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OPPORTUNITIES AND CHALLENGES IN E-COMMERCE LOGISTICS NETWORK MODELLING: A CRITICAL REVIEW

JÁNOS JUHÁSZ[1]

Abstract: *The rapid development of e-commerce has increased the complexity of logistics network design, last-mile delivery, demand forecasting and sustainability-oriented operational planning. The aim of this study is to critically review and synthesize recent modelling approaches applied to e-commerce logistics networks. The reviewed publications are organized into five thematic areas: network design, demand forecasting, route optimization, digital coordination and sustainability-oriented planning. The comparative analysis indicates a gradual transition from static and single-objective optimization models towards more adaptive, data-driven and multi-objective decision-support approaches. However, the literature remains fragmented, as strategic, tactical and operational decisions are frequently examined separately. Further limitations include the insufficient treatment of uncertainty, limited integration between digital technologies and formal optimization models, and a lack of real-world validation. The main contribution of the paper is a structured classification that connects logistics problems, modelling approaches and expected operational outcomes. Based on this synthesis, the study identifies current methodological limitations and future research directions in e-commerce logistics network modelling.*

Keywords: *e-commerce logistics; logistics network modelling; critical literature review; network design; last-mile delivery; optimization; digital technologies; sustainability*

1. INTRODUCTION

In today's globalized market environment, e-commerce logistics systems are increasingly developing more flexible, sustainable and intelligent distribution solutions as alternatives to conventional urban delivery systems. These developments aim to address changing customer expectations and the challenges of digital transformation, while also supporting innovation, operational resilience and environmental sustainability in modern e-commerce logistics networks [1].

The rapid growth of e-commerce has significantly transformed logistics and supply chain networks worldwide. Increasing customer expectations regarding fast delivery, service quality and flexibility have created new challenges for logistics network design and last-mile delivery systems. At the same time, sustainability requirements and industrial digitalization have increased the need for more adaptive, efficient and resilient logistics modelling solutions.

Opportunities in e-commerce logistics network modelling include the development of mathematical models and advanced data-driven technologies that can support the optimization of logistics processes and improve operational coordination. The integration of artificial intelligence, the Internet of Things, blockchain technologies and predictive analytics can support demand forecasting, decision-making and more flexible logistics operations [2, 3]. Furthermore, sustainability-oriented solutions, such as parcel lockers, distribution centres, electric vehicles and collaborative delivery networks, should be incorporated into regional logistics planning [4].

[1]Assistant Professor, University of Miskolc, Institute of Logistics, Hungary
janos.juhasz1@uni-miskolc.hu

The increasing complexity of logistics operations also requires integrated modelling approaches that support operational efficiency and service reliability within e-commerce networks [5]. These approaches can contribute to the continuous improvement of distribution processes under dynamically changing market conditions.

Fig. 1 presents the main components of adaptive e-commerce logistics systems, including digital technologies, standardized processes and data-driven logistics methods [2]. The main challenges of global e-commerce logistics are associated with increasing customer expectations, shorter delivery times and the growing complexity of urban distribution systems. Sustainability requirements and dynamically changing market conditions also create continuous pressure on logistics service providers.

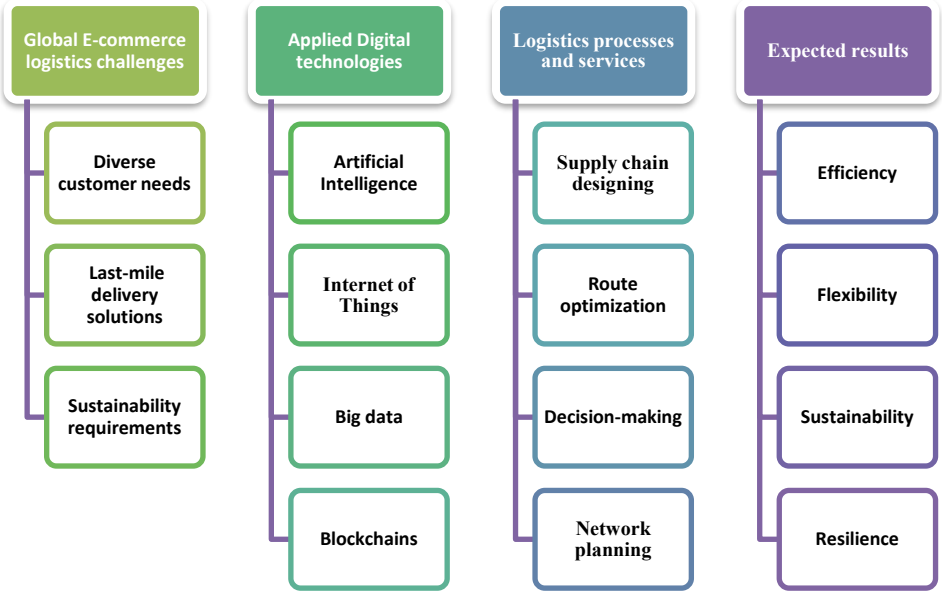

Figure 1. Structure of adaptive e-commerce logistics systems

Digital technologies can support the coordination and transparency of logistics activities. AI-based forecasting, IoT applications and digital data exchange can improve operational planning and support faster decision-making processes. Logistics processes and services include warehousing, transportation, inventory handling and last-mile delivery. These activities require flexible organizational methods and reliable information flows among supply chain participants.

The expected outcomes include higher operational efficiency, improved service quality and more sustainable logistics performance. Adaptive logistics systems can contribute to reducing delivery errors, operational costs and environmental impacts. The conceptual structure shown in Figure 1 illustrates how these methods support the development of more flexible, efficient and sustainable e-commerce logistics systems [3, 4].

2. LITERATURE REVIEW

The literature review was conducted using Scopus database. The search covered publications published between 2017 and 2026 and was performed using combinations of the following keywords: “e-commerce logistics”, “logistics network modelling”, “last-mile delivery”, “route optimization”, “demand forecasting”, “digital logistics” and “sustainable logistics”. The selected publications were compared according to the logistics problem addressed, the modelling approach applied, the expected operational effect and the main limitations identified. Finally, 15 studies were included in the qualitative analysis.

In recent years, e-commerce logistics distribution solutions have become important research areas in supply chain management. The increasing complexity of e-commerce logistics operations requires new integrated modelling approaches that can support both operational efficiency and service reliability within e-commerce networks [5]. These developments contribute to the continuous improvement of distribution processes under dynamically changing market conditions, similarly to the principles of Lean philosophy.

Recent studies have focused on urban last-mile delivery challenges, mathematical modelling, digital coordination and sustainability-oriented logistics strategies. This literature review summarizes the most relevant scientific contributions related to adaptive e-commerce logistics systems and services.

Several researchers have examined last-mile delivery systems, which represent one of the most complex areas of e-commerce logistics because of urban congestion, delivery errors and increasing customer expectations. Silva et al. highlighted the importance of innovative urban logistics concepts and sustainable distribution solutions for reducing environmental impacts and delivery inefficiencies [1]. Similarly, Cardenas et al. examined home-delivery systems and pickup-point solutions in urban logistics. They concluded that collection points could reduce failed deliveries and transportation distances within urban areas [6].

Several studies have examined operational risks in e-commerce last-mile logistics. Raj et al. identified limited shipment visibility, low delivery efficiency and uncertainty in delivery conditions as important operational risk factors [7]. Their findings indicate that e-commerce logistics networks require more flexible and transparent operational solutions to respond effectively to changing customer demand.

Ranathunga et al. reviewed approaches for integrating first-mile pickup and last-mile delivery operations in e-commerce networks. Their analysis showed that vehicle-routing models and approximation algorithms can improve delivery efficiency and support the coordination of pickup and delivery activities [8].

Optimization and predictive logistics models have also received considerable attention in recent years. Zhang et al. investigated a vehicle-routing problem involving simultaneous pickup and delivery operations. Their results showed that heuristic methods can improve collaborative logistics performance under dynamic demand conditions [9]. Santos et al. analysed middle-mile and last-mile optimization models and found that routing-based delivery systems may significantly reduce transportation costs compared with direct-delivery solutions [10].

Predictive methods are also becoming increasingly important in logistics planning. Wang developed a predictive framework for sortation and delivery optimization and demonstrated that forecasting methods can support resource allocation and improve operational performance in e-commerce logistics systems [11].

Digital technologies now play a central role in e-commerce logistics operations. Leong et al. examined IoT applications in supply chain management and reported that real-time tracking systems and digital data exchange improve logistics visibility and coordination among supply chain participants [2]. Their study also discussed the application of blockchain-supported traceability systems in logistics operations.

Meda et al. investigated predictive demand forecasting methods in e-commerce supply chains and showed that forecasting models can support inventory planning and operational decision-making under volatile market conditions [3]. Liu et al. analysed hybrid logistics frameworks and concluded that integrated digital systems improve operational coordination and logistics service quality in e-commerce networks [5].

Sustainability has also become an important factor in logistics planning and distribution-network development. Singh et al. proposed a low-emission last-mile logistics framework for urban e-commerce systems and showed that optimized distribution structures can reduce environmental impacts while maintaining logistics performance [4].

Other studies have focused on logistics service quality and operational efficiency. Zhou et al. examined the relationship between customer loyalty and logistics service processes in e-commerce systems. They found that delivery reliability, service accuracy and operational performance strongly influence customer satisfaction [12].

Environmental aspects of e-commerce logistics systems have also been widely investigated. Tian et al. analysed transportation-related emissions and emphasized the importance of sustainable fleet planning in urban logistics networks [13]. Their results showed that fleet composition and operational efficiency significantly affect the environmental performance of urban distribution systems. These findings suggest that sustainability has become a key strategic consideration in e-commerce logistics planning.

Overall, the reviewed studies provide valuable insights into last-mile logistics challenges, optimization methods, digital technologies and sustainability-oriented logistics planning. However, the studies generally examine these areas separately. Last-mile delivery research mainly focuses on delivery efficiency and operational risks [1, 6, 7], while optimization studies concentrate on routing, pickup-and-delivery coordination and transportation costs [8–10]. Predictive and digital approaches primarily address forecasting, visibility and information exchange [2, 3, 5, 11], whereas sustainability-oriented studies focus on emissions, fleet composition and low-emission distribution structures [4, 13].

This thematic separation indicates that the literature provides limited integration among forecasting, routing, digital coordination and sustainability-related decisions. In addition, the reviewed studies use different analytical perspectives and performance measures, which makes direct comparison difficult. Therefore, a structured classification is needed to clarify the relationships among the modelling approaches, the logistics problems they address and their expected operational outcomes.

3. MODELLING AND OPERATIONAL APPROACHES IN E-COMMERCE LOGISTICS

E-commerce logistics systems require adaptive modelling approaches to support logistics planning, operational coordination and service reliability. Recent research has increasingly focused on forecasting methods, route optimization and integrated operational frameworks that can improve flexibility under rapidly changing market conditions. This section reviews and compares the modelling and operational approaches identified in the literature. It does

not introduce a new mathematical model; instead, it examines how the reviewed methods contribute to different logistics decisions and operational objectives.

Several researchers examined predictive logistics methods in e-commerce systems. Vavliakis et al. proposed a hybrid ARIMA–LSTM forecasting model and demonstrated that combining statistical forecasting with neural network methods can improve forecasting accuracy in dynamic e-commerce environments [14]. Similarly, Abuhasel highlighted that AI-supported predictive analytics can improve operational decision-making by integrating weather, traffic and inventory-related data into logistics forecasting models [15].

These studies indicate that predictive methods can support more accurate demand estimation and resource planning. However, forecasting results provide operational value only when they are connected to inventory, transportation and capacity-planning decisions. Therefore, the integration of predictive models with optimization and decision-support systems represents an important development direction.

As Table I shows, recent modelling approaches mainly focus on operational flexibility, digital coordination and sustainability aspects. These approaches increasingly integrate forecasting methods, optimization techniques and adaptive operational planning into e-commerce logistics systems.

Table I.

Classification of recent modelling approaches in e-commerce logistics

Research area	Problem identification	Result	Related literature
Predictive forecasting	Planning demands and inventories	Efficient resource allocation	Vavliakis et al. [14], Abuhasel [15].
Route optimization	Reschedule delivery	Reduced delivery costs	Ranathunga et al. [8], Zhang et al. [9].
Digital coordination	Real-time visibility	Faster response	Liu et al. [5]
Sustainable planning	Emission reduction	Improved environmental performance	Singh et al. [4], Tian et al. [13].
Hybrid operational models	Integrated logistics Supply Chain Management	Higher flexibility	Raj et al. [7]

Optimization-based logistics planning has also become an important research direction in e-commerce logistics. Ranathunga et al. emphasized the importance of integrating first-mile pickup and last-mile delivery activities within vehicle-routing systems. Their review indicated that heuristic and approximation methods can support more efficient transportation coordination and reduce operational costs [8]. Zhang et al. similarly concluded that simultaneous pickup-and-delivery models can improve collaborative logistics coordination under dynamic delivery conditions [9].

These studies demonstrate that route optimization can improve the coordination of complex pickup and delivery operations. Nevertheless, the performance of such models

depends on the accuracy of demand, travel-time and customer-availability data. In real e-commerce environments, these parameters frequently change during operations, which limits the applicability of purely static routing approaches.

Digital coordination and hybrid operational frameworks have also become increasingly important in modern logistics systems. Liu et al. examined collaborative-filtering and reinforcement-learning-supported operational models and concluded that adaptive coordination methods can improve both operational efficiency and customer experience in e-commerce systems [5]. Raj et al. highlighted that limited visibility, operational uncertainty and delivery-related risks remain important challenges in last-mile logistics systems. Their findings demonstrated the importance of adaptive operational planning and integrated coordination methods in e-commerce logistics environments [7].

The two studies approach digital coordination from different perspectives. Liu et al. focus on the application of data-driven methods for improving operational performance and customer experience [5], whereas Raj et al. emphasize the operational risks caused by inadequate visibility and uncertain delivery conditions [7]. Together, these findings suggest that digital coordination should not be treated only as a technological issue. It also requires appropriate planning processes, reliable data exchange and clearly defined operational responsibilities.

Sustainability-oriented operational planning also represents an increasingly important research field in e-commerce logistics. Singh et al. developed a multi-objective optimization framework for low-emission urban logistics systems and demonstrated that adaptive distribution configurations can reduce transport-related emissions while maintaining acceptable service levels [4]. Similar conclusions were described by Tian et al., who highlighted the growing environmental importance of fleet composition and transportation planning within urban logistics systems [13].

These studies demonstrate that environmental objectives can be incorporated into logistics planning without disregarding operational performance. However, the relationship between emissions, delivery cost and service quality involves significant trade-offs. A distribution configuration that reduces emissions may require changes in fleet composition, delivery frequency or consolidation practices. Therefore, sustainability-oriented logistics planning should evaluate environmental and operational objectives jointly.

The reviewed studies demonstrate that modelling and operational approaches in e-commerce logistics increasingly combine predictive analytics, route optimization, digital coordination and sustainability-oriented planning principles. Forecasting models support the estimation of future demand and resource requirements [14, 15], while optimization methods improve pickup-and-delivery coordination [8, 9]. Digital and hybrid approaches enhance visibility and adaptive decision-making [5, 7], whereas sustainability-oriented models incorporate emission reduction and fleet-planning considerations into logistics decisions [4, 13].

Despite these developments, the approaches remain only partially integrated. Predictive results are not always connected directly to route-planning decisions, digital technologies are frequently examined separately from formal optimization models, and sustainability objectives are often added to existing models rather than incorporated into a unified decision framework. This fragmentation represents one of the main unresolved issues in e-commerce logistics network modelling.

4. OPERATIONAL IMPLICATIONS OF ADAPTIVE E-COMMERCE LOGISTICS SYSTEMS

The continuous development of e-commerce logistics systems has significantly influenced operational coordination, delivery planning and urban distribution processes. Based on the reviewed studies, adaptive logistics approaches increasingly support operational flexibility, service reliability and sustainability-oriented logistics planning within dynamically changing market environments.

The operational implications identified in the literature can be divided into five main areas: forecasting, route optimization, real-time monitoring, sustainable delivery planning and integrated digital coordination. Each area contributes to logistics performance in a different way, but their combined application can provide greater operational value than their isolated use.

As Table II shows, adaptive e-commerce logistics systems increasingly integrate forecasting methods, operational coordination and sustainability-oriented planning approaches. These developments can support more flexible logistics operations and improve service reliability under dynamically changing market conditions.

Table II.

Operational implications and implementation challenges of adaptive e-commerce logistics systems

Operational area	Identified impact	Expected logistics effect	Main implementation challenge
Forecasting systems	Improved orders scheduling	Better inventory planning	Forecasting errors and volatile demand
Route optimization	Adaptive delivery	Reduced delivery costs	Dynamic traffic and changing customer availability
Real-time monitoring	Faster response	Improved operational reliability	Data quality and system interoperability
Sustainable delivery systems	Reduced environmental impacts	Improved urban logistics	Trade-offs between emissions, cost and service level
Integrated digital e-commerce systems	Higher flexibility	More resilient logistics operations	Implementation cost, cybersecurity and organizational coordination

At the same time, each operational area involves specific implementation challenges. Forecasting systems are affected by demand uncertainty, while route-optimization methods must respond to changing traffic and delivery conditions. Real-time monitoring depends on reliable and interoperable data systems, and sustainable delivery planning requires the evaluation of trade-offs between cost, service quality and environmental performance. Therefore, the practical value of adaptive logistics approaches depends not only on model quality but also on data availability and organizational implementation.

The reviewed operational approaches indicate that adaptive logistics systems can improve transportation efficiency, delivery performance and operational responsiveness. They can

also support more sustainable and resilient logistics operations in urban distribution environments. However, these benefits are unlikely to be achieved through the isolated application of a single technology or modelling method. Effective implementation requires the coordination of forecasting, optimization, digital information exchange and sustainability-oriented planning.

Several modelling and optimization approaches examined in the literature review support the improvement of delivery coordination, forecasting accuracy and transportation efficiency. At the same time, sustainability requirements and digital logistics solutions increasingly influence operational decision-making and urban distribution planning.

The main operational challenge is to connect these methods within a consistent decision framework. Forecasting results should inform capacity and routing decisions, real-time information should support the continuous adjustment of operational plans, and sustainability objectives should be evaluated together with cost and service requirements. This integrated perspective provides the basis for the conclusions and future research directions presented in the following section.

5. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This study reviewed modelling and operational approaches related to predictive forecasting, route optimization, digital coordination, last-mile delivery and sustainability-oriented logistics planning. The reviewed studies indicate that forecasting methods can improve demand estimation and resource allocation, while route-optimization approaches can support the coordination of pickup and delivery activities. Digital technologies contribute to logistics visibility and faster information exchange, whereas sustainability-oriented models incorporate environmental considerations into network and transportation planning.

The comparative analysis also identified an important limitation in the existing literature. The main modelling approaches are generally examined separately, even though their decisions are closely connected in practice. Forecasting results are not always directly incorporated into routing and capacity-planning models. Digital technologies are frequently discussed as information and coordination tools without being fully integrated into formal optimization approaches. Similarly, sustainability objectives are often evaluated separately from service quality, operational flexibility and economic performance.

The main contribution of this study is the structured classification of the reviewed modelling approaches according to their primary logistics problems, applied methods and expected operational effects. The analysis also connects predictive, optimization-based, digital and sustainability-oriented perspectives within a common conceptual interpretation. This synthesis clarifies how the individual approaches contribute to adaptive e-commerce logistics systems and identifies the areas in which stronger methodological integration is required.

From a practical perspective, the findings indicate that logistics providers should select modelling approaches according to their specific operational problems, available data and technological capabilities. Forecasting methods can support inventory and capacity planning, while route-optimization tools can improve transportation coordination. Real-time monitoring and integrated digital systems can increase operational responsiveness, but their effectiveness depends on reliable data exchange, system interoperability and appropriate organizational processes. Sustainability-oriented planning additionally requires the joint evaluation of delivery cost, service quality and environmental performance.

Further research is needed on the integration of forward and reverse logistics processes. Product returns are a fundamental part of e-commerce, but delivery and return operations are often planned separately. Integrated pickup-and-delivery approaches could improve vehicle utilization and return management.

This study has several limitations. The analysis is based on a selected group of publications and does not cover every modelling approach within the rapidly developing field of e-commerce logistics. Furthermore, the proposed classification is conceptual and has not been validated through a separate empirical case study. Nevertheless, it provides a structured foundation for understanding the relationships among current modelling approaches and for identifying relevant directions for future research.

Overall, future e-commerce logistics research should focus on integrated decision-support methods that combine operational efficiency, service reliability, digital coordination and sustainability. Such integration could support logistics systems that respond more effectively to changing market conditions while maintaining acceptable economic and environmental performance.

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