighborhoods, closer to customers, speeding up short-distance deliveries. This decentralization reduces travel distances and allows orders to be fulfilled quickly, even enabling 2-hour or same-day delivery models for items in local stock. Another trend is the use of crowdsourced delivery: platforms that connect independent deliverers (motorcycle couriers, cyclists, private drivers) to make local deliveries, along the lines of transport apps. Such models increase flexibility and capillarity in the last mile, and can reduce costs in certain scenarios (APOL, 2025).

Technology is also a great ally in optimizing the last mile. Advanced routing systems with AI can draw up efficient routes taking into account real-time traffic and preferred delivery windows, increasing vehicle productivity. Communication apps keep the recipient informed and make it easy to reschedule deliveries, reducing failed attempts. In addition, solutions such as smart lockers and collection points are emerging as alternatives: instead of delivering to the door of each home, parcels can be consolidated in self-service lockers in strategic locations (stations, markets, condominiums), where the customer can pick them up at a convenient time. Large retailers and logistics operators in Europe have already installed locker networks, reducing last-mile costs and offering additional convenience to the customer.

In the field of sustainability, the last mile is the target of innovations such as electric delivery fleets (electric vans and tricycles) and the use of cargo bikes in urban centers. These low-impact vehicles make it possible to comply with environmental restrictions in cities and reduce emissions - at the same time, they are economically advantageous in the long term due to their lower energy costs compared to conventional vehicles. Pilot projects for delivery drones are also advancing, especially for rural areas that are difficult to access or for emergency deliveries (medicines, for example). Although regulatory and infrastructure challenges still exist for large-scale drones, European logistics companies and technology giants continue to experiment with their use, envisioning a future in which part of small parcels can literally "fly" to the customer.

In short, the last mile is no longer seen as just the "final link" but as a strategic component of the supply chain. Its intrinsic complexity demands creative solutions and targeted investments, but the potential gains are high: improved customer satisfaction, reduced total costs and competitive advantage. As noted, the last mile concentrates critical factors - cost, speed, customer interaction and environmental impact - so improving this stage means improving the entire logistics chain. In Europe, where e-commerce and service expectations have reached high levels, excellence in the last mile is increasingly synonymous with logistical success. The innovations and trends discussed consolidate the last mile as a key element in modern logistics, justifying the focus of recent studies and initiatives around its continuous improvement and innovation

3.9. Future trends in last-mile logistics

As e-commerce expands and consumers become more demanding, last-mile logistics is undergoing rapid transformation. Trends indicate a scenario that is increasingly automated, sustainable and centered on the customer experience.

One of the most promising trends is the total automation of urban delivery. The use of autonomous robots, drones and unmanned vehicles is likely to become more common, especially in urban and suburban areas. Overcoming regulatory barriers will allow these systems to optimize routes, reduce costs and speed up delivery times (AMAZON, 2022).

Another significant development is the strengthening of the Out-of-Home Delivery (OOHD) model, such as lockers, pick-up points and hybrid solutions. This approach brings greater flexibility to the consumer and reduces failures in delivery attempts, as well as contributing to more efficient urban logistics.

Sustainability will continue to be a central theme. With the advance of environmental regulations and ecological awareness, investment is growing in electric fleets, cargo bikes and delivery consolidation strategies to minimize carbon emissions and congestion.

In addition, the expansion of the use of artificial intelligence and big data promises to deliver substantial gains. Technology will enable more accurate demand forecasts, real-time routing, delivery personalization and multi-channel integration, transforming deliveries into operations that are not only agile, but also predictive and adapted to consumer behavior (MCKINSEY & COMPANY, 2022).

The model of microfulfillment and dark stores should also expand in large urban centers. These hubs close to the end consumer enable deliveries within a few hours, reduce logistics costs and increase responsiveness to peaks in demand.

Finally, strategic partnerships between retailers, logistics operators and log-tech startups are likely to shape more innovative, scalable and resilient ecosystems. The integration of these parties will be essential to respond quickly to the dynamics of the global digital market.

With this in mind, the last mile is consolidating itself as a strategic point in the consumer journey, connecting technology, sustainability and the customer experience in an integrated and competitive way.

4. Analysis of the literature review

4.1. Evolution of E-commerce in Europe

E-commerce in Europe has experienced accelerated growth over the last decade, driven by technological advances, changes in consumer behavior and the expansion of digital connectivity. In 2022, European B2C e-commerce turnover was estimated at approximately 899 billion euros, with growth forecast to reach 963 billion euros in 2023 (Ecommerce Europe, 2023).

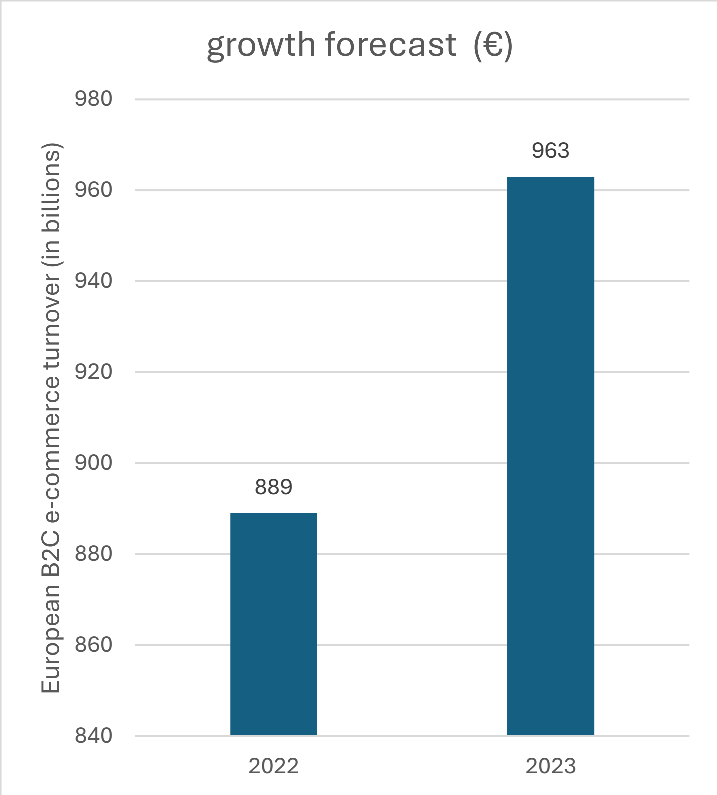

Chart 1 - European B2C e-commerce turnover (in billions) (self made)

The penetration of e-commerce has also increased significantly: around 76% of internet users in Europe made online purchases in 2022. Countries such as the United Kingdom, Germany, France, Spain and Italy lead the way in terms of the number of consumers and sales volume, accounting for more than 60% of the continent's turnover.

European consumer preferences have been changing rapidly. The demand for fast delivery, real-time tracking, flexible delivery options and simplified return policies has become a competitive standard. It is estimated that 80% of consumers would give up buying from sites with unclear or complex return policies, and 74% would switch brands if the buying process was considered difficult (Kinsta, 2024).

Despite the growth, the sector faces major challenges. Last-mile logistics account for up to 53% of total logistics costs, and return rates are high, especially in the fashion sector. In countries such as Germany, the Netherlands and the UK, more than 40% of consumers made at least one online purchase return in 2022. This puts pressure on companies to develop efficient and environmentally responsible reverse logistics strategies.

Growing ecological awareness is also influencing operations: consumers and regulatory bodies are demanding greater sustainability, encouraging practices such as the use of electric vehicles, recyclable packaging and the consolidation of deliveries. The clothing sector, for example, is one of the most critical: Europeans buy an average of 19 kg of clothes a year and generate 16 kg of textile waste - only 15% of which is recycled (El País, 2025).

Against this backdrop, European e-commerce is moving towards a more technological, sustainable and consumer-centric model, in which logistics - especially last-mile logistics - plays a decisive role in the competitiveness and socio-environmental responsibility of companies.

4.2. New demands from logistics

With the exponential growth of e-commerce, new logistics requirements have emerged, driven mainly by changes in consumer behavior and the need for competitive differentiation in the digital environment. Traditional logistics, with rigid deadlines and structures, has become insufficient in the face of a market that values speed, flexibility, traceability and sustainable deliveries.

Nowadays, consumers expect ever shorter delivery times, often on the same day or even within a few hours of purchase. In addition, there is a strong appreciation for real-time tracking systems, automated notifications, options for altering delivery (such as redirecting to lockers or rescheduling times) and sustainable alternatives that reduce the environmental impact of transportation. According to data from Kinsta (2024), 74% of consumers abandon a purchase if the process is not flexible, and 80% give up if the return policies are unclear or rigid.

This new consumer profile is forcing companies to reformulate their logistics strategies, investing in microfulfillment centers close to urban centers, using dynamic routing technologies and artificial intelligence to predict demand and avoid disruptions. At the same time, the adoption of electric vehicles and sustainable modes is growing, such as cargo bikes and collaborative fleets, especially in regions with environmental restrictions, such as zero emission zones.

In addition to the focus on efficiency and fast service, there is also growing pressure for responsible practices. Sustainability has become a decisive factor for a significant proportion of European consumers, influencing everything from the choice of packaging to the means of transportation used. This is leading companies to re-evaluate not only the efficiency of their operations, but also their environmental footprint, promoting green logistics as a competitive differentiator.

In this scenario, logistics is no longer just an operational support and is taking on a strategic role in customer loyalty and the sustainability of e-commerce operations.

4.3. Main Challenges: Operational and Environmental

The literature review highlights that the main challenges in last-mile logistics are both operational and environmental in nature, requiring special attention and the adoption of innovative solutions to mitigate their impacts.

From an operational perspective, the primary challenges in last-mile logistics include the high fragmentation of delivery routes, which results in less optimized routes and increased operational costs. This is compounded by frequent delivery attempt failures due to the absence of recipients, leading to additional costs and process inefficiencies. Low delivery density per route also undermines operational effectiveness, significantly increasing the cost per delivery. Furthermore, limited integration between tracking systems and distribution centers restricts operational visibility and hinders the ability to respond in real time to logistical demands.

High demand, combined with route fragmentation, significantly contributes to rising operational costs, such as those related to vehicle maintenance, investments in selecting the most suitable transport mode, and the infrastructure required for its implementation. If the preferred option is electric vehicles, for instance, it is essential to ensure the availability of charging stations to meet demand. Similarly, if there is reliance on rail or waterway systems, their feasibility and economic viability must be considered.

Environmental challenges have become increasingly critical, particularly in urban areas, due to the negative impacts associated with the growth of delivery activities. The increase in the number of vehicles used for deliveries significantly raises pollutant gas emissions, contributing to deteriorating air quality, exacerbating urban congestion, and intensifying noise pollution. Pressured by the need to adopt more sustainable practices, companies and government agencies have been exploring eco-friendly alternatives, such as the use of electric vehicles, the establishment of zero-emission zones in cities, and the adoption of non-motorized modes (e.g., electric bicycles and tricycles) for short-distance deliveries. These factors call for integrated solutions that balance operational efficiency with sustainable practices and social and environmental responsibility.

The choice of logistics model becomes a critical strategy to ensure the longevity and competitiveness of the whole business. With increasingly demanding and immediacy-driven consumers seeking diverse and fragmented purchases, the pressure for fast, high-quality, and low-cost deliveries continues to grow. In this context, logistics providers must innovate continuously to meet evolving market demands. Modern logistics faces the challenge of delivering faster, with higher quality, lower costs, and reduced environmental impact, making technology the most effective means to address this challenge.

Technologies and methodologies must be applied strategically to optimize the overall logistics flow. The use of artificial intelligence in route optimization, the adoption of alternative transport modes, and the implementation of quality methodologies, such as Lean, contribute to identifying improvement opportunities, reducing waste, lowering costs, and enhancing the quality of logistics services.

Challenges by Sector

Last-mile logistics presents different challenges depending on the sector, as each type of product imposes specific demands in terms of time, packaging, infrastructure and level of service. The main sectors affected and the initiatives that have been adopted to mitigate these challenges are analyzed below.

Frozen Food Sector: This sector requires strict temperature control, which makes the last mile particularly challenging. Breaking the cold chain can compromise the integrity of the product, directly impacting consumer health and brand reputation. Challenges include the high cost of refrigerated vehicles, urban restrictions on this type of fleet and the need for fast deliveries to maintain quality. In response, companies have invested in real-time thermal tracking technologies, route optimization with shorter transit times and the use of refrigerated urban micro-hubs.

Supermarkets and High Turnover Products: The high frequency of orders and the diversity of products make the operation complex. Efficient stock management, synchronization between the physical store and e-commerce (omnichannel model), and deliveries within short windows are critical factors. To meet these challenges, large chains have adopted automated microfulfillment centers close to consumers, reducing delivery lead times and increasing order accuracy.

Fashion and clothing sector: Fashion logistics faces high volumes of returns due to exchanges and dissatisfaction with the size or model. Seasonality and rapidly changing trends increase the complexity of inventory management and distribution. The adoption of solutions such as dark stores and demand prediction algorithms help to align stock with real demand. In addition, efficient reverse logistics policies and facilitated collection points have been adopted to deal with returns.

Electronics sector: Products with higher added value require secure transportation and strict tracking. Last-mile logistics in this sector faces challenges related to the fragility of items, the risk of theft and the need to schedule deliveries at specific times. Initiatives such as reinforced packaging, advanced tracking systems and the use of lockers with secure authentication are examples of risk mitigation.

Pharmaceutical sector: Similar to frozen food, medicines can require temperature control, as well as a high level of traceability and compliance with health regulations. The risk of counterfeiting and the requirement for proof of safe delivery are also relevant. Solutions employed include the use of blockchain for traceability, dedicated refrigerated vehicles and systems with digital validation of receipt by the consumer.

Each sector needs its own logistics solutions to make sure products get to customers on time, safely, and in good condition. That’s why it’s important to adopt last-mile strategies to fit the needs of each sector for e-commerce to succeed.

Challenge with reverse logistics

Reverse logistics has become one of the main challenges faced in the context of e-commerce, especially given the exponential increase in the volume of online purchases. As consumers demand greater convenience and flexibility in return processes, companies need to restructure their logistics operations to deal with this reverse flow of goods.

The increase in returns is directly linked to the high consumer demand driven by e-commerce. Sectors such as fashion, electronics and even food have experienced an increase in the number of returns for reasons ranging from dissatisfaction with the product to errors in the order or damage during transportation. This imposes significant additional costs, greater operational complexity and requires specific infrastructure for sorting, reconditioning and returning products to stock or, in irreversible cases, for proper disposal.

In addition to the financial impact, reverse logistics has important environmental implications. The additional transportation required for returns contributes to an increase in CO_2 emissions, intensifying the ecological impact of logistics operations. In response, companies have sought more sustainable alternatives, such as consolidating collections, partnering with physical collection points, using reusable packaging and implementing refund policies that encourage conscious consumption.
In addition, technologies such as blockchain tracking, artificial intelligence applied to predicting returns and automated sorting systems are being integrated into logistics strategies to increase efficiency and mitigate the negative effects of reverse logistics. This is therefore a challenge that goes beyond the operational sphere, requiring a strategic approach that takes into account the consumer experience, process efficiency and environmental responsibility.

Cost Challenges in Last Mile Logistics

The rising demand for fast, flexible, and personalized deliveries in e-commerce has caused a significant increase in logistics costs, especially in the last mile. This final stage, where the product is delivered to the customer's door, can account for up to 53% of the total logistics cost. (Ecommerce Europe, 2023) The main challenge is maintaining a high level of service without hurting profitability.

As the number of orders grows and the need for customized, individual deliveries increases, operational complexity rises and route efficiency drops. To meet tight delivery deadlines, companies must invest in micro-fulfillment centers, advanced routing technologies, highly available in-house or outsourced fleets, and urban infrastructure adapted to these demands.

Reverse logistics is another major cost driver, particularly in sectors like fashion and electronics, where return rates can exceed 20%. Handling returns involves expenses for collecting, sorting, reprocessing, or discarding products, not to mention the environmental impact and the challenge of keeping customers satisfied.

A Capgemini report (2023) shows that 74% of e-commerce companies see delivery costs as the biggest barrier to profitability. Meanwhile, 40% of European businesses say they lose money on last-mile delivery, choosing to absorb these costs to stay competitive and meet customer expectations.

To tackle these issues, many companies are adopting strategies like delivery consolidation, pick-up lockers and points, supply chain digitalization, and predictive analytics for routing and resource planning. Still, finding the right balance between service quality and cost control remains one of the toughest challenges in modern logistics.

4.4. Intelligent Technologies Applied to the Logistics Chain

Logistics 4.0 is the application of Industry 4.0 technologies to supply chain operations, bringing major changes to how logistics is managed. It focuses on using digital tools, automation, and real-time data through systems like artificial intelligence (AI), the Internet of Things (IoT), machine learning (ML), big data, and cloud computing.

In e-commerce, these technologies help tackle the growing challenges of logistics, especially in last-mile delivery. AI and ML allow companies to better predict customer buying patterns, using both historical and real-time data to adjust inventory and delivery capacity. This leads to fewer stockouts, less waste, and a better overall shopping experience.

IoT plays a key role by enabling constant monitoring of vehicles, cargo, and warehouses through connected sensors. These sensors track things like temperature, location, product condition, and delivery progress—vital for sensitive items such as medicines or perishable foods.

Smart routing systems use data on traffic, weather, and city regulations to plan faster and more efficient delivery routes, cutting costs and emissions. Companies like Amazon and DHL already use these technologies. For example, Amazon uses AI to predict demand and place inventory in advance, while DHL applies IoT and big data to manage its network and maintain its fleet proactively.

Automation has also advanced with the use of robots in micro-fulfillment centers. These robots handle picking, sorting, and packing quickly and accurately, improving space usage and response time. Companies like Alibaba and Ocado are leading in this area.

Blockchain is another tool being tested to improve tracking and trust in the supply chain, especially when handling sensitive goods that require security and verification, like regulated pharmaceuticals.

Overall, Logistics 4.0 helps businesses become more efficient and competitive, while also supporting sustainability and better customer service.

Recent studies highlight several promising solutions that boost efficiency, flexibility, and environmental responsibility in last-mile logistics. AI is being used for dynamic route planning, adjusting delivery paths in real time based on traffic, delivery schedules, and customer needs. When combined with big data, demand forecasting tools help predict order surges, improve resource planning, and avoid delays.

IoT sensors, along with smart dashboards, offer full visibility of the logistics chain, allowing teams to track operations and respond quickly to any issues. At the same time, alternative delivery methods, like smart lockers, local pickup points, and crowdshipping (using independent couriers), are gaining ground as ways to reduce costs and increase reach.

Autonomous delivery vehicles and drones are also being tested and show strong potential for delivering in remote or crowded urban areas. Meanwhile, micro-fulfillment centers and dark stores are being set up in large cities, acting as automated hubs close to customers. These setups speed up order processing and improve delivery times.

4.5. Examples of Application in a global company: Amazon

Amazon is currently one of the most advanced companies in the application of intelligent and automated logistics solutions. The transformation of its supply chain—particularly its last-mile logistics—has become a global benchmark and exemplifies the practical implementation of several theoretical concepts developed in the field of Logistics Engineering.

One of the core technologies in Amazon's logistics operations is the SCOT (Supply Chain Optimization Technologies) system, responsible for generating accurate, large-scale demand forecasts. Based on deep learning algorithms, SCOT analyzes historical sales data, seasonality, customer location, weather events, and promotional campaigns to predict with high accuracy the required volume of over 400 million products. (Amazon. (n.d.))

This forecasting model enables Amazon to implement the concept of prepositioned inventory, whereby products are strategically placed in warehouses closer to customers. As a result, there is a significant reduction in delivery time and travel distance per order. The company reported a 15-fold increase in forecasting accuracy following the adoption of deep neural networks, which directly contributed to minimizing waste, excess inventory, and stockouts.

In its logistics centers, Amazon utilizes over 750,000 mobile robots developed in-house, including Robin (which scans and directs packages) and Sequoia (which reduces sorting time by up to 75%)(Amazon. (n.d.)). These robots operate in integration with the Warehouse Management System (WMS), allowing for:

- Automated item picking;
- Internal goods transportation;
- Order sorting by destination and product type;
- AI-based analysis and classification of damaged packages.

The implementation of collaborative robotics (cobots) also allows human operators to perform more specialized tasks, such as quality control and handling fragile items, while robots handle bulk movement and classification. Operator productivity has increased by more than 40% with these systems.

Below is a table listing Amazon's main logistics robots, their primary functions, and embedded technologies:

Tabel 4 - List of Amazon Robots (source: Amazon. (2025a))

Robot	Main Function	Embedded Technologies
Sequoia	Fast sorting and package reorganization	AI for routing, optical sensors, predictive analytics
Hercules	Transport of entire shelving units within fulfillment centers	QR code navigation, high-precision motors
Titan	Transportation of heavier and bulkier items	Reinforced structure, proximity sensors, WMS integration
Vulcan	Handling and transportation of high-capacity racks	High-strength robotics, stability control
Sparrow	Picking of individual items on conveyor lines	Advanced computer vision, machine learning, adaptive robotic grasping
Packaging Automation	Automation of packaging and dimensioning processes	3D measurement algorithms, AI for packaging selection, SCOT integration
Robin	Scanning and routing of packages	Label reading AI, automated conveyors, computer vision
Cardinal	Automated sorting of heavy packages for shipping	Collaborative robotics, articulated robotic arms, integrated safety systems
Proteus	Autonomous navigation in shared environments with humans	LiDAR sensors, SLAM navigation, real-time obstacle detection and avoidance

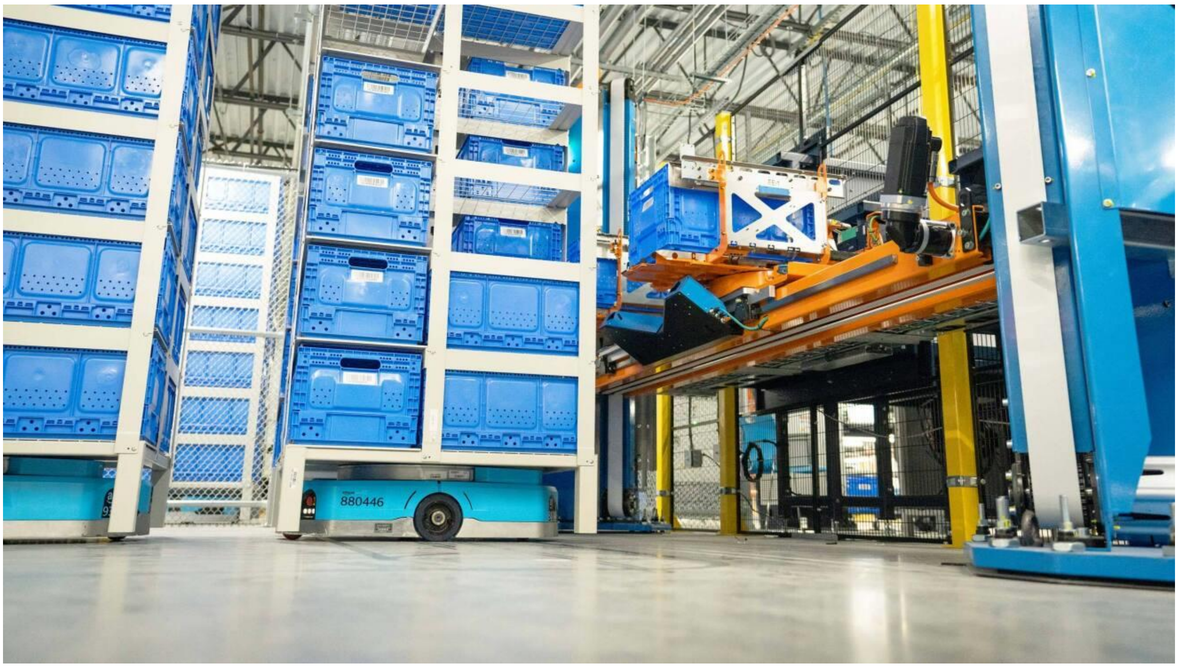

Figure 4 - Hercules robot (source: Amazon. (2025b)

These robots work seamlessly within Amazon's logistics and IT systems, enabling significant reductions in cycle time, increased productivity and safety, and improvements in delivery quality and customer satisfaction.

Amazon’s most disruptive innovation in last-mile delivery is the Prime Air program, which employs autonomous drones, such as the MK30 model, to deliver packages in under 60 minutes. These drones use LiDAR sensors, high-precision GPS, and onboard intelligence capable of detecting real-time obstacles. The project targets urban and suburban areas with payloads up to 2.3 kg and is already operational in select cities in the U.S. and U.K.

Figure 3 - MK30 Model (Source: Amazon, 2023)

In addition, Amazon has invested in autonomous ground vehicles, such as the Amazon Scout, a six-wheeled robot designed for neighborhood deliveries. Its embedded technologies include:

- Autonomous navigation based on HD maps;
- Real-time image processing to avoid pedestrians and animals;
- Customer communication via app for package retrieval.

Both systems are part of Amazon's strategy to reduce driver-related costs, lower carbon emissions, and enhance SLA (Service Level Agreement) performance in fast deliveries.

Amazon has also adopted urban microhubs and Amazon Lockers to minimize delivery failures and optimize last-mile logistics in densely populated areas. Lockers are automated cabinets placed in retail stores, malls, and gas stations, allowing customers to collect their packages using a QR code.

Simultaneously, the company is testing crowdshipping models through its Amazon Flex platform, which recruits independent drivers for on-demand deliveries. This strategy increases geographic coverage, reduces fixed costs, and speeds up peak-time deliveries.

To ensure real-time tracking and regulatory compliance, Amazon employs a robust standardization and traceability system, incorporating technologies such as:

- RFID (Radio Frequency Identification) in products and packaging;
- 2D barcodes integrated with GS1 and ISO standards;

Integrated dashboards with TMS (Transportation Management System) and WMS for end-to-end supply chain visibility.

This level of traceability allows customers to track their deliveries with minute-level precision and provides essential data for maintaining KPIs such as OTIF (on-time, in-full), Net Promoter Score (NPS), and return rates. Key results achieved through Amazon's logistics technologies include:

- Reduction in average delivery time from 5 days to under 24 hours in over 70% of serviced urban areas;

- 20% decrease in total logistics costs per delivered unit;
- Increase in customer satisfaction (NPS) in regions where drones and lockers are deployed;
- Reduction in CO_2 emissions through the use of electric vehicles and AI-optimized routing;
- Faster restocking and improved accuracy in demand forecasting.

The Amazon case represents a model of excellence in the integrated application of logistics technologies with a clear purpose: enhancing customer experience, reducing operational costs, and supporting scalable growth. The solutions implemented reflect key logistics concepts addressed in this study, such as automation, visibility, decentralization, sustainability, and standardization. It is a concrete and multifaceted example of how Logistics 4.0 can radically reshape the performance of a global e-commerce operation.

4.6. Impacts on Consumer Behavior and Logistics Performance

Improving last-mile logistics has a big impact on the customer experience, as people now see delivery as a key part of a product's overall value. Today's customers expect more than just on-time delivery, they want options to personalize their experience, like choosing delivery times or pickup locations and tracking their packages in real time.

These growing expectations mean companies need to rethink their logistics, investing in faster, more flexible systems that put the customer first. Businesses that embrace these changes can cut down on failed deliveries and costs, while also building stronger customer loyalty through transparency, convenience, and a clear commitment to sustainability.

In this way, last-mile delivery has gone from being a common challenge in logistics to a smart strategic advantage. When handled well, it becomes a key differentiator, boosting a company's reputation and helping e-commerce grow in a more sustainable way.

5. Final considerations

5.1. Conclusion

This study explored, from a Logistics Engineering perspective, how last-mile delivery is reshaping the online sales ecosystem. A systematic literature review, along with a critical analysis of European and global industry reports, showed that the final step in delivering products to consumers, traditionally seen as the most expensive and complex part of the logistics chain, has evolved from a secondary operational task into a strategic element for competitive advantage.

The data reviewed indicates that last-mile costs can account for more than 50% of a company's total logistics expenses in e-commerce. At the same time, ultra-fast delivery expectations are becoming the norm: around 60% of global consumers expect to receive their orders within two days. In response to this, several innovative solutions have emerged, such as smart lockers, crowdshipping, electric vehicle fleets, delivery drones (UAVs), and predictive routing powered by artificial intelligence. These technologies help reduce inefficiencies, cut emissions, and improve delivery reliability.

The conclusion is that in today's globalized world, where major players operate on a worldwide scale and consumers have become more digital and impatient, the market competition has become much more intense. As a result, investing in technology and adopting these innovations is no longer optional; it is essential for companies to achieve operational resilience and remain sustainable in today's fast-paced digital markets.

5.2. Work Contributions

In scientific terms, this study contributes by consolidating and connecting previously scattered knowledge about last-mile logistics, integrating topics such as Logistics 4.0, consumer behavior, and environmental goals. The challenge-solution matrix presented serves as a practical guide to steer future empirical research. For managers, the work provides a decision-making framework that links technological choices, demand profiles, urban density, and regulatory constraints, enabling a balanced evaluation of cost, service quality, and sustainability trade-offs.

Furthermore, the study emphasizes the importance of an integrated view across the entire logistics chain. It demonstrates that improvements in the last mile positively impact earlier stages, such as inventory planning, network design, and omnichannel strategies, reinforcing the need for end-to-end informational integration.

5.3. Research limitations

The main limitation of this study is its reliance solely on bibliographic sources, without including primary data. Additionally, while the analyzed period (2015–2025) covers a significant phase of technological and health-related changes (such as COVID-19), it may not account for newer transformations, such as those expected after the regulation of autonomous vehicles in 2026. Finally, the strong focus on the European context may limit the applicability of the findings to other regions.

5.4. Suggestions for future goals

- Empirical evaluation of ROI - Longitudinal case studies quantifying the financial and environmental return of electric fleets, UAVs or lockers in metropolises of contrasting density.
- Public policy modeling - Simulations that integrate zero emission zone restrictions, tax incentives and micro-hub infrastructure, verifying impacts on systemic costs.
- Application of Digital Twins - Development of digital twins to test real-time data integration scenarios (IoT + 5G) and adaptive routing algorithms.
- Consumer behavior analysis - Experiments that measure the elasticity of willingness to pay for sustainable versus ultra-fast deliveries.

5.5. Final Reflection

As cities move toward circular economy models and net-zero goals, last-mile logistics stands out as a critical area for balancing convenience with environmental responsibility. Consumers' increasingly digital behavior has driven exponential growth in online sales, with a consumption profile demanding fast, personalized, and sustainable deliveries. In recent years, this surge in demand has been matched by significant advancements in automation and robotics technologies, which are growing rapidly and paving the way for new, more efficient, and adaptable logistics flows. Artificial intelligence (AI), now more accessible, plays a central role in enabling these innovations by optimizing routes, forecasting demand,

and enabling real-time management. Additionally, recent global political changes, which have introduced new regulations and incentives for sustainable practices, underscore the need for logistics solutions that integrate technology, cross-sector collaboration, and regulatory compliance. This scenario presents a challenge for logistics engineers: to develop analytical, digital, and collaborative skills to overcome organizational and regulatory barriers, aligning the demands of e-commerce with sustainable development goal that impacts not only supply chains but the whole society.

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