Railway Sciences

Integrating rail transport with crowd logistics for sustainable urban freight: a systematic literature review

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Abstract

Purpose – This study systematically examines the potential for integrating crowd logistics (CL) with rail transport to enhance the efficiency, sustainability and multimodal performance of first and last-mile urban freight operations. It synthesizes the conceptual and empirical foundations of this emerging research area, identifies dominant scholarly trends and highlights gaps that constrain practical implementation of Rail-CL systems.

Design/methodology/approach – A systematic literature review was conducted following PRISMA 2020 guidelines. Fifty peer-reviewed publications from 2009 to 2025 were selected from major academic databases and evaluated using the 2018 Mixed Methods Appraisal Tool (MMAT). Extracted data covered study design, research aims, geographic scope, transport modes, technologies, sustainability outcomes, integration strategies and reported barriers. The evidence was synthesized using thematic and descriptive analysis.

Findings – The literature reveals a strong bias toward last-mile crowdshipping, with comparatively limited attention to first-mile operations and rail-based multimodal integration. Although environmental, economic and social benefits are frequently reported, most studies remain conceptual with limited real-world validation. Core challenges include regulatory uncertainty, inadequate rail-terminal infrastructure, coordination difficulties among stakeholders and persistent concerns regarding trust, liability and service reliability. Only a small number of studies propose integrated Rail and CL frameworks, confirming a substantial research gap.

Originality/value – This review offers the first comprehensive assessment of literature directly linking CL with rail freight transport. It establishes Rail and CL integration as an emerging research domain and outlines a forward-looking agenda focused on empirical testing, digital platform development and context-specific models particularly relevant for developing countries pursuing sustainable and resilient freight systems.

Keywords Crowd logistics, Crowdshipping, Rail freight, Urban freight transport, First-mile, Last-mile, Multimodal transport, Sustainability

Paper type Literature review

1. Introduction

Urbanization and the rapid expansion of e-commerce have significantly intensified pressure on urban freight transport systems. The increasing demand for fast, flexible, and reliable delivery services has led to a substantial rise in freight volumes, contributing to congestion, environmental pollution, noise and increased energy consumption in densely populated areas (Allen, Browne, & Cherrett, 2012; Bosona, 2020; El Moussaoui, Benbba, Jaegler, & El Andaloussi, 2022). Among the various components of the logistics chain, last-mile delivery is particularly inefficient and costly, often accounting for a disproportionate share of total logistics costs and emissions (Gatta, Marcucci, Nigro, & Serafini, 2019; Elbert & Rentschler,

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2021). These challenges highlight the urgent need for innovative and sustainable freight transport solutions that can improve efficiency while reducing environmental impact.

Rail transport is widely recognized as a sustainable alternative for long-haul freight movement due to its high capacity, energy efficiency and significantly lower carbon emissions per ton-kilometer compared to road transport (Alessandrini, Delle Site, Filippi, & Salucci, 2012; Crainic, Ricciardi, & Storchi, 2009; Gholamizadeh, Zarei, & Yazdi, 2022). However, its application in urban logistics remains constrained by limited flexibility, particularly in first- and last-mile operations where demand is fragmented and time-sensitive. In contrast, crowd logistics (CL), also referred to as crowdshipping, has emerged as a flexible and demand-responsive delivery model that leverages the unused capacity of individuals and their mobility resources to perform short-distance deliveries (Carbon, Rouquet, & Roussat, 2021; Buldeo Rai, Verlinde, Merckx, & Macharis, 2017; Le, Stathopoulos, Van Woensel, & Ukkusuri, 2019). By combining the structural efficiency of rail with the adaptability of CL, there is growing potential to develop integrated, multimodal freight systems capable of addressing urban logistics challenges more effectively.

Despite the increasing body of research on rail freight, urban logistics and CL, these domains have largely evolved in isolation. Existing studies predominantly focus either on road-based freight optimization or on last-mile crowdshipping solutions, with limited attention to their systematic integration (Elbert & Rentschler, 2021; Derse & Van Woensel, 2024). More critically, no prior study has provided a comprehensive and structured synthesis of how rail transport can be operationally and conceptually integrated with CL within a unified framework. As a result, current knowledge remains fragmented, particularly regarding integration models, technological coordination mechanisms and system-level sustainability outcomes. This gap is especially pronounced in the context of developing and road and rail-dependent economies, where such integration could offer significant efficiency and sustainability benefits.

To address this gap, the present study conducts a systematic literature review (SLR) following the PRISMA 2020 guidelines. The review synthesizes 50 peer-reviewed studies published between 2009 and 2025, with the aim of developing a comprehensive understanding of Rail-CL integration. The study is guided by the following research questions.

RQ1. What theoretical foundations, integration models, operational strategies and technological coordination mechanisms enable Rail-CL integration?

RQ2. What environmental, economic and social sustainability outcomes are reported in the literature?

RQ3. What barriers, implementation challenges and contextual constraints limit integration?

RQ4. What geographic, methodological and thematic research gaps remain?

This study makes three key contributions to the literature. First, it provides the first structured and comprehensive synthesis explicitly focused on the integration of rail freight and CL, thereby bridging two previously disconnected research streams. Second, it advances theoretical understanding by identifying and consolidating key integration models, system architectures and enabling mechanisms within a unified analytical framework. Third, it offers practical insights for policymakers, railway operators and logistics providers by highlighting critical barriers, infrastructure requirements and policy implications necessary for implementing integrated and sustainable freight systems, particularly in developing economies. The remainder of this article is structured as follows. Section 2 reviews the relevant literature on rail transport and CL and develops the conceptual foundation for integration. Section 3 describes the systematic review methodology. Section 4 presents and discusses the results of the analysis. Finally, Section 5 concludes the article by outlining key findings, contributions, limitations and directions for future research.

2. Literature review

2.1 Rail freight and its role in sustainable urban logistics

Rail transport has long been recognized as a key enabler of sustainable freight distribution, particularly for long-haul and high-volume transport. Its advantages include high carrying capacity, energy efficiency and significantly lower greenhouse gas emissions per ton-kilometer compared to road transport (Alessandrini *et al.*, 2012; Gholamizadeh *et al.*, 2022). These characteristics position rail as an environmentally favorable alternative within the broader context of decarbonizing freight transport systems. In the context of urban logistics, rail has been explored as a means to reduce road congestion and improve the environmental performance of freight distribution. Early and recent studies highlight the potential of urban rail systems, including freight trams and metro-based logistics, to support the movement of goods into city centers (Marinov *et al.*, 2013; Elbert & Rentschler, 2021). Such approaches can facilitate higher levels of consolidation and reduce the number of freight vehicles operating in urban areas.

However, the application of rail in urban freight systems remains limited. A key constraint is its lack of flexibility in handling first and last-mile deliveries. Rail systems typically require fixed infrastructure and schedules, making them less adaptable to dynamic urban delivery demands (Crainic *et al.*, 2009; Ozturk & Patrick, 2018). As a result, rail-based freight solutions often rely on complementary modes to ensure end-to-end service delivery, while rail transport offers significant sustainability benefits for long-distance freight movement. Critical observation from the literature is that rail's role in urban freight is almost exclusively framed as a line-haul backbone, with first/last-mile treated as a separate problem to be solved by other modes. This separation reflects an implicit theoretical assumption that modal boundaries are fixed rather than reconfigurable. Few studies challenge this assumption by exploring how rail infrastructure itself could be adapted for granular, crowd-based distribution. Consequently, the literature perpetuates a "modal silo" perspective that undermines genuine integration.

2.2 Principles of crowd logistics

CL represents an innovative strategy for enabling rapid shipping services by delegating last-mile delivery to ordinary individuals. These "crowd" participants agree to transport goods to customers along their planned routes, using personal vehicles in return for a modest incentive (Carbon *et al.*, 2021; Bortolini, Calabrese, & Galizia, 2022). At its core, CL builds on a network of interconnected users to enhance the efficiency and sustainability of goods movement, storage and delivery worldwide. It depends on individuals linked through mobile technologies and typically emphasizes small-scale operations (Carbon *et al.*, 2021; Le *et al.*, 2019). Essentially, CL fosters connections between those possessing logistics resources and those in need of them (Andrejić & Jeremić, 2019). No universal definition exists for crowdsourcing or its derivative CL. The roots of CL trace back to crowdsourcing, which combines "crowd" a large group of people with "outsourcing" delegating tasks to external parties (Buldeo Rai *et al.*, 2017). Crowdsourced delivery addresses escalating customer demands for quicker, more personalized and cost-effective services. It capitalizes on technological advancements, such as geolocation and mobile applications, alongside societal shifts toward sharing and collaboration (Rougès & Montreuil, 2014).

2.3 Conceptual framework and system boundaries of Rail-CL integration

Rail-CL integration can be defined as: A coordinated logistics system in which rail transport performs long-haul, high-volume freight movement, while CL facilitates first and last-mile distribution through decentralized, digitally coordinated delivery networks. Despite growing interest in rail freight and CL, their integration remains conceptually fragmented, with most studies addressing them independently (Bosona, 2020; Mohri, Ghaderi, Nassir, & Thompson, 2023). To address this gap and in line with RQ1, this study conceptualizes Rail-CL integration as a multimodal socio-technical system that combines rail's line-haul efficiency with flexible, crowd-enabled first and last-mile delivery.

The framework is grounded in socio-technical systems theory (Geels, 2004) and stakeholder theory (Freeman, 1984), emphasizing the interaction between infrastructure, digital technologies and institutional actors. Rail functions as a high-capacity, low-emission backbone for long-distance freight, while CL provides decentralized, demand-responsive distribution via digitally coordinated participants (Carbon *et al.*, 2021; Le *et al.*, 2019). This complementarity addresses inefficiencies in urban freight systems, particularly last-mile challenges (Gatta *et al.*, 2019; Elbert & Rentschler, 2021).

The framework comprises three interconnected layers. The line-haul layer represents rail-based bulk transport between major terminals (Crainic *et al.*, 2009; Gholamizadeh *et al.*, 2022). The node layer includes rail terminals and urban consolidation centers enabling freight transfer across modes (Alessandrini *et al.*, 2012). The distribution layer involves CL-based delivery using flexible modes such as bike and private vehicles, coordinated through digital platforms (Buldeo Rai *et al.*, 2017; Mladenow, Bauer, & Strauss, 2016). This layered structure captures system-wide freight integration. Four enabling components underpin system performance. Physical infrastructure ensures efficient transshipment and connectivity; digital platforms enable real-time matching, routing and tracking (Seng, Ang, Ngharamike, & Peter, 2023; Chen, Zhang, Lin, & Fang, 2019); the stakeholder ecosystem requires aligned incentives, governance and trust (Carbon *et al.*, 2021; Cebeci, Tapia, Kroesen, de Bok, & Tavasszy, 2023); and operational synchronization across consolidation, rail transport and last-mile delivery ensures reliability (Cheng, Fessler, Nielsen, Larsen, & Jiang, 2024; Maleki, Rayburg, & Glackin, 2025).

Aligned with RQ2, the framework supports triple bottom line sustainability outcomes. Environmental benefits include emission reduction and congestion mitigation, while economic gains stem from improved efficiency and asset utilization. Social benefits relate to accessibility and participation in logistics services (Buldeo Rai *et al.*, 2017; Naganawa, Hirata, & Thompson, 2025; Carbon *et al.*, 2021). However, these outcomes are constrained by regulatory uncertainty, infrastructure limitations and coordination challenges (Derse & Van Woensel, 2024; Cebeci *et al.*, 2023). Critical observation: More critically, the existing frameworks in the literature remain predominantly conceptual rather than operationalized, with limited empirical testing and no substantive validation in developing-economy contexts. Moreover, existing frameworks tend to assume seamless and benevolent coordination that rail operators, platform providers, crowd participants and regulators will naturally align incentives. This ignores well-documented principal-agent problems, trust deficits, and power asymmetries. A theoretically robust Rail-CL framework must therefore incorporate governance mechanisms (contract design, reputation systems, dispute resolution) rather than assuming coordination away.

2.4 Rail integration approaches with crowd logistics

The integration of rail freight with CL can be operationalized through three complementary approaches that structure freight flows, enhance system efficiency and support sustainable urban logistics. These approaches consolidation and deconsolidation, Freight-on-Transit (FOT) and co-modality reflect different but interrelated mechanisms for linking high-capacity rail systems with flexible last-mile delivery networks, directly addressing the study's objective of identifying integration models (RQ1).

The first approach consolidation and deconsolidation approach structures freight flows through strategically located rail hubs. Upstream, consolidation aggregates dispersed shipments into centralized terminals to improve load factors and achieve economies of scale in rail transport (Crainic *et al.*, 2009; Zhao, Zhao, Hu, Li, & Stoeter, 2018). Downstream, deconsolidation enables the fragmentation of bulk shipments into smaller consignments suitable for CL-based last-mile delivery (Alessandrini *et al.*, 2012). This approach enhances first and last-mile connectivity while maintaining rail efficiency. However, its effectiveness depends on terminal capacity, spatial configuration and coordination among logistics actors (Gholamizadeh *et al.*, 2022; Allen *et al.*, 2012).

The second approach, freight-on-transit (FOT), extends rail functionality by integrating freight into existing passenger rail and urban transit systems, thereby utilizing spare capacity and reducing reliance on dedicated freight infrastructure. Empirical and review-based studies demonstrate the feasibility of this model, particularly in dense urban contexts where passenger networks are underutilized during off-peak periods (Elbert & Rentschler, 2021; Bacher, Klopp, Ortbauer, & Lackner, 2024). Applications such as public transport-based crowdshipping and mixed passenger freight systems illustrate how FOT can improve asset utilization and reduce environmental impacts (Gatta *et al.*, 2019; Serafini, Nigro, Gatta, & Marcucci, 2018; Naganawa *et al.*, 2025). Nonetheless, operational challenges including scheduling conflicts, demand uncertainty and economic viability remain critical barriers to large-scale implementation (El Amrani, Fri, Benmoussa, & Rouky, 2024).

The third approach, co-modality, emphasizes the dynamic and optimized integration of multiple transport modes within a unified logistics system (Derse & Van Woensel, 2024). Unlike traditional multimodal transport, co-modality is inherently demand-responsive and enabled by advanced digital platforms and real-time data systems (Seng *et al.*, 2023). Within this approach, rail serves as the high-capacity backbone, while CL provides flexible, decentralized delivery through crowdsourced resources (Carbon *et al.*, 2021; Le *et al.*, 2019). Simulation and empirical studies indicate that integrating freight flows into passenger transport systems such as buses, rail and on-demand mobility can improve system efficiency by reducing empty trips and enhancing capacity utilization (Ronald, Yang, & Thompson, 2016; Yang, Wu, & Huang, 2023). However, co-modality introduces coordination complexity across heterogeneous stakeholders and requires robust digital infrastructure to ensure service reliability and synchronization (Cebeci *et al.*, 2023; Cheng *et al.*, 2024).

Critically, these three approaches are not mutually exclusive, yet the literature treats them as separate research streams. Consolidation studies rarely engage with FOT, and co-modality papers seldom cite consolidation research. This fragmentation is a theoretical weakness. A genuine Rail-CL integration framework should synthesize these approaches: using consolidation for volume aggregation, FOT for urban penetration and co-modality for dynamic mode switching. Furthermore, each approach embeds different assumptions about who controls the platform (rail operator vs. third-party vs. decentralized protocol), who bears risk, and how value is distributed. These questions are almost entirely absent from current theoretical models.

3. Methodology

This study adopts an SLR approach to provide a structured and transparent synthesis of existing research on the integration of rail transport and CL. The review follows the PRISMA 2020 guidelines to ensure methodological rigor and reproducibility. The process includes identification, screening, eligibility assessment and final inclusion of studies.

3.1 Search strategy and databases used

A comprehensive database search initially identified 587 records from major academic sources, including ScienceDirect, MDPI, IEEE Xplore, Emerald Insight and Springer Nature. Additional mixed sources were identified through Taylor & Francis Online, Wiley Online Library, Frontiers, conference proceedings and institutional repositories to ensure comprehensive coverage. The search was conducted between May 2, 2025 and March 3, 2026, covering publications from 2009 to 2025. The timeframe 2009–2025 was selected because CL and crowdshipping emerged as recognizable concepts in the late 2000s. The final database-specific search strings included.

(1) (“crowd logistic*” OR “crowdshipping*” OR “crowdsourcing*” OR “crowdsourced deliver*”) AND (“rail*” OR “rail freight” OR “multimodal transport” OR “intermodal”)

(2) (“urban freight” OR “first-mile” OR “last-mile”) AND (“rail*” OR “freight rail”) AND (“sustainable*” OR “barrier*” OR “challenge*”)

(3) (“co-modality” OR “freight-on-transit” OR “consolidation hub*”) AND (“crowd logistic*” OR “crowdshipping”). Figure 1 shows the distribution of records by source.

3.2 Inclusion and exclusion criteria

Inclusion criteria selected studies explicitly addressing rail transport, CL or their integration in urban or multimodal systems. Only English-language, peer-reviewed articles and reputable conference proceedings from 2009 to 2025 with full-text availability were considered.

Exclusion criteria removed studies on unrelated sectors (e.g., aviation or maritime) or general logistics without specific rail or CL applications. Non-peer-reviewed items, such as editorials, opinion pieces and blogs, were omitted to uphold academic credibility.

3.3 Study selection

The study selection followed a structured PRISMA approach. From the initial 587 records, title and abstract screening reduced the dataset to 82 articles for full-text assessment. After applying inclusion and exclusion criteria, 53 studies were retained for quality appraisal. Using the MMAT evaluation, studies that did not meet the quality threshold were excluded, resulting in a final sample of 50 studies included in the synthesis. The selection process is illustrated in Figure 2.

3.4 Data extraction and analysis techniques

Data extraction was conducted using a standardized Microsoft Excel framework to capture key variables, including authorship, publication year, study type, geographic focus, transport modes, technologies, sustainability outcomes, integration strategies, barriers, mathematical models and limitations. The final dataset consisted of 50 studies. The analysis combined

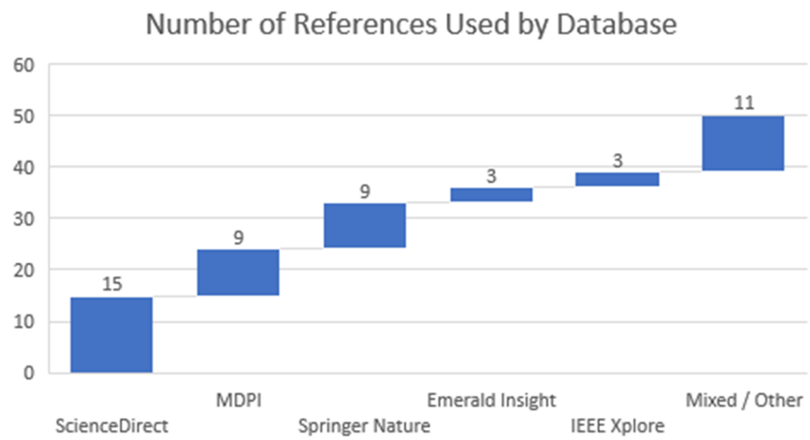

Figure 1. Source of information. Source: Excel; authors’ elaboration

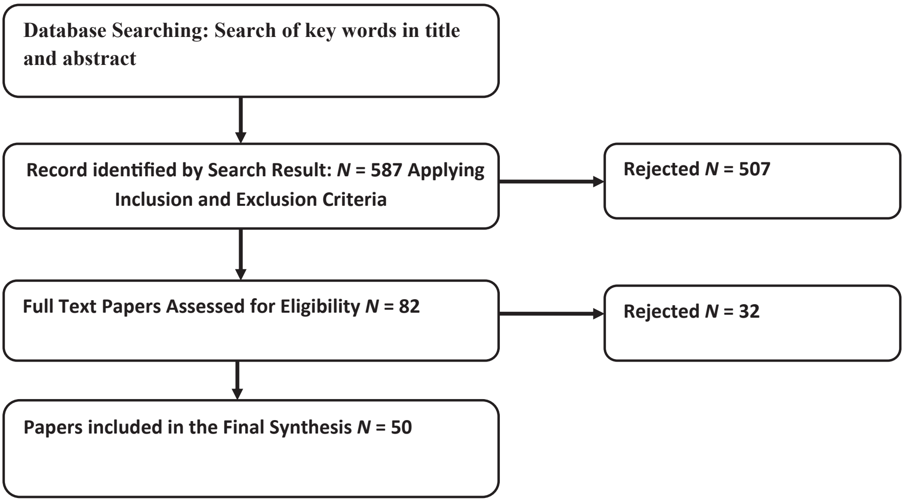

Figure 2. PRISMA flow diagram for selection process. Source: Authors' elaboration

thematic synthesis for qualitative insights and descriptive analysis for quantitative patterns. Due to heterogeneity in study designs, meta-analysis was not performed.

3.5 Quality assessment

The methodological quality of the selected studies was evaluated using the Mixed Methods Appraisal Tool (MMAT) (2018), which assesses studies across five criteria with scores ranging from 0 to 5. A total of 53 studies were appraised, and those scoring below 3 were excluded to ensure methodological rigor, resulting in 50 studies retained for analysis. The appraisal was conducted by dual reviewer using predefined criteria, and ambiguous cases were re-evaluated to enhance consistency and minimize bias.

4. Results and discussion

This section provides a complete synthesis of 50 reviewed studies, classified into qualitative 20 papers, quantitative 23 papers and mixed-methods 7 papers. The analysis focuses on study types, objectives, geographic focus, first and last mode of transportation, technology, sustainability, integration focus, integration barriers, mathematical model and study limitations.

4.1 Bibliometric analysis

A bibliometric analysis was conducted on the chosen corpus using VOSviewer to understand how keywords and topics evolved. A minimum keyword co-occurrence of $n = 2$ was selected, resulting in the retention of 105 keywords and the creation of Figure 3. The analysis reveals a clear structural evolution in the literature on urban freight and CL. Early research is predominantly anchored in urban freight systems, rail transport and sustainability, reflecting foundational concerns with efficiency and environmental performance. Over time, the field has shifted toward digitally enabled, decentralized logistics models, with increasing emphasis on CL, platform-based coordination, and innovative business models. A critical observation is that rail transport and CL remain weakly interconnected research clusters. While "urban freight" and "last-mile delivery" act as central nodes, rail-related keywords are only loosely connected to emerging CL concepts, indicating that integration is still conceptually

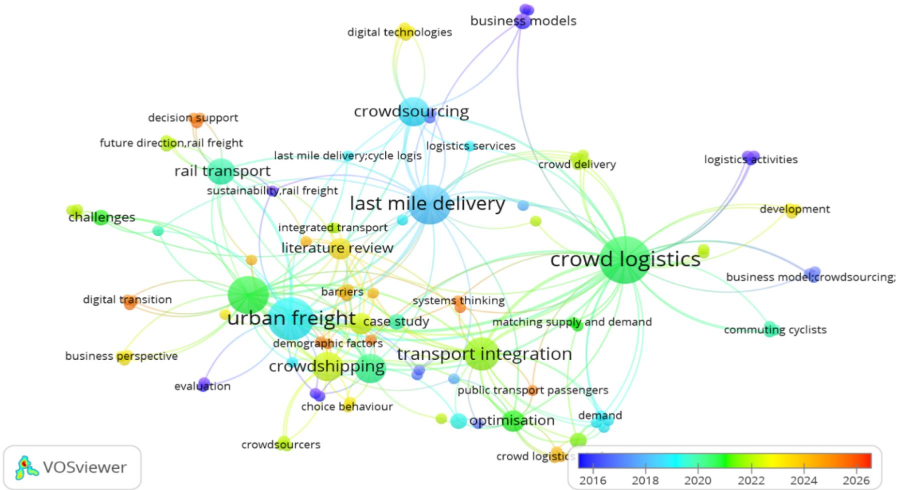

Figure 3. Keywords used in the network visualization by VOSviewer. Source: Authors' elaboration

underdeveloped. This directly supports RQ4, confirming that Rail-CL integration is an emerging but fragmented research domain. Furthermore, the temporal overlay suggests that post-2020 research is increasingly driven by digitalization and platform economies, yet this shift has not been matched by corresponding advances in multimodal integration frameworks. This imbalance highlights a structural gap, namely that technological innovation is advancing faster than system-level integration.

4.2 The geographical scope of sector studies

The geographical scope of sector studies demonstrating Figure 4, Approximately 73% of the studies originate from Europe, indicating a strong regional concentration of research on CL and rail transport. This dominance reflects advanced policy frameworks, infrastructure

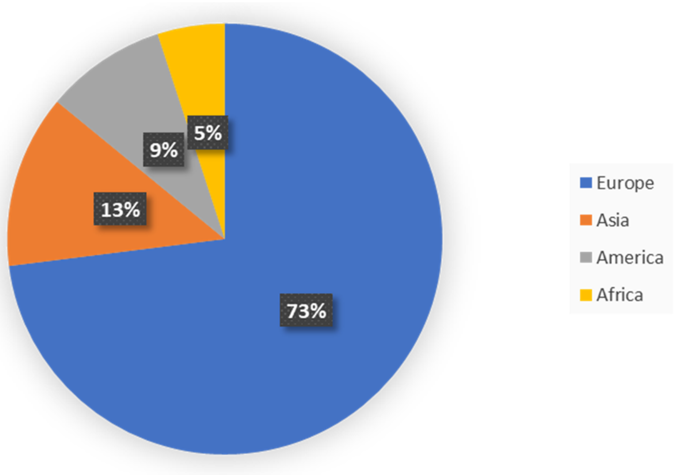

Figure 4. Number of published papers by geography. Source: Excel; authors' elaboration

maturity and early adoption of sustainable urban logistics practices in European contexts. Asia and America contribute 13% and 9 respectively, showing growing interest in these areas. Africa has the least, about 5%. This imbalance directly addresses RQ4, indicating a clear geographic research gap. The dominance of European studies reflects advanced policy frameworks and established urban logistics systems, which may not be transferable to developing regions.

4.3 First and last mode of transport

The reviewed studies reveal distinct patterns in transport modes used for first and last-mile operations in CL. First-mile activities predominantly rely on motorized, higher-capacity vehicles, with private cars being the most common (12 studies), followed by vans and trucks (10 studies). Public transport modes such as trains (9 studies) and buses (4 studies) appear less frequently, indicating limited integration of shared mobility in early-stage freight movement. Nonmotorized modes bicycles (3 studies) and motorbikes/scooters (1 study), are rarely utilized, and no study reports on-foot first-mile delivery. Eleven studies do not specify the mode used, reflecting inconsistent reporting (see Figure 5).

In contrast, last-mile delivery shows a strong shift toward flexible, low-cost and urban friendly modes. Motorbikes and scooters feature most prominently (16 studies), followed by bicycles (9 studies). Private cars (7 studies) and on-foot delivery (8 studies) also play a notable role, highlighting the diversity of last-mile participants. Vans and trucks appear in only four studies, while no evidence supports the use of buses or trains, underscoring their limited practicality for door-to-door distribution. Six studies do not specify last-mile modes (See Figure 6).

Overall, the evidence indicates that first-mile tasks depend on larger motorized vehicles suited for consolidation and longer distances, whereas last-mile activities favor agile, low-emission options like walking, cycling and two-wheel motorized modes. The distribution across modes is detailed in Table 1.

This pattern partially addresses RQ1**,** indicating that Rail and public transport modes are rarely utilized in first or last-mile operations, highlighting weak multimodal coordination. From a sustainability perspective (RQ2), the increasing use of nonmotorized and low-emission modes in last-mile delivery suggests positive environmental outcomes. However, the continued reliance on motorized vehicles in first-mile operations limits overall system sustainability. The findings also reinforce RQ4, as the limited use of rail and public transport in

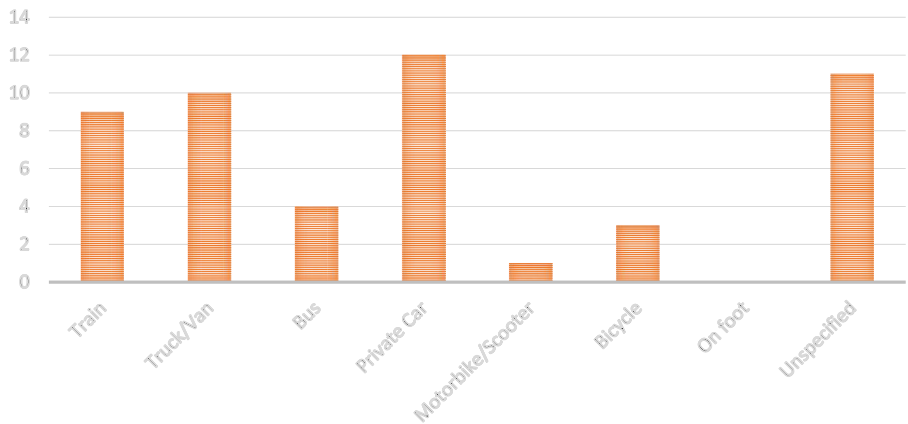

Figure 5. First mode of transportation. Source: Excel; authors' elaboration

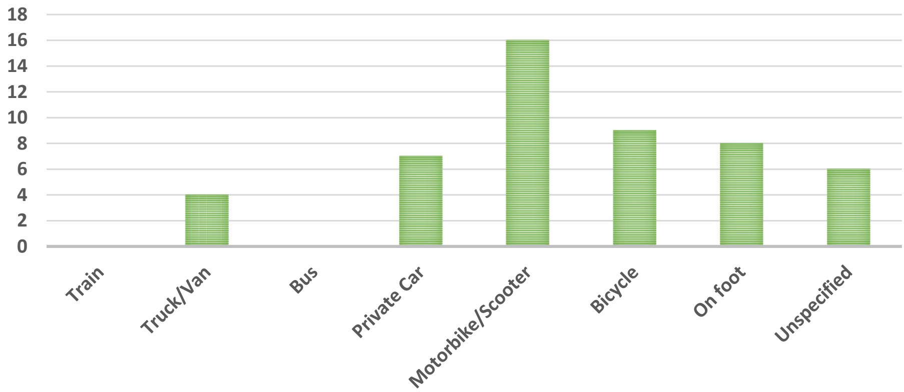

Figure 6. Last mode of transportation. Source: Excel; authors' elaboration

first and last-mile logistics reveals a significant thematic gap. Existing studies focus primarily on road-based CL systems, with minimal attention to Rail-CL integration.

4.4 Insights from qualitative studies

This section synthesizes findings from 20 qualitative studies; the review is organized by main dimensions study including type, objectives, technologies, sustainability, integration aspects, integration barriers and limitations. A detailed classification of studies is presented in Table 2.

4.4.1 Study type. The 20 qualitative studies comprise three main designs: case-based studies, conceptual analyses and literature reviews. Four case-based studies (e.g., Frehe, Mehmann, & Teuteberg, 2017) provide practical insights into CL feasibility, operational features and implementation challenges. Seven conceptual studies (e.g., Carbon *et al.*, 2021; Andrejić & Jeremić, 2019) develop theoretical models and frameworks for integrating CL into broader transport and supply chain systems. Nine literature reviews (e.g., Bosona, 2020) synthesize existing knowledge, identify dominant themes and highlight methodological gaps. Overall, this distribution reflects a balance between theoretical development and empirical exploration; however, the limited number of case-based studies suggests a need for more real-world validation of CL applications.

4.4.2 Objectives of the study. The qualitative literature reveals four interconnected research objectives that collectively shape the trajectory of CL research. Sustainability and freight optimization dominate the literature, with nine studies examining how CL improves resource efficiency, reduces delivery costs and lowers environmental impacts in urban last-mile operations (Samad, Ganguly, & Das, 2023). Conceptual framework development represents the second major objective, with five studies clarifying CL's role within multimodal freight systems and defining its operational principles and integration potential (Bosona, 2020; Elbert & Rentschler, 2021). Value co-creation, addressed by only two studies, explores the collaborative nature of CL, emphasizing digital platforms and stakeholder interactions that generate shared value among logistics providers, crowd participants and end users (Carbon *et al.*, 2021; Rougès & Montreuil, 2014). Three studies focus on business model development, examining CL system design, implementation and scalability across different contexts while highlighting economic viability and incentive structures (Frehe *et al.*, 2017; Odong, 2017). More critically, integration-specific research remains marginal, indicating that Rail-CL interaction is still peripheral rather than central in the literature. This directly supports RQ1, confirming the absence of well-developed integration models.

4.4.3 Technology used. Technology plays a central role in enabling CL systems. Digital platforms and mobile applications are reported in 3 of the 20 studies, including Mohri *et al.*

Table 1. Classification table for study type, first and last mode of transport and country of publication

Reference	Study type	First mode of transport	Last mode of transport	Country of publication
1. Alessandrini *et al.* (2012)	Qualitative	Train	Truck	Italy
2. Allen *et al.* (2012)	Qualitative	Van/Truck	Truck/Van	UK
3. Andrejić and Jeremić (2019)	Qualitative	Unspecified	On foot	Serbia
4. Bajec and Tuljak-Suban (2024)	Quantitative	Unspecified	Unspecified	Slovenia
5. Bakioglu (2025a)	Quantitative	Unspecified	Unspecified	Germany
6. Bakioglu (2025b)	Quantitative	Train	Unspecified	Canada
7. Batarlienė and Bazaras (2023)	Quantitative	Bus	Private car	Lithuania
8. Binetti, Caggiani, Camporeale, and Ottomanelli (2019)	Quantitative	Bicycle	Bicycle	Italy
9. Bortolini *et al.* (2022)	Mixed	Private car	Bicycle	Italy
10. Bosona (2020)	Qualitative	Unspecified	Unspecified	Sweden
11. Buldeo Rai *et al.* (2017)	Qualitative	Private car	Bicycle	Belgium
12. Carbon *et al.* (2021)	Qualitative	Private car	Bicycle/On foot	Italy
13. Cebeci *et al.* (2023)	Qualitative	Private car	Motorbike/ Scooter	Netherlands
14. Chen *et al.* (2019)	Quantitative	Motorbike	Motorbike/ Scooter	China
15. Cheng *et al.* (2022)	Quantitative	Van/Truck	Motorbike/ Scooter	Denmark
16. Cheng *et al.* (2024)	Quantitative	Van/Truck	Motorbike/ Scooter	Denmark
17. Crainic *et al.* (2009)	Quantitative	Train	Motorbike/ Scooter	Canada
18. Cramer and Fikar (2024)	Qualitative	Private car	Bicycle	Austria
19. Cramer and Fikar (2025)	Quantitative	Unspecified	Motorbike/ Scooter	Austria
20. de Oliveira Leite Nascimento, Gatta, and Marcucci (2023)	Qualitative	Unspecified	Private car	Brazil
21. Devari, Nikolaev, and He (2017)	Quantitative	Private car	Private car	USA
22. Derse and Van Woensel (2024)	Qualitative	Bus	Bicycle	Netherlands
23. El Amrani *et al.* (2024)	Qualitative	Train	On foot	Morocco
24. El Moussaoui *et al.* (2022)	Qualitative	Unspecified	Unspecified	Morocco
25. Elbert and Rentschler (2021)	Qualitative	Van/Truck	On foot	Germany
26. Frehe *et al.* (2017)	Qualitative	Private car	Private car	Germany
27. Gatta *et al.* (2019)	Quantitative	Bus	Private car	Italy
28. Gdowska, Viana, and Pedroso (2018)	Quantitative	Van/Truck	Motorbike/ Scooter	Portugal
29. Gholamizadeh *et al.* (2022)	Qualitative	Train	Motorbike/ Scooter	Iran
30. Karakikes and Nathanail (2022)	Quantitative	Van/Truck	Van	Greece
31. Kourounioti *et al.* (2021)	Mixed	Van/Truck	Motorbike/ Scooter	EU
32. Le *et al.* (2019)	Mixed	Train	Motorbike/ Scooter	EU
33. Lin, Nishiki, and Tavasszy (2020)	Mixed	Bicycle	Bicycle	Netherlands
34. Maleki *et al.* (2025)	Mixed	Train	On foot	Switzerland
35. Marinov *et al.* (2013)	Mixed	Train	Motorbike/ Scooter	EU
36. Masson *et al.* (2017)	Quantitative	Van/Truck	Van	France
37. Melo and Baptista (2017)	Quantitative	Bicycle	Bicycle	Portugal
38. Mladenow *et al.* (2016)	Qualitative	Private car	On foot	Austria
39. Mohri, Nassir, Thompson, Lavieri, and Ghaderi (2025)	quantitative	Bus	On foot	Austria
40. Mohri *et al.* (2023)	Qualitative	Unspecified	Unspecified	Iran

(*continued*)

Table 1. Continued

Reference	Study type	First mode of transport	Last mode of transport	Country of publication
41. Naganawaetal. (2025)	Mixed	Van/Truck	Private car	Japan
42. Odong (2017)	Qualitative	Unspecified	Motorbike/ Scooter	Finland
43. Rougès and Montreuil (2014)	Qualitative	Unspecified	Private car	Canada
44. Samad *et al.* (2023)	Qualitative	Unspecified	Motorbike/ Scooter	Malaysia
45. Sárdi (2022)	Quantitative	Van/Truck	Motorbike/ Scooter	Hungary
46. Seng *et al.* (2023)	Quantitative	Private car	Motorbike/ Scooter	Singapore
47. Serafini *et al.* (2018)	Quantitative	Train	Motorbike/ Scooter	Italy
48. Tadić, Veljović, and Zečević (2022)	Qualitative	Private car	On foot	Serbia
49. Wicaksono, Lin, and Tavasszy (2022)	Quantitative	Private car	Bicycle	Netherlands
50. Yang *et al.* (2023)	Mixed	Private car	Bicycle/On foot	China

Source(s): Authors' elaboration

(2023), enabling real-time matching and tracking of delivery tasks. A majority (13 studies), such as Allen *et al.* (2012), employ mixed technology approaches without specifying particular systems. Algorithmic optimization appears in one study, Bosona (2020), while 3 studies do not specify the type of technology used. These results indicate that although technology is widely acknowledged as a key enabler, the limited use of advanced technologies such as artificial intelligence, blockchain and IoT suggests a gap in innovation and scalability within current CL systems.

4.4.4 Sustainability benefit aspects. Sustainability is a prominent theme, with 15 of the 20 studies assessing it through the triple bottom line (TBL) framework. These studies show that CL enhances environmental performance, reduces emissions and improves resource efficiency in urban freight systems. Four studies focus mainly on environmental outcomes, such as de Oliveira Leite Nascimento *et al.* (2023), while one study, Allen *et al.* (2012), emphasizes economic sustainability. Overall, these findings confirm that CL contributes significantly to sustainable urban logistics; however, the limited focus on social and economic dimensions highlights an important research gap, particularly in areas such as labor conditions, equity and long-term economic viability.

4.4.5 Integration focus and barriers. Among the 20 qualitative studies, seven examine CL integration in last-mile delivery, emphasizing its feasibility through flexible modes such as personal vehicles, bicycles, scooters and walking. Nine studies focus on sustainability, while two studies explore integration with traditional freight systems and two analyze multimodal configurations.

Regarding barriers, 13 studies describe general challenges without specifying detailed integration constraints. Four highlight infrastructure limitations and coordination gaps, two identify regulatory uncertainty and one underscores trust and liability concerns. One study does not specify barrier types (Gholamizadeh *et al.*, 2022). Overall, findings show that CL integration is hindered by multifaceted operational, regulatory and infrastructural barriers, pointing to the need for supportive policies and technological enablers. This reinforces the argument that Rail-CL integration is not merely a technical challenge but a socio-technical transformation, requiring alignment across institutional, technological and operational dimensions.

4.4.6 Limitation of the study. The 20 qualitative studies reviewed exhibit several common limitations. Seven studies rely heavily on conceptual models with limited empirical validation,

Table 2. Classification table for qualitative papers

Reference	Study type	Research objectives	Technology used	Sustainability benefits	Integration focus	Integration barriers	Study limitations
1. Alessandrini *et al.* (2012)	Conceptual	Sustainability and freight optimization	Not explicitly specify	Environmental benefits focus	Freight multi modal integration	Infrastructure limit and Stakeholders Coordination	multimodal integration
2. Allen *et al.* (2012)	Literature review	Conceptual Framework and urban logistics system	Mixed-type technology	Economic benefits focus	Urban last-mile integration	Infrastructure limit and Stakeholders Coordination	Narrow scope (Last-mile)
3. Andrejić and Jeremić (2019)	Conceptual	Conceptualization and business model development	Not explicitly specify	Triple bottom line benefits	Freight sustainability integration	Regulatory uncertainty	Theoretical focus
4. Bosona (2020)	Systematic review	Conceptual Framework and urban logistics system	Algorithmic optimization social network	Triple benefits aspects	Urban last-mile integration	All Aspects of Barriers	Narrow scope (last-mile)
5. Buldeo Rai *et al.* (2017)	Conceptual	Sustainability and freight optimization	Mixed-type technology	Triple bottom line benefits	Freight sustainability integration	All Aspects of Barriers	Narrow scope (Last-mile)
6. Carbon *et al.* (2021)	Conceptual	Conceptual Framework and Value Co-Creation	Mixed-type technology	Triple bottom line benefits	Freight sustainability integration	All Aspects of Barriers	Theoretical focus
7. Cramer and Fikar (2024)	Systematic review	Sustainability and freight optimization	Mixed-type technology	Triple bottom line benefits	Integrate with traditional logistics	Lack of Stakeholders Coordination	Theoretical focus
8. de Oliveira Leite Nascimento *et al.* (2023)	literature review	Conceptualization and business model development	Mixed-type technology	Environmental benefits focus	Integrate with traditional logistics	All aspects of barriers	Theoretical focus
9. Derse and Van Woensel (2024	Systematic literature review	Conceptual framework and urban logistics system	Mixed-type technology	Triple bottom line benefits	Freight sustainability integration	All aspects of barriers	Theoretical focus

(*continued*)

Table 2. Continued

Reference	Study type	Research objectives	Technology used	Sustainability benefits	Integration focus	Integration barriers	Study limitations
10. El Amrani *et al.* (2024)	Systematic review	Sustainability and freight optimization	Mixed-type technology	Triple bottom line benefits	Freight sustainability integration	All aspects of barriers	Developing nation focus
11. Elbert and Rentschler (2021)	Systematic review	Conceptual framework and urban logistics system	Not explicitly Specify	Environmental benefits	Freight multimodal integration	All aspects of barriers	Multimodal integration
12. El Moussaoui *et al.* (2022)	Literature review	Sustainability and freight optimization	Mixed-type technology	Triple bottom line benefits	Urban last-mile integration	Infrastructure limitation and coordination	Developing nation. Focus
13. Frehe *et al.* (2017)	Case based	Conceptualization and business model development	Mixed-type technology	Triple bottom line benefits	Freight sustainability integration	All aspects of barriers	Theoretical focus
14. Gholamizadeh *et al.* (2022)	Conceptual	Sustainability and freight optimization	Digital platform	Triple bottom line benefits	Freight sustainability integration	Not explicitly specify	Theoretical focus
15. Mladenow *et al.* (2016)	Conceptual	Sustainability and freight optimization	Mixed-type technology	Environmental benefits focus	Urban last-mile integration	Trust and reliability	Theoretical focus
16. Mohri *et al.* (2023)	Systematic review	Conceptual framework and urban logistics system	Digital platform and mobile app	Triple bottom line benefits	Urban last-mile integration	All aspects of barriers	Theoretical focus
17. Odong (2017)	Multiple Case based	Conceptualization and business model development	Mixed-type technology	Triple bottom line benefits	Urban last-mile integration	All aspects of barriers	Narrow scope (last-mile)
18. Rougès and Montreuil (2014)	Case based	Conceptual framework and value co-creation	Mixed-type technology	Triple bottom line benefits	Freight sustainability integration	All aspects of barriers	Theoretical focus
19. Samad *et al.* (2023	Conceptual	Sustainability and freight optimization	Mixed-type technology	Triple bottom line benefits	Freight sustainability integration	Regulatory uncertainty	Theoretical focus
20. Tadić *et al.* (2022)	Case based	Sustainability and freight optimization	Digital platform and mobile app	Triple bottom line benefits	Urban last-mile integration	All aspects of barriers	African study

Source(s): Authors' elaboration

restricting insights into real-world logistics performance. Most research is concentrated in developed countries, with only two studies addressing developing contexts, limiting broader applicability. The scope is often narrow, focusing primarily on last-mile delivery while overlooking first-mile operations, reverse logistics and longer-distance integration. Additionally, multimodal coordination is insufficiently explored, with only two studies (e.g., Elbert & Rentschler, 2021) examining transport integration, highlighting a significant gap in the qualitative literature. Overall, these limitations reduce the generalizability of findings and highlight critical research gaps, particularly in developing regions and in comprehensive CL-Rail integration frameworks that address entire logistics chains.

4.5 Insights from quantitative and mixed studies

This section synthesizes insights from 30 studies (23 quantitative and 7 mixed-methods) examining various dimensions of Rail-CL integration. The analysis covers study type, objectives, technologies, sustainability, integration focus, barriers, modeling approaches and limitations. A summary is provided in Table 3.

4.5.1 Study type. Among the 30 quantitative and mixed-methods studies reviewed, case-based research dominates (18 studies), reflecting a strong emphasis on practical, application-oriented investigations of Rail-CL integration. Eleven studies adopt conceptual or modeling approaches, offering valuable theoretical frameworks but with limited empirical validation. Only one study is a mixed-method literature review, indicating a significant gap in comprehensive knowledge synthesis. Overall, the distribution suggests that while practice-focused studies are prevalent, theoretical consolidation and systematic review efforts remain insufficient to support broader, scalable implementation of CL within rail systems.

4.5.2 Objectives of the study. Quantitative and mixed-methods studies cluster around four main objectives, revealing a strong emphasis on operational and sustainability outcomes with limited attention to technological innovation. Urban last-mile solutions dominate the literature, with 15 of the 30 studies focusing on improving last-mile delivery through CL by addressing congestion, service reliability, and operational efficiency in dense urban areas (e.g., Maleki *et al.*, 2025; Gatta *et al.*, 2019). Sustainability and freight optimization represent the second major objective, with eleven studies examining the environmental and economic benefits of CL and demonstrating its potential to reduce emissions while supporting greener, more efficient freight distribution (e.g., Naganawa *et al.*, 2025). Business model development receives comparatively less attention, with only three studies exploring CL platform business models, thereby highlighting limited research on strategic design and commercial feasibility (e.g., Yang *et al.*, 2023). Technology and algorithm development remains the least explored objective, with just one study centering on technological or algorithmic innovation, underscoring a significant gap in advanced system design for CL-Rail integration (e.g., Seng *et al.*, 2023).

4.5.3 Technology used. Across the 30 quantitative and mixed-methods studies, three main technology categories emerge. Mobile apps and digital platforms are most common (9 studies), reflecting their central role in real-time communication, routing and coordination in CL systems (e.g., Le *et al.*, 2019; Seng *et al.*, 2023). Mixed-technology approaches appear in 7 studies, combining digital platforms with network-based coordination to support more complex, hybrid solutions (e.g., Lin *et al.*, 2020; Sárdi, 2022). Algorithmic optimization and social network tools are used in 6 studies, underscoring the importance of computational methods for routing, forecasting and participant matching (e.g., Chen *et al.*, 2019; Masson *et al.*, 2017). Notably, 8 studies do not explicitly specify the technologies applied (e.g., Gatta *et al.*, 2019; Mohri *et al.*, 2025).

4.5.4 Sustainability benefits aspects. Sustainability assessments across the 30 studies show a strong alignment with the Triple Bottom Line (TBL) framework. Fifteen studies address all three dimensions environmental, economic and social indicating a growing shift toward holistic sustainability evaluation in Rail-CL integration research. Nine studies focus primarily

Table 3. Classification table for quantitative and mixed papers

Reference	Study type	Objectives of study	Technology used	Sustainability benefits	Integration focus	Integration barriers	Mathematical model	Limitation Of study
1. Bajec and Tuljak-Suban (2024)	Quantitative Case based	Urban last-mile solution	Not explicitly specify	Not explicitly specify	Urban last-mile integration	All types of barriers	Stochastic model	Narrow scope & last-mile focus
2. Bakioglu (2025a)	Quantitative Conceptual	Sustainability and freight optimization	Mobile app and digital platforms	Environmental benefits focus	Technological integration	All types of barriers	Fuzzy MCDM model	Developed nation focus
3. Bakioglu (2025b)	Quantitative Conceptual	Sustainability and freight optimization	Not explicitly specify	Economic benefit focus	Multimodal integration	Infrastructure limitation and stakeholder coordination	Fuzzy MCDM model	Developed nation focus
4. Batarlienė and Bazaras (2023)	Quantitative Case based	Urban last-mile solution	Mixed technology	Environmental benefits focus	Urban first and last-mile integration	Infrastructure limitation & stakeholder coordination	Not explicitly specify	Developed nation focus
5. Binetti *et al.* (2019)	Quantitative Case based	Urban last-mile solution	Mixed technology	Environmental benefits focus	Urban last-mile integration	All types of barriers	Deterministic model	Theoretical and narrow scope focus
6. Bortolini *et al.* (2022)	Mixed Case based	Urban last-mile solution	Mobile app and digital platforms	Triple bottom line	Urban last-mile	All types of barriers	Not explicitly specify	Developed nation focus
7. Cebeci *et al.* (2023)	Quantitative Conceptual	Urban last-mile solution	Not explicitly specify	Environmental benefits focus	Urban last-mile	Trust and liability	Stochastic model	Theoretical and narrow scope focus
8. Chen *et al.* (2019)	Quantitative Conceptual	Urban last-mile solution	Algorithmic optimization & social networks	Triple bottom line	Technological integration	All types of barriers	Deterministic model	Theoretical and narrow scope focus
9. Cheng *et al.* (2022)	Quantitative Case based	Urban last-mile solution	Mixed technology used	Triple bottom line benefits	Technological integration	Not explicitly specify	Deterministic model	Developed nation and last mile

(*continued*)

Table 3. Continued

Reference	Study type	Objectives of study	Technology used	Sustainability benefits	Integration focus	Integration barriers	Mathematical model	Limitation Of study
10. Cheng *et al.* (2024)	Quantitative Case based	Urban last-mile solution	Algorithmic optimization & social networks	Economic benefits focus	Urban last-mile integration	Infrastructure limitation & stakeholder coordination	Deterministic model	Developed nation and last mile
11. Crainic *et al.* (2009)	Quantitative Conceptual	Sustainability and freight optimization	Not explicitly specify	Triple bottom line benefits	Freight optimization	Infrastructure limitation & stakeholder coordination	Deterministic model	Theoretical focus and developed
12. Cramer and Fikar (2025)	Quantitative Conceptual	Sustainability and freight optimization	Not explicitly specify	Triple bottom line benefits	Urban last-mile integration	All types of barriers	Stochastic model	Theoretical and narrow scope focus
13. Devari *et al.* (2017)	Quantitative Case based	Urban last-mile solution	Mobile app and social networks	Triple bottom line benefits	Urban last-mile integration	All types of barriers	Stochastic model	Developed nation focus
14. Gatta *et al.* (2019)	Quantitative Case based	Urban last-mile solution	Not explicitly specify	Environmental benefits	Urban last-mile integration	All types of barriers	Stochastic model	Narrow scope & last-mile focus
15. Gdowska *et al.* (2018)	Quantitative Case based	Urban last-mile solution	Not explicitly specify	Economic benefits focus	Urban last-mile integration	Infrastructure limitation and Stakeholder coordination	Stochastic model	Developed nation and last mile
16. Karakikes and Nathanail (2022)	Quantitative Case based	Sustainability and freight optimization	Mobile app and digital platforms	Triple bottom line benefits	Multimodal integration	All types of barriers	Deterministic model	Developed nation focus
17. Kourounioti *et al.* (2021)	mixed Conceptual based	Sustainability and freight optimization	Mixed-method technology	Triple bottom line benefits	Freight optimization	All aspects of barriers	Stochastic models	Theoretical & developed nation focus
18. Le *et al.* (2019)	Mixed Systematic review	Business model development	Mobile app and digital platforms	Triple bottom line benefits	Urban last-mile integration	All types of barriers	Stochastic model	Theoretical and narrow scope focus

(*continued*)

Table 3. Continued

Reference	Study type	Objectives of study	Technology used	Sustainability benefits	Integration focus	Integration barriers	Mathematical model	Limitation Of study
19. Lin *et al.* (2020)	Mixed Case based	Urban last-mile solution	Mixed technology used	Triple bottom line benefits	Urban last-mile integration	Not explicitly specify	Not explicitly specify	Narrow scope (last mile focus)
20. Maleki *et al.* (2025)	Mixed Quantitative Study	Urban last-mile solution	Mixed technology used	Environmental benefits	Urban last-mile integration	Trust and liability	Not explicitly specify	Narrow scope (last mile focus)
21. Marinov *et al.* (2013)	Mixed Case based	Sustainability and freight optimization	Algorithmic optimization and social networks	Environmental benefits focus	Urban last-mile integration	Infrastructure limit and stakeholder coordination	Deterministic model	Narrow scope (last-mile)
22. Masson *et al.* (2017)	Quantitative Case based	Sustainability and freight optimization	Algorithmic optimization and social network	Triple bottom line benefits	Multimodal integration	Infrastructure limitation & stakeholder coordination	Deterministic model	Theoretical & developed nation focus
23. Melo and Baptista (2017)	Quantitative Case based	Sustainability and freight optimization	Mobile app and digital platforms	Triple bottom line benefits	Freight optimization	All types of barriers	Not explicitly specify	Narrow scope (last-mile focus)
24. Mohri *et al.* (2025)	Quantitative Conceptual	Urban last-mile solution	Not explicitly specify	Economic benefits focus	Urban last-mile integration	Not explicitly specify	Stochastic models	Developed nation focus
25. Naganawa *et al.* (2025)	Quantitative Case based	Sustainability and freight optimization	Algorithmic optimization and social networks	Environmental benefits	Freight optimization	Not explicitly specify	Deterministic models	Theoretical & developed nation focus
26. Sárdi (2022)	Quantitative Case based	Sustainability and freight optimization	Mixed technology used	Triple bottom line benefits	Urban last-mile integration	Infrastructure limitation & stakeholder C	Deterministic model	Developed nation focus
27. Seng *et al.* (2023)	Quantitative Conceptual	Technology and algorithm development	Mobile app and digital platforms	Social benefits	Digital platform synergy	All types of barriers	Deterministic model	Developed nation focus

(*continued*)

Table 3. Continued

Reference	Study type	Objectives of study	Technology used	Sustainability benefits	Integration focus	Integration barriers	Mathematical model	Limitation Of study
28. Serafini *et al.* (2018)	Quantitative Case based	Urban last-mile solution	Mobile app and digital platforms	Environmental benefits	Urban last-mile integration	Not explicitly specify	Stochastic models	Developed nation and last mile
29. Wicakso *et al.* (2022)	Quantitative Conceptual	Business model development	Algorithmic optimization and social networks	Triple bottom line benefits	Digital platform synergy	All types of barriers	Stochastic models	Developed Nation focus
30. Yang *et al.* (2023)	Mixed Conceptual	Business model development	Mobile app and digital platforms	Triple bottom line benefits	Technological Integration	Trust and liability	Deterministic models	Theoretical & developed nation focus

Source(s): Authors' elaboration

on environmental benefits, particularly emission reduction and lower urban pollution through measures such as consolidation and integration with public transport systems (e.g., Naganawa *et al.*, 2025; Bakioglu, 2025a). Four studies examine only economic benefits, while one focuses solely on social outcomes, highlighting the persistence of single-dimension assessments. One study does not clearly specify sustainability benefits (Bajec & Tuljak-Suban, 2024). Overall, the prominence of TBL-based analysis reflects increasing recognition of multi-dimensional sustainability in the field.

4.5.5 Integration focus and barriers. The 30 quantitative and mixed-methods studies cluster around four main integration focuses: urban first/last-mile integration**,** freight optimization**,** technological integration and multimodal integration. Urban last-mile integration dominates (16 studies), reaffirming its central role in improving delivery efficiency in congested cities (e.g., Gatta *et al.*, 2019). Four studies examine broader freight optimization, while six explore technological integration involving digital platforms, mobile apps and algorithmic tools. Multimodal integration appears in three studies, and just one study investigates first-mile integration.

Key barriers commonly reported include trust and reliability issues**,** infrastructure constraints and stakeholder coordination challenges. Fifteen studies discuss multiple barrier types, underscoring the complex obstacles to Rail-CL integration. Infrastructure and collaboration issues are highlighted in eight studies (e.g., Cheng *et al.*, 2024), while trust and liability concerns appear in three (e.g., Yang *et al.*, 2023). Four studies do not specify barriers. Overall, the findings point to a need for more context-specific analyses that differentiate technical, regulatory, institutional and social challenges.

4.5.6 Mathematical modeling. Across the 30 quantitative and mixed-methods studies, mathematical modeling plays a central role in CL research. Deterministic models are used in 12 studies, providing fixed-input, predictable solutions for routing, scheduling and operational planning (e.g., Cheng *et al.*, 2024). Stochastic models appear in 11 studies and address uncertainty related to travel times, traffic variability and dynamic demand (e.g., Gdowska *et al.*, 2018), offering more flexible and resilient system designs. Five studies do not specify their modeling approach, indicating gaps in methodological transparency. Only two studies focus on the fuzzy MCDM model (e.g. Bakioglu, 2025a, b). Overall, both deterministic and stochastic models contribute substantially to understanding and optimizing crowd-based delivery systems.

4.5.7 Limitations of study. Study limitations fall into four main categories: theoretical focus**,** narrow scope**,** geographic bias and limited multimodal integration. Many studies adopt a narrow lens, concentrating primarily on urban or last-mile delivery and overlooking wider logistics networks and multimodal connections, particularly with rail freight. Several papers are heavily theoretical and lack validation through real-world cases or pilot implementations. Geographic bias is also evident, with most studies conducted in developed countries and only a few addressing developing contexts. Finally, multimodal integration remains underexplored, as most research centers on road-based CL systems with minimal attention to coordination with rail or other transport modes. Overall, these limitations highlight the need for broader, more context-sensitive research that expands multimodal perspectives and includes underrepresented regions.

4.6 Cross-cutting synthesis and system-level insights

The synthesis of findings across Sections 4.1 - 4.5 reveals that research on rail transport and CL remains fragmented across conceptual, operational, and geographic dimensions. While individual studies provide valuable insights, a coherent system-level understanding of Rail-CL integration is largely absent.

First, the literature demonstrates a structural separation between rail freight and CL systems. Rail is predominantly examined in terms of line-haul efficiency, whereas CL is positioned as a last-mile solution. This results in a lack of integrated models addressing intermodal coordination and operational synchronization, confirming that current integration approaches remain limited and largely conceptual (RQ1).

Second, a clear modal imbalance is observed, with strong emphasis on last-mile optimization and limited attention to first-mile logistics and rail coordination. Although CL contributes to environmental improvements, the absence of upstream integration constrains system-wide efficiency, indicating that sustainability outcomes are partial and uneven (RQ2).

Third, the field is dominated by conceptual and simulation-based studies, with limited empirical validation. Quantitative research primarily focuses on isolated optimization problems, while qualitative studies emphasize frameworks without sufficient real-world testing. This highlights a methodological gap and limits the practical applicability of proposed solutions (RQ4).

Fourth, the literature exhibits a strong geographic bias toward European and developed nation contexts, raising concerns about the transferability of findings to developing regions. Given differing infrastructural and institutional conditions, existing models may not be directly applicable, underscoring the need for context-sensitive approaches (RQ4).

Overall, the findings indicate that Rail-CL integration should be understood as a socio-technical system challenge, requiring alignment between infrastructure, digital technologies, stakeholders and regulatory frameworks. Future research should therefore move beyond isolated analyses toward integrated, empirically grounded models that capture the complexity of multimodal urban freight systems.

5. Conclusion and contribution

5.1 Conclusion

This SLR examined the emerging interface between rail transport and CL by synthesis of 50 peer-reviewed studies published between 2009 and 2025. While rail freight and CL have developed as distinct research streams, their integration remains conceptually fragmented and empirically underexplored. The evidence confirms that Rail-CL integration represents a promising but strategically significant domain within sustainable freight research.

The review shows that current theoretical foundations are primarily derived from collaborative logistics, sharing-economy models and synchro-modal transport frameworks. Rail is generally conceptualized as a high-capacity trunk mode supporting long-distance consolidation, whereas CL provides flexible first and last-mile connectivity through digitally coordinated CL delivery. However, explicitly articulated and empirically validated Rail-CL integration models are very few. Existing studies tend to propose conceptual architectures rather than operationally tested systems. In terms of sustainability, the literature aligns strongly with triple bottom line objectives, reported environmental benefits include emission reduction, congestion mitigation and improved resource efficiency through modal shift and consolidation strategies. Economic gains relate to cost optimization, asset utilization and enhanced delivery flexibility. Social impacts, although less frequently quantified, include improved service accessibility and employment opportunities within crowd networks. Nevertheless, despite these positive indications, much of the evidence remains model-based and highlighting the need for empirical testing through pilot applications.

The review further identifies structural barriers limiting implementation, these are regulatory uncertainty regarding liability and labor classification, insufficient rail-terminal interfaces for first and last-mile integration, digital interoperability challenges and stakeholder coordination complexity emerge as critical constraints. These findings suggest that Rail-CL integration is a socio-technical transformation requiring institutional alignment alongside technological development.

Significant research gaps continue; that is, empirical evidence from developing economies is limited, despite strong relevance for rail-dependent corridors. Methodologically, the field is dominated by conceptual and simulation-based research, with a shortage of longitudinal and large-scale experimental studies. Thematically, attention remains concentrated on last-mile delivery, leaving first-mile logistics and platform governance mechanisms comparatively underdeveloped.

5.2 Theoretical and practical contributions

This review makes three principal contributions. First, it provides the first structured synthesis explicitly focused on the integration of rail freight and CL, bridging two previously disconnected research streams. By consolidating theoretical foundations, operational strategies, sustainability outcomes and implementation barriers within a single analytical framework, the study advances conceptual clarity in an emerging field.

Second, the review identifies a critical gap between conceptual ambition and empirical validation. By highlighting the absence of tested Rail-CL operational models, it establishes a clear agenda for future research centered on pilot implementation, interoperability design and performance-based sustainability assessment.

Third, the study offers practical implications for policymakers and industry actors. Successful integration requires coordinated regulatory reform, targeted infrastructure investment at rail hubs and interoperable digital platforms capable of supporting multimodal coordination. For developing economies in particular, Rail-CL integration presents a potentially scalable pathway toward low-carbon and inclusive urban freight systems.

Overall, the findings position Rail-CL integration as a promising yet underdeveloped strategy for enhancing freight efficiency, sustainability and system resilience. The study contributes original insight by clarifying current knowledge boundaries and defining priority directions for research, policy and practice.

5.3 Limitations and future research directions

This review is subject to some limitations. The analysis was restricted to English-language, peer-reviewed publications from 2009 to 2025, potentially excluding relevant grey and non-English literature. The dominance of conceptual and simulation-based studies limits empirical generalizability, while the geographic concentration on developed regions constrains applicability to developing countries' contexts. Although the MMAT-based appraisal followed a structured dual-review process, some degree of subjectivity remains.

Future research should prioritize empirical validation through pilot implementations and real-world case studies, particularly in developing economies. Longitudinal and large-scale experimental designs are needed to assess operational feasibility and sustainability performance. Further work is also required on first-mile logistics integration, governance of digital CL platforms and regulatory frameworks to support multimodal coordination.

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