Integrating Urban Freight Distribution into the 15-Minute City Framework. A Sustainable Development Perspective from Poland

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Abstract

The 15-minute city concept focuses on residents' proximity to basic services but often overlooks the logistical flows needed to sustain them. This paper examines integrating freight distribution into proximity-based urban planning to align with sustainable development goals. While density and mixed land use reduce passenger travel distances, they often paradoxically increase the complexity and frequency of goods movements.

This study implements a mixed-method research design: (1) a systematic literature review of international green logistics models, (2) a comparative analysis of European best practices (Paris, Barcelona, Utrecht), and (3) primary empirical research conducted in Poland. The primary research includes semi-structured interviews with municipal planners and a diagnostic survey of last-mile operators and local business owners.

The results identify a planning gap in Polish metropolitan areas, where freight is frequently treated as a private commercial issue rather than a public utility. The findings suggest that successful integration requires a tiered infrastructure of decentralized micro-hubs, flexible loading zones, and the promotion of cargo-bike logistics. The paper concludes with a proposed conceptual framework for medium-sized European cities to harmonize freight efficiency with walkable urban environments by linking strategic spatial planning with mandatory logistics regulations.

Keywords: Type your keywords here, separated by semicolons;

1 Introduction

Although the 15-minute city (15mC) concept was originally developed in regard to people's movement, its practical implementation also depends on how goods circulate within urban space. Even the most walkable neighbourhoods require a well-organised supply chain to keep local shops, services, and households functioning (Graells-Garrido et al., 2021; Iqbal et al., 2025). As neighbourhoods change into multifunctional areas, the movement of goods becomes more noticeable in their everyday functioning. The growing importance of online shopping only strengthens this trend, increasing the number of deliveries that must be accommodated within already busy streets. Such proximity-oriented urban forms place additional demands on local delivery networks and the public spaces they rely on, making freight no longer an afterthought in sustainability-oriented planning.

Taking freight into account when shaping compact urban districts is therefore essential. Higher urban density might lower the impact of passenger travel, but it also raises the intensity of freight flows, as more supplies must be delivered into already crowded multi-functional spaces. Bringing housing, retail, and services together in one area naturally increases the demand for everyday deliveries. As a result, freight vehicles are required to operate in spaces shared with pedestrians and cyclists, placing additional pressure on streets and public spaces. This situation makes freight management a critical aspect of urban planning where an environmental responsibility with a high quality of urban life is required. Additionally despite its importance, freight movement is still too often treated as a secondary concern in conventional urban planning, even in areas pursuing ambitious sustainability and accessibility goals.

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This paper aims to show how freight distribution planning can be integrated into the 15-minute city to support sustainability. Particular attention is given to solutions like micro-hubs, cargo bikes, and delivery consolidation. These are analyzed both for their ability to reduce congestion and for their compatibility with the spatial requirements of proximity-based neighborhoods.

Despite the growing popularity of the 15mC model current urban planning focuses mainly on residential accessibility and active mobility while the organization of urban goods distribution receives far less attention. This imbalance demonstrates a significant research gap, in the form of the lack of an integrated framework that treats urban freight as a part of urban transport system and a vital urban utility within compact districts. In particular, there is a shortage of empirical evidence on how cities, especially in Central and Eastern Europe, can adapt Western best practices to their specific socio-economic and infrastructural realities.

This study aims to address this gap by proposing a conceptual framework that integrates sustainable freight distribution into the 15mC model. To achieve this, the author formulated three specific objectives:

1. To evaluate the compatibility of existing sustainable logistics solutions.
2. To diagnose the implementation gap between urban planning strategic goals and the operational reality of last-mile delivery stakeholders.
3. To identify key success factors and policy measures that can harmonize freight efficiency with the preservation of high-quality public space.

To guide the empirical investigation, the following research questions have been formulated:

- **RQ1:** How does the transition to a 15-minute city impact the last-mile delivery operations?
- **RQ2:** To what extent do current urban planning tools in European cities account for the spatial and infrastructural requirements of sustainable freight?
- **RQ3:** Which regulatory, technical, and collaborative factors are essential for the successful integration of sustainable freight solutions into the 15-minute city framework?

2 Literature Review

First introduced by Carlos Moreno, the 15-minute city concept (Moreno et al., 2021, 2025) links urban quality of life to the amount of time people spend traveling (Iqbal et al., 2025)/Recent research shows that this model has the potential to reorganize fragmented metropolitan areas into more self-sufficient neighborhoods. In these neighborhoods, residents can reach work, shops, healthcare, and schools within a short walk or bike ride (Baldwin, 2026; Bencekri & Lee, 2025; Monzon et al., 2025). However, cities around the world often use different names and time limits for this same concept. While the 15mC remains the most dominant term, it is frequently used interchangeably with or adapted into versions such as *15-minute* or *20-minute neighbourhoods.* (J. Wang et al., 2025; S. Zhang et al., 2025) which together account for a majority of documented case studies (Monzon et al., 2025). Location and culture play a big role in these models. Oslo, for example, uses a stricter *10-minute* standard to ensure even higher accessibility (Akrami et al., 2024; Pira & Hansson, 2025) and Hamburg (Khatibi et al., 2025), respectively. On the other hand, cities with lower density, like Tempe (USA) or Singapore, typically follow the *20-minute* standard instead (Sepehri & Sharifi, 2025; S. Zhang et al., 2025)

In the Asian context, specifically in China, the concept of *15-minute Community Life Circles* has been an established planning standard for years, predating the recent global surge in popularity of the 15mC. (Chen et al., 2025; Li et al., 2025; X. Wang et al., 2025; B. Zhang & Jiang, 2025). Other established models like Barcelona's *superblocks* (Frago & Morcuende, 2024; Pérez et al., 2025) and *complete neighborhoods* are also being adapted locally. A key example is the *Nordic Superblock* project in Tampere, Finland (Makkonen et al., 2023; Sjöblom et al., 2021). Even though the model has been adapted in many ways, the 15mC remains the most widely recognized version globally and serves as the primary guide for urban reorganization.

While the 15mC focuses on human mobility, its success also depends on efficient delivery systems. In dense, mixed-use areas, freight distribution is a key factor that either supports or challenges green planning goals. Because of this, integrating logistics into the 15mC framework is a critical task for modern cities. Rising urban density and economic uncertainty have turned this idea into a strategic challenge for municipalities. (Birkenfeld et al., 2023; Iqbal et al., 2025)

Urban freight transport faces growing challenges, driven by a dynamic growth in freight flows additionally intensified by globalization and the expansion of e-commerce. Last-mile logistics, representing the final segment of the supply chain is particularly problematic as it constitutes the least efficient and most expensive part of goods delivery, accounting for up to 28% of total delivery costs (Pourmohammadreza et al., 2025). These problems are even worse in crowded cities. Limited space, traffic jams, and pollution goals make it very difficult to run smooth delivery operations. Combining 15mC planning with freight distribution is difficult due to interrelated issues. For instance, cargo bikes have limited speed and capacity, while drones are still hard to integrate into the city. Additionally, managing the flood of individual online orders is complex. This e-commerce boom has shifted urban freight patterns, creating a fragmented research landscape. Because people shop online more often, logistics systems now have to deal with more frequent, smaller shipments that they weren't originally designed for (Biancolin & Rotaris, 2024; Teo et al., 2012; Ystmark Bjerkan & Babri, 2024)

Despite the model's popularity, a key challenge that has been neglected in many studies is the supply-side sustainability of proximity-based districts. Most 15mC frameworks emphasize passenger travel, while the operational logistics required to support a dense neighborhood have received less attention. In practice, this means that the very features making a city walkable also make it harder for delivery vehicles to operate. Research suggests that higher service concentrations increase the frequency and fragmentation of goods movements (Russo & Comi, 2012). Consequently, the 15mC cannot be viewed as a static spatial arrangement, but rather as a dynamic flow system where logistics resilience is a determining factor for long-term viability. Neighborhoods with integrated, decentralized supply networks exhibit significantly higher social and economic resilience during periods of market uncertainty.

Figure 1 provides a clear overview of the literature, mapping the relationship between urban design and freight transport studies. By processing metadata from Scopus and Web of Science using VOSviewer (v. 1.6.20) and applying a threshold of 70 occurrences, the analysis identified 85 most impactful terms that define the field's chronological evolution.

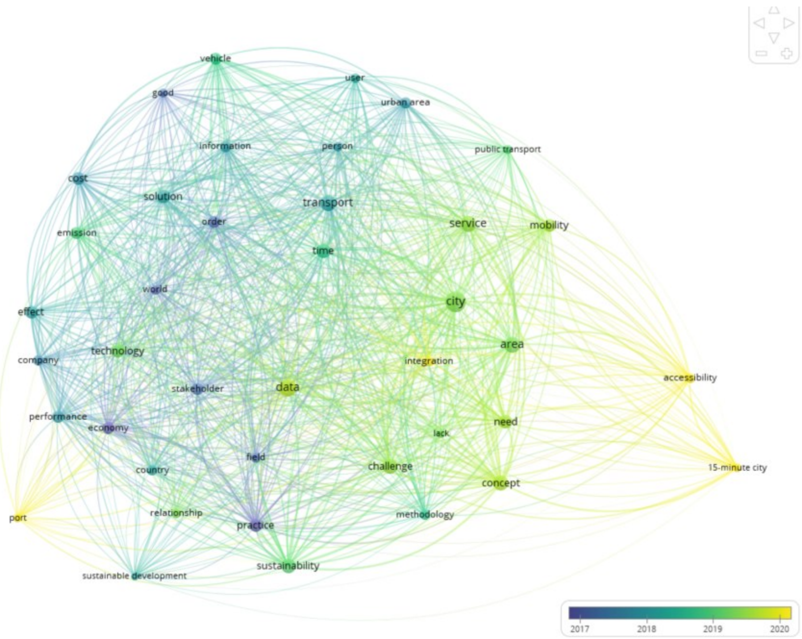

Fig. 1. Bibliometric map of emerging trends in urban logistics and the 15-minute city

The map illustrates a shift in research focus. Traditional logistics terms, such as *transport, goods,* and *cost* appear in darker shades, representing the earlier stage of the study period (2017–2018). Although these traditional logistics topics are well-documented, their distance from new concepts shows they represent an older approach, one that hadn't yet adapted to the high density and proximity required by current urban planning

The emergence of the *15-minute city* node, highlighted in bright yellow alongside *accessibility, mobility,* and *sustainability*, confirms that proximity-based planning has only recently intersected with distribution studies, primarily from 2020 onwards. The distance between the yellow (*15mC*) and darker green (*logistics*) clusters reveals a disconnect. It confirms that city design is changing much faster than the delivery models needed to serve it. This is also shown in the word cloud (Fig.2), where general environmental goals dominate the discussion. However, practical tools for the 15mC such as cargo bikes and micro-hubs, remain much less prominent. Recent research has identified several promising approaches to address this gap. L. Ranieri et al. (Ranieri et al., 2018) provide a classification of innovations including innovative vehicles, proximity stations, and transport optimization. Electric and alternative-fuel vehicles represent a significant opportunity, with smaller, cleaner units like cargo bikes and mopeds better suited to the spatial constraints of 15-minute neighborhoods. Parallel to this, the concept of micro-distribution hubs and proximity stations enables shorter delivery distances and reduced vehicle movements (Castillo et al., 2024; de Bok et al., 2024).

The successful integration of freight into 15mC also requires advanced digital management of urban space. Recent research shows that real-time data and Digital Twins help manage curb space and delivery times more effectively. These digital tools improve communication between cities and logistics companies, reducing conflicts in crowded neighborhoods (Hribernik et al., 2020).

In conclusion, cities need a plan that connects social goals with the practical needs of urban transport systems. Recognizing these neighborhoods as both social spaces and logistics nodes allows for a more realistic and sustainable approach to modern city management. To address this**,** this study proposes a new framework that combines spatial planning with stakeholder cooperation to make urban logistics more efficient while helping the 15mC meet its environmental and social targets.

3 Methodology

This study employs a mixed-methods research design to bridge the gap between high-level urban theory and the operational realities of the last-mile transport. The research was conducted in three stages. The first was based on source analysis, the second on a qualitative approach, and the third on a quantitative approach.

Table 1. Integrated Research Framework: Phases, Methods and Stakeholder Groups

Phase	Research Method	Sample and Stakeholder Group	Analytical Objective	Related Research Questions
Phase I: Theoretical and Benchmark Foundation	Systematic Literature Review (SLR) following PRISMA protocol and bibliometric mapping (VOSviewer)	85 peer-reviewed publications; benchmark case studies: Paris, Barcelona, Utrecht	Identification of the global urban logistics gap and conceptualization of the spatial characteristics of leading 15-minute city models	Conceptual benchmark
Phase II: Qualitative Stakeholder Perspectives	Semi-structured Individual Deep Interviews (IDI)	Municipal planning experts (N = 12) representing Gdańsk, Warsaw and Katowice	Assessment of the degree of freight integration within Local Spatial Development Plans (MPZP)	RQ2, RQ3
Phase II: Qualitative Stakeholder Perspectives	Focus Group Interviews (FGI)	Local business owners (N = 20) operating in high-density urban districts	Examination of delivery frequency patterns and stakeholder readiness for shared-responsibility logistics models	RQ1, RQ3
Phase III: Quantitative Operational Diagnostics	Diagnostic survey (CAWI) combined with structured on-site observations	Last-mile delivery operators (N = 55): couriers (N = 50) and operations managers (N = 5)	Quantification of operational inefficiencies and evaluation of technical feasibility thresholds for modal shift toward cargo-bike logistics	RQ1, RQ3

3.1 Systematic Literature Review

The study began with a systematic literature review conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol. (Yepes-Nuñez et al., 2021) This process was designed to verify the current state of knowledge in the analysed field. A predefined search protocol was applied across Scopus, Web of Science, ScienceDirect, and Mendeley covering the period from 2016 (the formal conceptualization of the 15mC) to April 2025. To ensure methodological rigor, the search was restricted to English-language, peer-reviewed journal articles and conference papers. The screening process involved the following stages:

(1) Defining the search method for the identification of studies. The research used the search engines ResearchGate, Google Scholar, Mendeley, and Scopus. In the first stage, articles were identified by title. A total of 2188 sources were selected with the key phrases: *15-minute city; city logistics; urban freight; last-mile delivery; micro-hubs; urban form; sustainability; cargo bikes; proximity; curb management; e-commerce; urban governance; resilient supply chain.*

(2) Screening of the studies stage. After the first step, 1432 items were scanned, excluding 953 sources identified as duplicate studies.

(3) Eligibility criteria establishing. From 479 selected sources, 394 were excluded after establishing the eligibility criteria that were: objective clarity, methodological appropriateness, and analytical transparency; • papers aiming at integrating passengers and freight transport in urban areas.

(4) Selection of the sources included in the analysis.

To complement the qualitative review, a bibliometric analysis was performed using VOSviewer (v. 1.6.20). A co-occurrence analysis of author keywords (utilizing a threshold of 70 occurrences across 46 core terms) revealed three dominant thematic pillars:

- stakeholder cooperation - literature addressing the governance of public-private partnerships in urban supply chains (Koumoutsidi et al., 2022; Lindholma & Browneb, 2013);
- infrastructure requirements - studies on the spatial allocation of micro-hubs and unloading bays in dense urban forms (Risimati et al., 2021; Schiewe & Knura, 2021);
- technological innovations – where papers focusing on the role of digital management tools and smart logistics technologies in mitigating delivery-related conflicts were included (Anthony, 2024; Ljungholm, 2018; Verlinde & Macharis, 2016).

The visualization confirmed a significant supply-side knowledge gap, while city logistics is an established field, it remains methodologically distant from the 15-minute city nodes on the research map. This diagnostic serves as the scientific benchmark for the primary research conducted in the Polish context.

3.2 Case Mapping of Benchmark European Cities

Together with the systematic literature review, a comparative case mapping was conducted to examine the practical implementation of 15mC logistics strategies in leading European urban centers (Graells-Garrido et al., 2021; Iqbal et al., 2025). While the literature review provided a theoretical foundation, the case mapping aimed to identify the core components of successful proximity-based freight models, selecting Paris, Barcelona, and Utrecht as benchmark cases due to their advanced stage of operationalization (Branco da Silva et al., 2025; Vich et al., 2022). The mapping process focused on a few areas, starting with where to place micro-hubs. It also examined how to reuse urban space to address the shortage of space in crowded districts. This was complemented by an evaluation of regulatory and policy frameworks, focusing on factors such as Barcelona's digital curb management and Utrecht's zero-emission zones. Finally, we examined how to shift from heavy vehicles to active freight, focusing on cargo bike networks and safe unloading bays. This mapping transformed 15mC theory into concrete logistics data, including optimal hub distances and bay frequencies. It also helped define the implementation problems during the field research in Poland. Documenting these international cases allowed us to see the full potential for sustainable freight in cities built around short distances.

However, the systematic review reveals that despite this theoretical framework for human-centric urbanism, the supply-side operationalization remains significantly underdeveloped. While existing knowledge identifies the technological potential of digital management tools, smart logistics technologies (Spickermann et al., 2014), and cargo bikes (Bissel & Becker, 2024; Dybdalen & Ryeng, 2022; Galkin et al., 2025), it fails to provide an integrated framework for spatial and regulatory implementation across diverse urban contexts.

Specific barriers define this problem. The planning gap, where freight is left out of urban design, the operational gap, where density blocks delivery flow. The last one is the cooperation gap, where fragmented interests prevent a shared approach to the last mile. This study addresses these points by moving from a theoretical framework to an empirical investigation. Through the research questions RQ1-RQ3, we examine these gaps specifically within the socio-economic and spatial realities of Polish metropolitan areas.

Consequently, the following methodology describes the transition from international best practices identified in Phase I to the diagnostic and evaluative primary research design executed in Phases II and III. While existing knowledge identifies the technological potential of smart urban tools and cargo-bike networks, it often fails to provide an integrated framework for spatial and regulatory implementation across different urban areas. This study takes successful solutions from European cities and turns them into measurable logistics factors. We then test these factors against the actual infrastructure and economic conditions in Polish metropolitan areas.

3.3 Qualitative Stakeholders Research

The qualitative inquiry in Phase II was designed to ground the theoretical 15mC framework in the socio-economic reality of three Polish metropolitan areas: Gdansk, Warsaw, and Katowice. Following the guidelines for exploratory urban research, this phase focused on capturing the priorities and barriers perceived by two distinct stakeholder groups: municipal planners and local business owners.

Semi-structured Individual Deep Interviews (IDI) were selected as the primary method for evaluating the strategic perspective of local authorities. This method is widely recognized in city logistics literature as effective for identifying institutional barriers and policy priorities (Iwan et al., 2024; Lah, 2018; Pascual-Torres, 2024). The expert sample consisted of twelve senior officials (N=12) from municipal transport and spatial development departments. The research sample was non-random and purposive, ensuring that all participants possessed direct influence over Local Spatial Development Plans (MPZP) and urban mobility strategies (Balawejder et al., 2021; Nowak & Śleszyński, 2023; .Dudek & Nowel-Śmigaj, 2025)

Complementing the expert interviews, Focus Group Interviews (FGI) were conducted to capture the demand-side perspective of the 15-minute commercial ecosystem. These were conducted in high-density districts (Gdansk, Gdynia) with a group of 20 SME owners from the retail and gastronomy sectors. The sample's diversity, including various business profiles and district locations, enabled a comprehensive assessment of supply frequency and private stakeholders' willingness to adopt shared responsibility models, such as district-level goods consolidation.

3.4 Quantitative Research – Operational Diagnostics

Phase III addressed the operational disconnect identified in the literature by quantifying the impact of urban density on the daily reality of the last mile. This research phase focused on the couriers and logistics managers who deal with city space limits every day. We used a mixed-method approach, starting with a diagnostic survey (CAWI technique) and adding direct observations in busy city streets. The final study group included 55 participants: 50 active couriers and 5 operations managers (N=55) from major companies such as InPost, DPD, DHL, and GLS. The group was carefully selected to represent different transport modes: 80% were van drivers and 20% were cargo bike operators. This composition allowed for a comparative evaluation of how different transport modes cope with infrastructure inadequacies, such as the lack of dedicated loading bays. The survey questionnaire focused on quantifying operational delays and identifying the technical thresholds required for a successful transition to micro-electric vehicles or cargo bikes.

We structured the research in stages, starting with global benchmarking (Phase I) and then moving to institutional and operational tests in Poland (Phases II–III). This approach helps us identify where 15mC theories don't align with the practical realities of how goods are delivered in cities.

3.5 Research Synthesis and Data Triangulation

Upon completion of the three research phases, the findings were synthesized using a data triangulation approach. This step is crucial for addressing RQ3, as it facilitates the alignment of often-conflicting objectives from municipal planners, local business owners, and delivery operators. We combined interviews and observations with numerical data to find where the implementation gap really lies. This mix of information is the foundation for our new framework, making sure the results are practical for real-world European cities. Our approach brings together three groups: city planners and their visions, business owners, and couriers. By merging these qualitative and quantitative insights, the study identifies the points that prevent 15mC plans from working in practice.

This synthesis serves as the essential foundation for the proposed conceptual framework, ensuring that the final recommendations are not merely sustainable in theory but fully operationalizable within the complex urban environments of European cities. By combining these different perspectives, the study identifies the proximity paradox**.** This happens when high-density urban design, which tends to be sustainable, actually makes deliveries more difficult. Our research shows that without the spatial and regulatory tools proposed in this study, these logistics problems remain unsolved. Ultimately, this multi-dimensional analysis bridges the gap between the theory of the 15mC and the practical needs of last-mile delivery.

4 Results

4.1 Text Analysis and Text Mining: Stakeholder Perceptions (RQ1 & RQ2)

The first stage of the results analysis focuses on identifying the primary goals and terminological patterns within the Polish urban logistics landscape by applying text mining to transcribed interviews from Phase II conducted in Gdańsk, Warsaw, and Katowice.

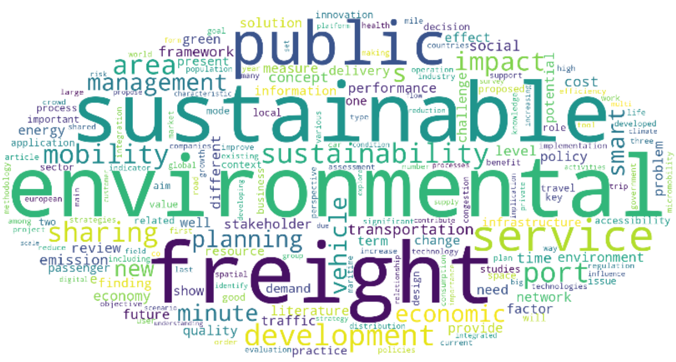

Fig. 2. Word cloud

The results shown in Fig. 2 indicate that, while terms such as *sustainable, environmental,* and *freight* dominate stakeholder discourse, operational terms such as *micro-hubs, cargo bikes,* and *unloading bay*s appear much less frequently. This diagram contrast confirms the planning gap showing that despite a strong strategic vocabulary, the practical tools needed to implement 15mC logistics are not yet a priority for stakeholders. Furthermore, the high frequency of keywords like *congestion* across all groups indicates that traffic-related delays remain the most significant shared concern, even more crucial than long-term structural solutions.

Municipal planners prioritize SUMP goals, like reducing pollution and making services easier to reach. But in practice, their focus suggests that freight logistics is often left out of the planning for proximity-based neighborhoods. A key problem came up during the research, the strategic vision for green logistics in SUMPs is almost never reflected in binding MPZP regulations. This creates a regulatory gap: delivery needs are recognized on paper, but there is no designated space in the laws governing the use of city land. A sharp divergence appears when comparing these strategic visions with the practical needs of local business owners, whose priorities are instead dominated by *delivery time, punctuality,* and *service availability.*

This data proves the proximity paradox in practice. While narrowed streets and expanded sidewalks help residents, they simultaneously damage the logistics network by making it harder for delivery vehicles to operate. This lack of alignment reveals a significant communication gap. Many carriers and forwarders are unaware of formal city logistics tools, often viewing them as rather voluntary. Similar to international trends, the Polish private sector sees the 15mC model as a set of instruments dedicated to city inhabitants and passenger transport rather than an opportunity for innovation.

The results of the text mining and thematic analysis provide a direct response to the first two research questions of this study. Regarding RQ1, the findings demonstrate that the transition to a 15mC model is perceived by the private sector primarily as a source of operational problems. The high frequency of terms related to logistical constraints such as *pedestrianization and parking restrictions* indicates that at the district level, the 15mC shift is currently viewed as a challenge to delivery fluidity rather than an opportunity for innovation.

Regarding RQ2, the analysis of planning documents and interviews reveals a major institutional gap. While Polish planning tools like SUMPs focus on the human side of the 15mC, they only address sustainable freight at a superficial level. In practice, the strategic goals of SUMPs are not integrated into the binding Local Spatial Development Plans (MPZP), leaving logistics without a secured legal or spatial standing. This planning gap proves that current frameworks are passenger-oriented and ignore the supply-side of the neighborhood

4.2 Quantitative Analysis of Last-Mile Delivery Efficiency in the 15MC

The operational diagnostics of last-mile delivery within the 15mC framework were further validated through a comparative analysis of delivery modes (motorized vs. active). To ensure the robustness of the findings, both the Mann-Whitney U test and the Kolmogorov-Smirnov test were applied to the dataset. The results, presented in the statistical matrix below, reveal significant disparities in how different operators manage the challenges of dense urban corridors.

Table 2. Non-parametric test results for delivery mode comparison

Variable	**Mann–Whitney U test (Delivery Mode)**		**Kolmogorov–Smirnov test (Delivery Mode)**			
	Z	p	Z corr.	p	Max. pos.	Max. neg.
Parking Accessibility	-2.21	0.027	-2.28	0.023	-0.41	0.00
Delivery Time Loss	-1.98	0.048	-2.05	0.041	-0.36	0.02
Congestion Exposure	-2.34	0.019	-2.42	0.015	-0.44	0.00
Loading Infrastructure	-1.41	0.158	-1.47	0.142	-0.21	0.05
Accessibility Constraints	-1.72	0.085	-1.79	0.073	-0.28	0.04
Operational Efficiency	1.89	0.059	1.95	0.051	0.00	0.31
Emissions Awareness	2.05	0.040	2.11	0.035	0.00	0.39
Micro-hub Availability	-1.12	0.262	-1.18	0.238	-0.17	0.06
Route Reliability	-1.77	0.076	-1.84	0.066	-0.29	0.03
Shared Responsibility	1.94	0,052	2.01	0.044	0.00	0.34

The strongest operational barrier is congestion exposure, with both statistical tests confirming its high significance: the Mann-Whitney U ($p = 0.019$) and Kolmogorov-Smirnov ($p = 0.015$). This is closely followed by Parking Accessibility, where the p-values (0.027 and 0.023 respectively) confirm that motorized operators face significantly higher barriers than active operators when competing for limited curb space. Furthermore, significant differences in delivery time loss (p = 0.048 for Mann-Whitney U), confirm that traditional motorized logistics suffer more from the 15-minute city design than other delivery modes.

The analysis also highlights a divergence in environmental and strategic alignment among operators. A significant difference was identified in Emissions Awareness (p = 0.04 for Mann-Whitney U; p = 0.035 for Kolmogorov-Smirnov), with active delivery providers demonstrating a higher level of ecological commitment compared to motorized counterparts. Interestingly, Shared Responsibility and Operational Efficiency showed only a trend in the first test, but the Kolmogorov-Smirnov test confirmed significant differences ($p < 0.05$). This indicates that while the averages are similar, the overall distribution of responses differs between the two groups. This suggests that the distribution of operational priorities between these two groups is fundamentally distinct, even when the median values remain close.

Table 3. Kruskal-Wallis test results by stakeholder group and city location

Variable	**Stakeholder Group vs.**	**KW**	**p**	**City Location vs.**	**KW**	**p**
Congestion	Congestion	11.531	0.042	Congestion	8.604	0.014
Accessibility	Accessibility	7.754	0.170	Accessibility	5.365	0.068
Delivery Time Loss	Delivery Time Loss	12.884	0.018	Delivery Time Loss	7.221	0.027
Loading Bays	Loading Bays	4.200	0.521	Loading Bays	2.651	0.266
Parking Availability	Parking Availability	14.683	0.012	Parking Availability	6.041	0.049
Micro-hubs	Micro-hubs	10.082	0.073	Micro-hubs	7.552	0.023
Emissions	Emissions	8.229	0.144	Emissions	2.199	0.333
Operational Delays	Operational Delays	12.703	0.026	Operational Delays	6.894	0.032
Route Reliability	Route Reliability	3.779	0.582	Route Reliability	2.378	0.305
Shared Responsibility	Shared Responsibility	12.374	0.030	Shared Responsibility	0.683	0.711
Variable	Stakeholder Group vs.	KW	p	City Location vs.	KW	p

Conversely, variables like Micro-hub Availability (p = 0.262) and Loading Infrastructure (p = 0.158) showed no significant differences. This proves that the lack of infrastructure is a shared problem for all operators. These results confirm that while the 15mC model encourages green transport, it currently punishes traditional delivery fleets without providing the necessary facilities for a real change.

As shown in the Kruskal-Wallis analysis (Table 3), the city location significantly impacts Congestion (p = 0.014) and Time Loss (p = 0.027). These findings confirm that a successful 15mC logistics model requires two things: filling the infrastructure gaps and reducing the operational difficulties faced by traditional delivery trucks.

In summary, the statistical evidence provided in this section directly addresses the primary operational impacts and barriers of the 15mC transition. Regarding RQ1, significant differences in congestion and parking ($p < 0.03$) prove that the 15mC layout penalizes traditional delivery vans. It confirms that high urban density creates difficulties for delivery flow unless the city adapts its infrastructure.

Furthermore, the results regarding RQ3 highlight that the infrastructure deficit is not mode-specific but systemic. The lack of significant differences in the perception of Micro-hub Availability (p = 0.262) and Loading Infrastructure (p = 0.158) indicates that these gaps represent a universal obstacle for all logistics operators. These findings suggest that the problem with micro-hubs isn't a lack of interest from operators, but a simple lack of physical space and facilities. This proves that we need a collaborative governance model (RQ3) to bridge the gap between planning and reality

4.3 Stakeholder Consensus and Solution Feasibility (RQ3)

To address the specific barriers to micro-hub adoption and the potential for multi-stakeholder cooperation (RQ3), the dispersion coefficient D_r was used to assess consensus across the identified groups. The results, presented in Table 4, indicate a strong consensus regarding the severity of Congestion Impact D_r = 0.32 for planners and 0.41 for operators, confirming that traffic delays are the main reason all groups see a need for change in every city studied.

Table 4. Stakeholder Alignment Matrix: Evaluation of Consensus Gaps in Urban Freight Integration.

Criteria	Municipal Planners	Entrepreneurs	Delivery Operators	Interpretation
Congestion Impact	0.32	0.48	0.41	Strong Consensus
Delivery Time Reliability	0.71	0.46	0.38	Divergent vs. Strong
Parking Availability	0.52	0.67	0.42	Operational Priority
Emissions Reduction	0.39	0.66	0.74	Policy vs. Practice
Micro-hub Implementation	0.68	0.73	0.69	Weak Consensus (RQ3)
Shared Responsibility Model	0.74	0.70	0.65	Low Alignment (RQ4)
Operational Efficiency	0.58	0.49	0.45	Economic Alignment

However, a significant consensus gap exists regarding Micro-hub Implementation (D_r values ranging from 0.68 to 0.73), which directly addresses RQ3. While the theoretical need for such hubs is established in the literature, the lack of consensus shows that barriers like high costs and competition for limited urban space (land-use) are still preventing a unified strategy for micro-hubs.

Furthermore, regarding the structure of multi-stakeholder cooperation, the data reveal a cooperation gap. Municipal planners show a strong internal agreement on Emissions Reduction (D_r = 0.39), whereas delivery operators remain highly fragmented on this issue (D_r = 0.74), prioritizing Delivery Time Reliability (D_r = 0.38) instead. This gap proves that *shared responsibility* won't work if it's only forced from the top down. Instead, we need a system that balances the city's green goals with the delivery companies' need for efficiency.

5 Conclusion

The research evaluates 15mC logistics and reveals a clear conflict. Higher urban density benefits residents but creates significant challenges for urban freight. Although the 15mC concept improves accessibility for residents, it simultaneously blocks the efficient movement of goods. Data confirms that motorized delivery vehicles struggle significantly compared to active transport. This proves that today's 15mC implementations are being designed without considering the practical limits of urban logistics. These findings indicate that sustainable 15mC development depends on recognizing goods distribution as a core urban service, ensuring its requirements are embedded directly into the city's operational framework. To bridge the identified planning gap, urban policy must adopt a multi-modal spatial strategy where freight logistics and passenger mobility are treated as equally essential components of the transport system. Instead of optional guidelines, cities should introduce mandatory rules that protect the space needed for logistics hubs and loading zones in dense areas. Furthermore, the lack of agreement found in our analysis shows we need to shift toward multi-stakeholder governance. Rather than using top-down regulations, cities should build partnerships that balance environmental goals with the practical and economic needs of private logistics companies.

Ultimately, this study demonstrates that a sustainable 15mC requires more than just walkable streets. It demands a synchronized physical and digital supply network. Addressing these physical and regulatory barriers allows for a more functional integration of freight into the 15mC model. Future research is needed to verify these findings in other geographic locations, ensuring that new logistics policies remain compatible with the socio-economic needs of both residents and businesses."

6 Limitations and future research

There are a few key limitations to this research. First, the sample (N=87) was specifically chosen to provide deep insights, making it a detailed diagnostic rather than a representative sample of the national population. Still, the method's accuracy ensures the results provide a solid starting point for the studied areas. Second, although looking at Gdańsk, Warsaw, and Katowice offers diverse views on city shapes, the study remains focused on Poland's major cities. We cannot yet say if these results apply to smaller towns, which would require more comparative studies. The next limitation is that we relied on subjective stakeholder feedback instead of GPS or telematics data. This feedback is key to identifying planning issues, but future studies would benefit from using hard operational data to track delivery efficiency. Looking ahead, research should also track pilot micro-hubs over longer periods. This would help measure their real impact on urban congestion and the long-term costs for logistics companies.

Beyond these constraints, future inquiries should focus on longitudinal evaluations of pilot micro-hubs to assess their long-term impact on urban congestion and operational costs. Additionally, exploring the role of digital twin technologies in simulating the interaction between pedestrians and delivery flows could further bridge the gap between theory and practice. Nevertheless, this paper fills a critical research gap by providing the first empirical link between 15mC theory and last-mile reality in Poland, establishing a baseline for future sustainable urban freight policies.

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