logistics

MDPI

Article

A Holistic Human-Based Approach to Last-Mile Delivery: Stakeholder-Based Evaluation of Logistics Strategies

Aleksa Maravić , Vukašin Pajić * and Milan Andrejić *

Faculty of Transport and Traffic Engineering, University of Belgrade, Vojvode Stepe 305, 11000 Belgrade, Serbia; aleksamaravic16012002@gmail.com
* Correspondence: v.pajic@sf.bg.ac.rs (V.P.); m.andrejic@sf.bg.ac.rs (M.A.)

Abstract

Background: The growing complexity of last-mile logistics (LML) in urban environments has created an urgent need for sustainable, efficient, and stakeholder-inclusive solutions. This study addresses these challenges by exploring a holistic, human-centered approach to evaluating LML strategies, recognizing the diverse expectations of logistics service providers, delivery personnel, customers, and local authorities. *Methods*: To capture both subjective and objective factors influencing decision-making, the study employs a Multi-Criteria Decision-Making (MCDM) framework that integrates the Fuzzy Analytic Hierarchy Process (FAHP) and Evaluation based on Distance from Average Solution (EDAS). Evaluation criteria encompass operational efficiency, environmental impact, social acceptance, and technological feasibility. *Results*: Six LML solutions were assessed and ranked using this approach. The results indicate that the cargo bike (A_2) emerged as the most favorable alternative, while electric freight vehicles (A_5) ranked lowest. These findings reflect significant trade-offs between stakeholder priorities and the varying performance of different delivery strategies. *Conclusions*: The proposed methodology offers practical guidance for designing balanced and socially responsible urban logistics systems. By emphasizing inclusivity in decision-making, this approach supports the development of LML solutions that are not only operationally effective but also environmentally sustainable and broadly accepted by stakeholders.

Keywords: last-mile delivery; logistics; stakeholder; human-based; distribution; FAHP; EDAS

check for updates

Received: 24 July 2025
Revised: 15 September 2025
Accepted: 19 September 2025
Published: 23 September 2025

Citation: Maravić, A.; Pajić, V.; Andrejić, M. A Holistic Human-Based Approach to Last-Mile Delivery: Stakeholder-Based Evaluation of Logistics Strategies. *Logistics* **2025**, *9*, 135. https://doi.org/10.3390/logistics9040135

1. Introduction

The demand for urban freight transport has grown substantially, driven by rapid urbanization, demographic expansion, the proliferation of e-commerce, the adoption of modern management strategies (e.g., Just-In-Time), and the integration of emerging technologies [1]. The surge in e-commerce, in particular, has profoundly transformed the logistics landscape, especially last-mile logistics (LML), which is increasingly recognized as a critical component of the supply chain [2]. This transformation has resulted in a sharp increase in the number of parcels requiring daily delivery, particularly in densely populated urban areas. Consequently, the need for delivery vehicles to fulfill last-mile services has risen significantly, further intensifying urban freight traffic.

This intensification has amplified several urban challenges, including traffic congestion, reduced availability of public space, air and noise pollution, and an overall decline in urban quality of life [1]. Addressing these challenges is of paramount importance, given that approximately 54% of the global population currently resides in cities, with projections suggesting an increase to 66% by 2050 [3].

Urban areas, while generating substantial freight flows, simultaneously create significant logistical challenges that affect both city infrastructure and residents [3]. In response, logistics providers are increasingly adopting advanced technologies to deliver personalized and flexible services, which in turn raise customer expectations. However, these heightened expectations, coupled with increasing operational complexity, have introduced new difficulties in achieving efficient and sustainable last-mile logistics (LML) [2].

LML constitutes a complex system encompassing strategic planning, execution, and control of goods transportation and storage, with the goal of meeting end-user demands. It involves the design of distribution channels, inventory management, delivery scheduling, and order fulfillment at the tactical level. On the operational level, last-mile transportation depends on routing, vehicle selection, order consolidation, order processing, and warehouse optimization [4]. Urbanization, limited land availability, and megatrends such as the continued growth of e-commerce significantly influence the delivery of transport services. The emergence of new mobility demands, particularly regarding freight movement, threatens to further burden urban infrastructure with increased congestion and parking scarcity, issues that may worsen if current road networks are not adapted [5].

In this context, LML transcends mere convenience and cost-efficiency. It has become a strategic priority, as recent crises have exposed the vulnerabilities of global supply chains and urban delivery networks. The COVID-19 pandemic, for instance, underscored the fragility of these systems as surges in online shopping placed unprecedented pressure on logistics operations. In such conditions, the development of public–private partnerships, geared toward environmentally sustainable and technologically integrated solutions, is more essential than ever [6].

Among all segments of the supply chain, the last mile is recognized as the most expensive and environmentally detrimental. Common challenges include a high rate of failed home deliveries (e.g., recipients being absent), which in turn result in additional trips, higher emissions, and increased vehicle kilometers. Door-to-door deliveries also often generate empty return trips. In certain urban zones, the volume of goods may be insufficient to justify efficient routing, while the widespread use of small vans, common in such deliveries, leads to a disproportionately high carbon footprint per kilogram compared to larger vehicles [7]. Furthermore, LML has become a strategic differentiator for retailers, who now compete by offering innovative delivery solutions such as same-day delivery, store pickup, autonomous delivery systems, parcel lockers, and free shipping options. These solutions aim to enhance consumer convenience and flexibility, particularly in sectors such as groceries, prepared meals, and fast-moving retail. In response, logistics providers are increasingly investing in automated distribution centers located within urban environments to enable faster and more reliable delivery services [8].

Despite its importance, LML remains the most costly segment of logistics operations accounting for up to 75% of total logistics expenses. Nevertheless, its intangible nature often leads consumers to undervalue the service, showing limited willingness to pay for improved performance. This disconnect complicates efforts to enhance LML, as evidenced by the failure of numerous city logistics initiatives. These circumstances highlight the inadequacy of traditional delivery models and point to the urgent need for innovative, forward-thinking approaches [9]. In this context, distribution channels are an essential component of the operations of logistics providers. They represent a complex network of entities responsible for facilitating the flow of goods from producers to consumers. Effective decision-making in distribution is becoming increasingly important in today's business environment. To ensure success, it is necessary to make timely decisions based on accurate information that supports the efficient execution of goods flows, an aspect of particular relevance given the continuous growth of e-commerce [10].

This study contributes by integrating Fuzzy Analytic Hierarchy Process (FAHP) and Evaluation based on Distance from Average Solution (EDAS) to evaluate LML solutions while incorporating both subjective and objective criteria and capturing the perspectives of multiple stakeholder groups. This approach provides actionable insights for designing more balanced and socially acceptable last-mile solutions, which are not addressed in traditional cost-focused models. Given the complexity of last-mile systems and their strong interdependence with market dynamics, any effective strategy must be context-sensitive and adaptable. Because the selection of appropriate strategies involves multiple, often conflicting criteria, Multi-Criteria Decision-Making (MCDM) approaches are required. In designing the methodological framework for this study, several established approaches in urban logistics and decision-support research were evaluated. Stated Preference (SP) surveys and Discrete Choice Experiments (DCE) are well suited for uncovering individual preferences and assessing trade-offs through advanced choice modeling, yet their reliance on extensive data collection and complex experimental design makes them less practical for exploratory, multi-stakeholder analyses. Delphi studies and Participatory Multi-Criteria Analysis provide iterative and deliberative processes to capture expert consensus and stakeholder input but require significant time, resources, and repeated engagement rounds. Agent-Based Modeling (ABM) offers valuable insight into system-level dynamics and actor interactions but depends on detailed parameterization and comprehensive datasets, typically available only in advanced phases of research and policy development.

FAHP integrates fuzzy set theory with the Analytic Hierarchy Process, enabling the evaluation of decision problems under uncertainty by applying pairwise comparisons to determine the relative importance of criteria. On the other hand, unlike traditional approaches such as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and VIšekriterijumsko KOmpromisno Rangiranje (serb.) (VIKOR), which focus on identifying the optimal alternative based on proximity to ideal and anti-ideal solutions, real-world decision-making scenarios often demonstrate that minimizing the distance to the ideal and maximizing the distance from the anti-ideal solution does not always ensure the most appropriate outcome. The EDAS method addresses this limitation by employing a normalization technique based on the average solution. Given these considerations, FAHP combined with EDAS was chosen for its ability to integrate expert evaluations with objective indicators, manage uncertainty through fuzzy logic, and deliver clear, computationally efficient rankings of LML alternatives. This hybrid approach offers a balance between analytical rigor and operational feasibility, making it suitable for early-stage assessment of diverse LML strategies. Future work could extend this study by incorporating SP/DCE methods for more detailed behavioral insights, participatory techniques for richer stakeholder engagement, and ABM for exploring long-term systemic impacts.

To this end, a novel hybrid MCDM framework is proposed, integrating FAHP with the EDAS method. This hybrid model provides a robust tool for evaluating and selecting optimal LML strategies, offering both theoretical advancement and practical utility.

The paper is structured as follows. Section 2 presents a comprehensive literature review, identifying the research gap that informs the core aim of the study. Section 3 describes the methodological framework. Section 4 illustrates the application of the proposed MCDM model through a case study analysis. Section 5 discusses the theoretical and managerial implications of the findings. Finally, Section 6 concludes the study by summarizing key insights and offering directions for future research.

2. Literature Review

In recent years, the increasing complexity of urban environments and rapid growth of e-commerce have intensified the need to optimize sustainable and efficient LML systems.

This has sparked growing interest in MCDM methods to evaluate delivery options. Despite notable progress, key challenges remain, including inconsistent criteria selection, fragmented stakeholder engagement, and limited real-world validation. This review organizes the literature into four key themes: (1) methodological approaches, (2) sustainability criteria and trade-offs, (3) stakeholder integration, and (4) technological and contextual factors. This structured synthesis reveals gaps and informs the practical framework proposed in this study.

2.1. Methodological Approaches in Last-Mile Delivery Decision-Making

The literature applies a wide range of hybrid MCDM methods, such as FAHP, fuzzy TOPSIS (FTOPSIS), Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE), Step-wise Weight Assessment Ratio Analysis (SWARA), DEcision-MAking Trial and Evaluation Laboratory (DEMATEL), and VIKOR. These methods are chosen to handle uncertainty and subjectivity in complex logistics evaluations, integrating qualitative and quantitative data for robust decision-making. For example, Sangkhiew et al. [11] combined FAHP and FTOPSIS to reflect customer preferences, demonstrating how subjective assessments can be effectively modeled. However, to address the limitations of focusing solely on customer perspectives, other studies have explored more comprehensive approaches. The study by Le Pira et al. [12] explores how integrating discrete choice and ABM can capture diverse stakeholder preferences and interactions, offering a powerful tool for assessing policy acceptance in urban freight transport planning. However, focusing primarily on customer perspectives risks overlooking broader system impacts and other stakeholder needs, which limits managerial relevance.

Similarly, Wang et al. [13] employed FAHP and FWASPAS to assess Vietnamese B2C delivery providers across economic, social, technological, environmental, and service criteria. This multidimensional approach highlights the complexity in selecting criteria but also reveals inconsistency across studies, which hampers direct comparison and practical application. Pourmohammadreza et al. [14] addressed additional factors such as disaster resilience and accessibility through SWARA and COmbined COmpromise SOlution (COCOSO), stressing the critical role of infrastructure in last-mile solutions.

Approaches combining DEMATEL with VIKOR [15] or AHP [16] provide insights into interrelations and priorities among criteria and stakeholders but often rely on specific contextual data, limiting transferability. Emerging methods like Picture Fuzzy Decision-Making [17,18] enhance uncertainty handling but require intensive expert input, potentially reducing scalability. Furthermore, recent studies have incorporated methods such as Multi-Criteria Decision Analysis (MCDA), Multi-Actor Multi-Criteria Analysis (MAMCA), Ordinal Priority Approach (OPA), Multi-Attribute Ranking method based on COmpromise Solution (MARCOS), and Multi-Attribute Value Theory (MAVT) to capture multiple stakeholder views and complex decision contexts [12,19,20].

The use of MAMCA enables active stakeholder engagement in planning off-hour delivery solutions, facilitating the assessment of acceptance and feasibility from multiple perspectives [19]. OPA and Fuzzy MARCOS (FMARCOS) support ranking and prioritization under uncertainty and ambiguity [20]. MAVT provides a framework for integrating operational and TBL criteria to assess urban freight strategies in real-world contexts [12]. Despite the advances in methodological approaches, the lack of standardized criteria and inconsistent stakeholder involvement continue to impede comparability and limit wider application of these tools in LML decision-making.

2.2. Sustainability Dimensions and Evaluation Criteria

Sustainability in LML is typically framed through the Triple Bottom Line (TBL)—economic, environmental, and social aspects. However, the emphasis on each dimension varies across studies, reflecting different research priorities and contexts. Gonzalez et al. [21] offer a comprehensive European urban framework integrating job quality, neighborhood livability, pollution metrics (greenhouse gases, nitrogen oxides, particulate matter, noise), and economic factors like cost and congestion. This is further illustrated in the study by Melkonyan et al. [20], which aims to create a framework for assessing the sustainability of LML. The authors evaluated three distribution strategies: centralized click & collect, decentralized home delivery, and crowd-based distributed logistics. This highlights the importance of context-specific criteria but also the difficulty in transferring frameworks across settings.

Other studies, including Wang et al. [13], Švadlenka et al. [17], Simić et al. [18], and Wang et al. [22], adapt sustainability metrics to diverse contexts, such as developing countries where air pollution, mobility, and stakeholder cooperation are critical. Garus et al. [23] and Kijewska et al. [24] expand this view by evaluating vehicle types and including urban planning and governance dimensions. These broader perspectives emphasize systemic changes required for sustainable last-mile transformation, moving beyond immediate logistics factors.

A major gap lies in insufficient exploration of trade-offs among sustainability dimensions. For instance, varying prioritization of criteria in Simić et al. [18] and Wang et al. [22] leads to contradictory conclusions, exposing the lack of a universally accepted framework to balance economic, environmental, and social goals. This inconsistency complicates decision-making for policymakers and practitioners striving for balanced and sustainable LML solutions. This inconsistency further highlights the need to systematically incorporate diverse stakeholder perspectives, as their varying priorities and trade-offs are central to developing balanced and sustainable LML solutions.

2.3. Stakeholder Perspectives and Trade-Offs

Incorporating diverse stakeholder perspectives is essential for effective LML strategies, yet this is unevenly addressed in the literature. Harrington et al. [25] and Aljohani & Thompson [26] include a broad range of actors from logistics providers to citizens, illustrating the benefits of comprehensive stakeholder mapping and tailored evaluation criteria. Crowd logistics studies [16,27] integrate operational and ethical concerns from authorities, transport operators, and the public.

However, many studies mainly emphasize customer preferences [11,14] or managerial and expert views [22,28], often marginalizing delivery personnel. The frequent omission of delivery workers, who directly experience the impacts of LML strategies, leaves a critical gap in understanding real-world trade-offs. Recognizing the importance of broader stakeholder engagement, Gatta et al. [19] examines the potential of off-hour deliveries in Rome, with particular attention to stakeholder acceptance as a key barrier, combining qualitative insights from in-depth interviews with a quantitative evaluation through interactive multi-actor multi-criteria analysis. This study explicitly includes delivery personnel as a primary stakeholder group, thereby enhancing the human-centeredness and practical relevance of the evaluation framework.

While some studies [25,26] acknowledge trade-offs such as cost versus environmental impact or customer satisfaction versus urban livability, integrated frameworks to systematically balance these tensions are lacking. Developing such tools is crucial for equitable and effective LML planning. Moreover, without clear methodologies to navigate these trade-offs, decision-makers risk prioritizing short-term gains over long-term sustainability goals, undermining the overall effectiveness of LML strategies.

2.4. Technological Solutions and Context-Specific Alternatives

Technological innovations in LML span from conventional vehicles to advanced options such as drones, autonomous robots, e-cargo bikes, and pneumatic tube systems [15,17,18]. These technologies promise improved sustainability and operational efficiency, but face challenges regarding maturity, acceptance, and unintended consequences. Furthermore, the integration of these innovations requires careful consideration of local regulatory frameworks and infrastructure capabilities, which can significantly influence their feasibility and impact.

A critical but often overlooked issue is the rebound effect, where efficiency gains and cost reductions, such as those from adopting electric vehicles, can lead to increased delivery demand, potentially offsetting the expected environmental benefits. Patella et al. [1] highlight that green vehicles remain competitive in dense, stop-and-go delivery contexts, yet they also underscore that "incentives are still necessary for their adoption", which implies that reliance solely on technological efficiency may not suffice to achieve sustainable outcomes. In light of this, it becomes essential to incorporate behavioral and demand-induced feedback mechanisms—such as rebound effects—when assessing the true sustainability impacts of innovations in LML.

Mishra [28] and Wątróbski et al. [29] emphasize integrating technical feasibility, costs, and stakeholder acceptance when evaluating electric freight and robotic delivery vehicles. Operational and regulatory factors, such as disaster resilience and legal frameworks, also influence technology adoption [14,24]. Socio-economic and urban context significantly shapes prioritization of delivery solutions, as shown by Gonzalez et al. [11] and Wang et al. [22]. Without such contextual sensitivity, technology solutions risk misalignment with real-world needs.

Despite advances, empirical validation and practical implementation insights remain limited. This gap restricts transferability and managerial usefulness, underscoring the need to bridge theory and practice for sustainable LML technology adoption. Strengthening collaborations between researchers and industry practitioners could enhance real-world testing and adaptation of innovative delivery technologies.

2.5. Identified Gaps and Justification for Current Research

This review reveals several critical gaps in the existing literature that the present study aims to address comprehensively. First, most literature reviews tend to be descriptive rather than analytical or thematic, which obscures contradictions and prevents clear identification of research gaps. Without a structured synthesis, it becomes difficult to build upon prior work or develop unified evaluation frameworks for LML.

Second, there is notable inconsistency in the selection and application of evaluation criteria across studies. This fragmentation complicates direct comparisons and hinders the emergence of standardized tools that can be widely applied in practice. In particular, studies vary in their emphasis on economic, environmental, and social dimensions of sustainability, leading to contradictory findings and unclear guidance for decision-makers.

Third, stakeholder engagement is often partial or uneven. While customers and logistics providers are frequently included, delivery personnel (who experience direct operational impacts) are commonly marginalized or excluded. This omission results in incomplete understanding of the real-world trade-offs and practical challenges inherent in LML strategies. Without incorporating delivery workers' perspectives, frameworks risk missing critical considerations, reducing relevance for policy and management.

Fourth, many studies rely predominantly on expert opinions and theoretical models without sufficient empirical validation or real-world testing. This gap diminishes the practical applicability and managerial relevance of research findings. Frameworks developed under controlled conditions may fail to capture the complexity and dynamism of urban logistics systems, limiting their usefulness for practitioners.

Fifth, a particularly important yet overlooked gap is the insufficient attention to rebound effects in sustainability assessments. Although emissions reduction is mentioned in several studies, critical debates about how innovations such as electric vehicles may lead to increased delivery demand through cost reductions are often neglected. This rebound effect can offset environmental benefits and complicate sustainable LML evaluation.

This study presents a holistic, human-centered approach to evaluating LML systems by integrating multiple stakeholder groups, including logistics providers, delivery personnel, customers, and local authorities. By emphasizing the inclusion of all relevant actors, it enables a transparent analysis of trade-offs across operational, environmental, social, and technological dimensions. Furthermore, by explicitly addressing potential unintended consequences, such as increased demand resulting from greater efficiency, the framework enhances preparedness for real-world challenges. This comprehensive approach, bridging theory and practice, provides a robust foundation for designing resilient, equitable, and sustainable LML systems, supporting policymakers and practitioners in making balanced decisions that address both operational needs and environmental responsibilities.

These insights and identified gaps are summarized in an overview of key studies in the field of LML (Table 1). The overview illustrates the wide range of research topics, methods used, evaluation criteria, and stakeholders involved, as well as the variety of alternative solutions considered. This diversity reflects the complexity of LML decision-making, but also reveals inconsistencies in how studies define and address critical factors such as sustainability dimensions, stakeholder engagement, and practical feasibility. The summary underlines the need for more integrated and comprehensive approaches that can bridge these gaps, facilitate comparability, and support decision-makers in developing more effective and balanced LML strategies. Building on this foundation, the present study proposes a holistic approach that explicitly incorporates diverse stakeholder perspectives. By doing so, it aims to provide a more nuanced evaluation of logistics strategies that balances operational efficiency with social and environmental considerations, ultimately contributing to more sustainable and equitable LML solutions.

Table 1. Literature review.

Ref.	Problem/Focus	Method(s)	Key Criteria	Stakeholder(s)	Alternatives
[11]	Mode selection for LML	FAHP, FTOPSIS	Cost, environment, convenience	Customers	Home delivery, collection points
[12]	Ex-ante freight policy evaluation	Discrete choice & ABM	Stakeholder preferences, policy acceptance	Authorities, businesses, citizens	Urban freight policy options
[13]	Context-based sustainability evaluation	Expert-based weighting	TBL	Policy experts	European cities
[14]	Sustainable B2C LML evaluation	FAHP, FWASPAS	Cost, service, technical, social, environment	Experts	13 delivery providers (Vietnam)
[15]	Multi-stakeholder last-mile criteria	Interviews, case studies	Delivery performance, satisfaction	Industry, consumers, institutions	Transit chain elements

Table 1. *Cont.*

Ref.	Problem/Focus	Method(s)	Key Criteria	Stakeholder(s)	Alternatives
[16]	Sustainable urban delivery fleets	FAHP, PROMETHEE	Custom per stakeholder	Logistics Service Providers, authorities, citizens	Cargo bikes, eco-fleets
[17]	Urban goods distribution measures	AHP, DEMATEL	Implementation, environment	Authorities, carriers	5 measure types
[18]	Crowd logistics assessment	AHP	TBL, ethics, cooperation	Mixed public and private	Various crowd logistics models
[19]	Off-hour delivery solutions planning	Interviews, MAMCA	Acceptance, urban impact, cost, feasibility	Authorities, providers, receivers, residents	Off-hour delivery, urban consolidation center, standard delivery
[20]	Sustainability of LML	System dynamics, MCDA	Emissions, cost, jobs, energy use	Cooperatives, providers, consumers	Click & collect, home delivery, crowd logistics
[21]	Sustainable delivery tech selection	Picture Fuzzy	TBL, technical	Experts, managers	Drones, lockers, robots
[22]	LML mode comparison	FWASPAS	TBL, technical	Experts	Drones, Autonomous Vehicles, postomats
[23]	Smart LML evaluation	SWOT, DEMATEL-VIKOR	Cost, traceability, training, barriers	Experts	Smart lockers, electric vehicles
[24]	Service option optimization	SWARA, COCOSO	Availability, disaster resilience	Experts, customers	Pick-up points
[25]	Real-world LML sustainability	MAVT	Operational, TBL	Experts, Joint Research Centre	EURO Light Commercial Vehicles (LCV), droids
[26]	Electric van analysis	PROMETHEE II, FTOPSIS	Performance, battery, price	Urban freight stakeholders	Electric van types
[27]	LML in developing context	OPA, FMARCOS	TBL, traceability	Experts, managers	Green, autonomous, crowdsourcing
[28]	Stakeholder priorities for crowd logistics	AHP, DEMATEL, interviews	TBL, network/ethics	Broad mix	Crowd logistics
[29]	Adoption potential of new methods	Composite Aggregation Method, Survey	Reliability, environment, scalability	Shippers, citizens, city authorities	Electric LCVs, robots

3. Methodology

Given the focus of this study, this section outlines the adopted methodology. The core issue addressed is as follows: LML encompasses a wide array of solutions aimed at enhancing the efficiency of logistical operations. Throughout the decision-making process, the interests of multiple stakeholders are duly considered. Within this framework, the following section defines the alternatives (logistical solutions applied in LML), the evaluation criteria (which facilitate the assessment of these alternatives), and the stakeholders involved in the decision-making process, with particular emphasis on the customer perspective. Our study differentiates itself by explicitly integrating multiple stakeholder perspectives into a single evaluation framework, allowing the assessment of trade-offs between operational efficiency, social acceptability, and environmental impact, which is less emphasized in prior MCDM studies.

In order to derive a ranking of the proposed solutions, it is essential first to establish the weights of the evaluation criteria. This weighting enables a systematic comparison among the defined alternatives. Specifically, this research employs two complementary methods: the FAHP for criteria weighting, and the EDAS method for ranking the alternatives. A detailed description of these methods and the steps involved in their application are presented in the following sections (Figure 1).

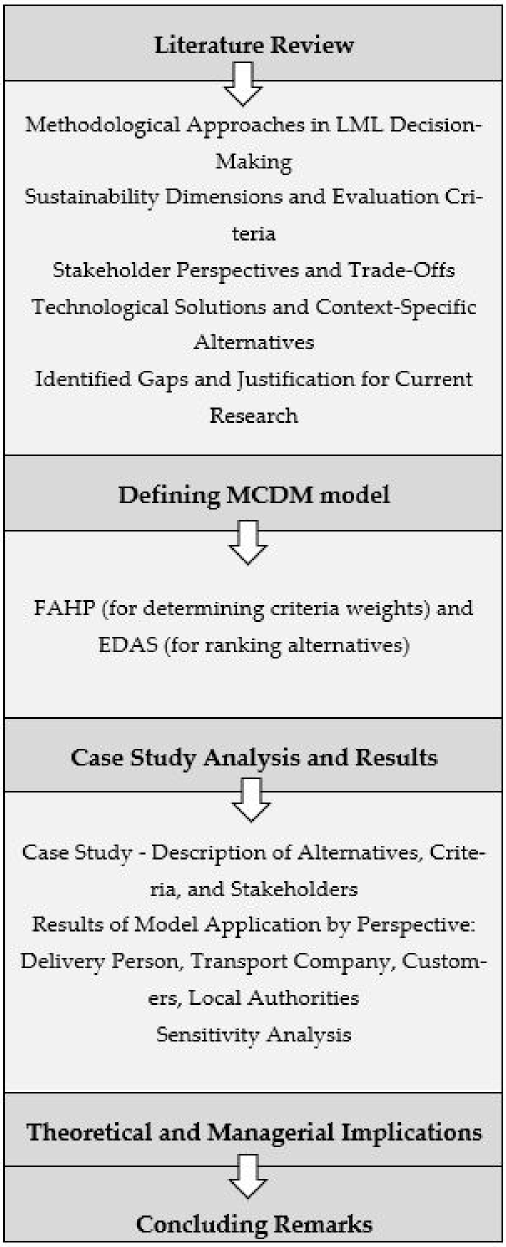

Figure 1. Overall methodology of the study, including literature review, model definition, application, and implications.

3.1. The Fuzzy AHP Method

As one of the most widely used MCDM methods, the AHP was developed by Saaty [30]. The AHP method offers numerous advantages; for instance, it provides a measure of consistency in decision makers' judgments or preferences. AHP also allows decision makers to start from pairwise comparisons that are simple enough to work with and often are preferred by the decision makers. FAHP is used for obtaining more decisive judgments by prioritizing the selection criteria and weighting them in the presence of vagueness in the problems [31]. In order to determine criteria weights, the following steps must be conducted according to the FAHP method [32].

Step 1—Defining the Decision Structure

The process begins by arranging the decision-making problem into a hierarchical structure. This framework aligns with the principles of both AHP and FAHP approaches. It typically consists of the overall goal at the highest level, followed by a breakdown into criteria, sub-criteria, and the potential alternatives at the lowest level.

Step 2—Performing Pairwise Evaluations

Comparative judgments are made between criteria using Saaty's scale ranging from 1 to 9 in traditional AHP. FAHP adapts this process by employing fuzzy logic, assigning fuzzy sets corresponding to the same numerical scale. Each criterion and sub-criterion are compared relative to elements one level above in the hierarchy. Table 2 illustrates the linguistic terms used along with their respective triangular fuzzy values.

Table 2. Linguistic scale for evaluation.

Linguistic Term	Triangular Fuzzy Number
Absolutely preferable (AP)	(8,9,10)
Very preferable (VP)	(7,8,9)
Strongly preferable (SP)	(6,7,8)
Pretty preferable (PP)	(5,6,7)
Quite preferable (QP)	(4,5,6)
Moderately preferable (MP)	(3,4,5)
Remotely preferable (RP)	(2,3,4)
Barely preferable (BP)	(1,2,3)
Equally important (EI)	(1,1,2)

Step 3—Building the Fuzzy Comparison Matrix

In this phase, a fuzzy pairwise comparison matrix is created for each group of criteria or sub-criteria. Each matrix entry consists of a triangular fuzzy number, forming a square matrix of the following structure:

$$\tilde{\in} = \begin{bmatrix} \tilde{a}_{11} & \cdots & \tilde{a}_{in} \\ \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \cdots & \tilde{a}_{nn} \end{bmatrix} \quad (1)$$

Step 4—Deriving Relative Weights

To determine the importance of each criterion, a weight vector $W = (w_1, \ldots, w_n)$ is computed, where all weights are positive and collectively sum to one. This study applies the Logarithmic Fuzzy Preference Programming method, introduced by Wang and Chin [33]. Each fuzzy entry $\tilde{a}_{ij}$ is expressed as a triple (l_{ij}, m_{ij}, u_{ij}), which is logarithmically transformed:

$$ln\tilde{a}_{ij} \approx (lnl_{ij}, lnm_{ij}, lnu_{ij});\ i, j = 1, \ldots,\ n \quad (2)$$

$$Min\ J = (1-\lambda)^2 + M \times \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left(\delta_{ij}^2 + \eta_{ij}^2\right) \quad (3)$$

$$
s.t. \begin{cases} x_i - x_j - \lambda ln(m_{ij}/l_{ij}) + \delta_{ij} \geq lnl_{ij},\ i = 1,\ldots,n-1; j = i+1,\ldots,n \\ -x_i + x_j - \lambda ln(u_{ij}/m_{ij}) + \eta_{ij} \geq -lnu_{ij},\ i = 1,\ldots,n-1; j = i+1,\ldots,n \\ \lambda, x_i \geq 0,\ i = 1,\ldots,n \\ \delta_{ij}, \eta_{ij} \geq 0,\ i = 1,\ldots,n-1; j = i+1,\ldots,n \end{cases} \quad (4)
$$

Here x_i^* represents the optimized score of criterion i, and M is a large constant (10^3) used to ensure the constraints are met. The auxiliary variables δ_{ij} and η_{ij} maintain the inequalities derived from the fuzzy logic formulation.

$$
lnw_i - lnw_j - \lambda ln\left(\frac{m_{ij}}{l_{ij}}\right) + \delta_{ij} \geq lnl_{ij},\ i = 1,\ldots,n-1; j = i+1,\ldots,n \quad (5)
$$

$$
-lnw_i + lnw_j - \lambda ln(m_{ij}/l_{ij}) + \eta_{ij} \geq -lnu_{ij},\ i = 1,\ldots,n-1; j = i+1,\ldots,n \quad (6)
$$

The crisp, normalized weight for each criterion is calculated using:

$$
w_j = \frac{w_j^l + 4w_j^m + w_j^u}{6},\ j = 1,\ 2,\ \ldots,\ n \quad (7)
$$

Step 5—Verifying Consistency

To ensure logical consistency in the comparison matrices, the Consistency Ratio (CR) is computed using the formula:

$$
CR = \frac{CI}{RI} \quad (8)
$$

The Consistency Index (CI) is calculated following the method of Wind and Saaty [34]:

$$
CI = \frac{Z_{max} - 0}{0 - 1} \quad (9)
$$

Here Z_{max} refers to the largest eigenvalue of the fuzzy matrix. The Random Index (RI), which depends on matrix size, is drawn from Saaty's standard table. A CR value below 0.10 indicates acceptable consistency.

3.2. The EDAS Method

The EDAS method was developed by Keshavarz Ghorabaee et al. [35]. The method is particularly useful when conflicting criteria exist. According to the EDAS method, the best alternative is related to the distance from average solution (AV). It is needed to calculate two measures dealing with the desirability of the alternatives: the positive distance from average (PDA) and the negative distance from average (NDA) [31]. According to Ecer [31] and Torkayesh et al. [36], the EDAS method for evaluating and ranking alternatives involves the following steps:

Step 1—Forming the Decision Matrix

Begin by creating a matrix X, where each element x_{ij} represents how the ith alternative performs with respect to the jth criterion. The matrix has m rows (alternatives) and n columns (criteria):

$$
X = [x_{ij}]_{mxn} = \begin{bmatrix} x_{11} & \ldots & x_{1n} \\ x_{21} & \ldots & x_{2n} \\ \vdots & \ldots & \vdots \\ x_{m1} & \ldots & x_{mn} \end{bmatrix} \quad (10)
$$

Step 2—Computing the Average Solution

For each criterion j, calculate the average performance across all alternatives. The average value vector is:

$$
x_j{}^* = (x_1{}^*,\ x_2{}^*,\ \ldots,\ x_m{}^*) \quad (11)
$$

$$x_j{}^* = \frac{\sum_{i=1}^m x_{ij}}{m} = \left(\frac{\sum_{i=1}^m x_{i1}}{m}, \frac{\sum_{i=1}^m x_{i2}}{m}, \ldots, \frac{\sum_{i=1}^m x_{im}}{m}\right), \; j = 1, \ldots, n \quad (12)$$

Step 3—Measuring Positive and Negative Distances

Each alternative's deviation from the average is computed and categorized as either a positive distance (PD) or a negative distance (ND), depending on whether the criterion is to be maximized or minimized. The matrices are defined as:

$$PD = \left[pd_{ij}\right]_{mxn} \quad (13)$$

$$ND = \left[nd_{ij}\right]_{mxn} \quad (14)$$

For benefit-type (maximization) criteria:

$$pd_{ij}{}^+ = \frac{max\left(0, \left(x_{ij} - x_j{}^*\right)\right)}{x_j{}^*} \quad (15)$$

$$nd_{ij}{}^+ = \frac{max\left(0, \left(x_j{}^* - x_{ij}\right)\right)}{x_j{}^*} \quad (16)$$

For cost-type (minimization) criteria:

$$pd_{ij}{}^- = \frac{max\left(0, \left(x_j{}^* - x_{ij}\right)\right)}{x_j{}^*} \quad (17)$$

$$nd_{ij}{}^- = \frac{max\left(0, \left(x_{ij} - x_j{}^*\right)\right)}{x_j{}^*} \quad (18)$$

Step 4—Aggregating Weighted Distances

Using the weights w_j assigned to each criterion, calculate the weighted sums of PD and ND for each alternative:

$$SP_i = \sum_{j=1}^n W_j pd_{ij}, \; i = 1, \ldots, m \quad (19)$$

$$SN_i = \sum_{j=1}^n W_j nd_{ij}, \; i = 1, \ldots, m \quad (20)$$

Step 5—Normalizing the Aggregated Scores

To make the scores comparable, normalize the sums as follows:

$$NSP_i = \frac{SP_i}{max_i(SP_i)}, \; i = 1, \ldots, m \quad (21)$$

$$NSN_i = 1 - \frac{SN_i}{max_i(SN_i)}, \; i = 1, \ldots, m \quad (22)$$

Step 6—Determining the Final Score (Appraisal Score)

The overall appraisal score AS_i for each alternative is the mean of its normalized PD and ND values:

$$AS_i = \frac{1}{2}\left(NSP_i + NSN_i\right), \; i = 1, \ldots, m \quad (23)$$

This value ranges between 0 and 1, with higher values indicating better alternatives.

Step 7—Ranking the Alternatives

Finally, alternatives are ranked based on their AS_i scores in descending order. The alternative with the highest score is identified as the most suitable option.

4. Case Study Analysis and Results

In accordance with the previously defined Methodology, this section of the study is dedicated to the application of the proposed model and the analysis of results from the perspectives of the identified stakeholders. It is worth mentioning that a panel of experts from key stakeholder groups was consulted to assess the relative importance of criteria using fuzzy pairwise comparisons. Experts were chosen for their practical experience and knowledge, and they expressed their evaluations through linguistic terms translated into triangular fuzzy numbers to account for uncertainty and subjectivity. The resulting judgments were combined using the geometric mean method, producing consensus-based weights that reduce individual bias and strengthen the reliability of the decision-making framework. In this context, a description of the case study will first be provided, followed by the presentation of the results.

4.1. Case Study Description

This case study offers a rigorous examination of diverse LML alternatives within the framework of urban logistics, underscoring the growing strategic imperative of achieving sustainable and efficient parcel distribution. The following sections systematically present the selected alternatives, articulate the evaluation criteria employed to assess their relative effectiveness, and identify the principal stakeholders involved in the decision-making process. By integrating these components, the study aims to advance a comprehensive understanding of the operational challenges and prospective opportunities inherent in LML, thereby supporting evidence-based and balanced decision-making for the development of sustainable delivery strategies.

4.1.1. Alternative Description

Taking into account the rising demand for home deliveries, LML is gaining increasing strategic importance. In response, logistics service providers are adopting a wide range of approaches. Some of the most significant strategies are outlined below.

Electric bicycles (e-bikes) **(A_1)** are predominantly used in LML for food delivery due to their flexibility, ability to reach relatively high speeds, ease of travel, and low cost. They typically travel at speeds of 15–20 km/h, are more maneuverable than other motorized vehicles in urban congestion, and their average price, depending on the type, is below 280 US dollars. In addition to these advantages, e-bikes promote a healthier and more active workforce. However, a key issue in LML using e-bikes is the vulnerability of riders. Accidents often lead to severe injuries, with 53% of fatal cases reportedly caused by aggressive driving. Typical behaviors include weaving through traffic, excessive horn use, and overtaking, often driven by the pressure to deliver orders quickly [37]. Despite these safety challenges, the growing popularity of e-bikes presents opportunities for production growth and economic development. They currently account for about 15% of the global electric vehicle market, and this share is expected to rise. However, many governments still lack clear standards on where and how e-bikes should operate, causing confusion among riders and vendors, especially regarding lithium-ion battery safety and low-quality chargers. This issue has been recognized in a recent report by the Institute for Transportation & Development Policy, part of the global "Cycling Cities" campaign, which offers policy recommendations to help governments fully leverage the economic, climate, and mobility benefits of e-bikes. One of the main recommendations is for governments to view e-bikes, and cycling more broadly, as a key component of urban transport systems. In support of this view, countries like China and Brazil offer valuable insights into implementation challenges and opportunities. China already has hundreds of millions of e-bikes in use, requiring authorities to set quality standards, safety rules, and mobility plans. Meanwhile, Brazil's growing e-bike market highlights the need for improved governance. The experience of both countries shows the strong potential of well-managed, well-funded e-bike policies in future urban transportation [38].

Cargo bicycles **(A_2)** offer a practical alternative to traditional delivery vans, as they are unaffected by traffic congestion and parking limitations. They can operate in restricted zones, navigate narrow streets, and park on sidewalks, allowing closer access to delivery points. This results in shorter delivery times, reduced distances, lower costs, and improved delivery reliability. Moreover, the use of cargo bicycles helps reduce emissions and parking space usage, contributing to cleaner and more sustainable urban transport. However, these benefits are most evident in areas with high delivery density and short distances between shipment origins and customer locations [39]. Compared to motor vehicles, cargo bicycles are smaller, quieter, emission-free, and cheaper to purchase and maintain, while labor costs remain similar. On the other hand, they face limitations such as lower load capacity, restricted battery range, reduced speed, and potential rider fatigue. Successful implementation also depends on micro-depots, small distribution hubs near end customers that receive bulk shipments from larger centers via vans, after which cargo bicycles complete the LML [40]. In terms of sustainability, cargo bicycles align with urban decarbonization goals and can enhance quality of life, but their integration into logistics systems is complex. It requires coordination among transport and urban planners, government institutions, and non-governmental organizations, and is strongly influenced by socio-economic conditions and policy support [41]. While most studies focus on logistics and routing, the work of Ritzer et al. [42] adds a valuable operational perspective by examining how varying traffic conditions affect the performance of cargo bicycle deliveries. This study provides insight into when and where cargo bicycle-based delivery is most feasible within urban environments.

Autonomous vehicles **(A_3)** are emerging as a promising solution for LML, particularly in addressing urban challenges intensified by rising transportation demand, congestion, pollution, and accident rates. This trend is fueled by the growth of e-commerce, which increases pressure on logistics providers to meet fast and high-quality delivery expectations. Electrified autonomous vehicles can operate 24/7 and help address labor shortages [5]. To meet these demands, two autonomous electric ground vehicle types are gaining attention in courier services: droids and robotic vans. Droids are small autonomous vehicles that move slowly on sidewalks and pedestrian zones. While still supervised and limited by range and capacity, they offer potential for short, urgent, and unpredictable deliveries. Their use does not require specific road infrastructure, but relies on digital tools such as mobile apps, strong internet access, and software capable of handling delivery adjustments. This dependence on digitalization poses challenges in user interaction and accessibility, especially for broader adoption. In addition to droid technologies, robotic vans represent a more robust autonomous delivery model. These driverless electric vehicles support shipment consolidation, reduce human error, and lower emissions, noise, and operational costs. They offer flexible services tailored to customer preferences and delivery windows. However, their adoption is hindered by limited charging infrastructure, unclear policy support, and low public awareness. Despite these limitations, robotic vans are designed for integration with other autonomous systems and are considered key components of future logistics networks [43].

Drones **(A_4)** relieve road traffic by transferring part of transportation to the air. They require only an operator and can be equipped with automated loading and unloading devices. Their use in urban LML can improve service speed, network flexibility, and environmental performance. However, challenges include noise emissions, cargo security risks, safety concerns for people and objects below flight paths, and underdeveloped regulations [44]. Drones avoid road congestion and use electric motors, making them environmentally friendly. Still, weather conditions, complex urban settings, and end-user identification require careful consideration for successful implementation. Studies in Europe suggest drones could cover up to 7% of LMLs, with Italy reaching 20% coverage in optimal scenarios. Two delivery models exist [45]: (i) autonomous drones that depart from and return to a depot, and (ii) drones linked to a van acting as a mobile depot and charging station, shifting the routing problem from the Traveling Salesman Problem to the Clustered General Traveling Salesman Problem. Drones are becoming an attractive solution for express deliveries within the growing e-commerce market, supporting guaranteed timeframes and high service quality. Companies like Amazon, Google, and DHL have been pioneers in testing and implementing drones for LML [5].

***Electric freight vehicles* (A_5)** use energy from batteries, external infrastructure, or fuel cells. While batteries are expensive, heavy, and have limited range and long charging times, electric vehicles are well suited for short-distance distribution with low speeds. They produce no harmful emissions and operate with minimal noise, but high costs require subsidies to encourage wider adoption. Studies indicate that reducing battery prices by 10–30% would make electric vehicles competitive with conventional vans for urban deliveries. Research from the FREVUE project shows electric vehicles need less maintenance than combustion engines, though challenges remain in repairs and battery charging [44]. The adoption of electric vans (e-vans) in LML can boost electric mobility in the commercial sector. Electrifying high-mileage light commercial vehicles reduces air pollution, energy use, and greenhouse gas emissions more effectively than passenger cars, yet electrification efforts mostly focus on the latter. Major companies like Amazon have invested heavily in e-vans, purchasing thousands of vehicles such as Rivian's electric vans and Mercedes-Benz eSprinters and eVitos, with charging infrastructure expanding accordingly. in recent years, the market for electric LCV (eLCV) has expanded, with logistics operators increasingly adopting them for urban LMLs. Despite high upfront costs, eLCVs offer fuel and maintenance savings, and production scale is expected to lower prices as with electric passenger cars. Total cost of ownership is now comparable to diesel vans in regions with high diesel prices. switching to electric vehicles reduces energy use per kilometer and eliminates tailpipe emissions, while decarbonizing electricity grids further improves environmental benefits. Policy incentives and falling renewable energy costs continue to drive this electrification trend in LML [46].

***Electric trolleys (eTrolleys)* (A_6)** require minimal maintenance and offer a solution to fuel shortages and rising environmental pollution. Besides environmental benefits, they can empower lower socio-economic groups by providing an affordable and comfortable transport option. The eTrolley is favored in last-mile parcel delivery due to low maintenance, fuel costs, quiet operation, and easy maneuverability. Without large physical or financial investments, it offers good income potential for individuals and logistics providers. Experts suggest battery-powered trolleys could supplement low-emission transport for low-income populations lacking mobility. They are more energy-efficient than other motor vehicles and suitable for transporting goods through narrow streets thanks to their size and load capacity. Typical uses include carrying cartons, bottles, water jugs, supplying shops, construction materials, food, and packages. While advantages include green transport, affordability, low maintenance, and employment opportunities, disadvantages include higher electricity consumption due to daily charging and lower maximum speeds compared to other vehicles [47].

The previously described alternatives vary significantly in maturity and feasibility, which crucially shapes their practical applicability within LML systems. These variations also affect the speed and scale at which they can be implemented in real-world logistics operations. For instance, e-bikes (A_1) are among the most mature and widely adopted options due to their flexibility, relatively high speeds, and low costs; however, they pose significant safety risks to riders, largely stemming from aggressive driving behaviors and insufficient regulation [37]. In contrast, cargo bikes (A_2), while less widespread, offer a more environmentally sustainable and quieter option, especially suited for high-density urban areas with short delivery distances [39]. Yet, their lower capacity and speed compared to motorized vehicles necessitate complex logistical arrangements such as the use of micro-depots, involving coordinated efforts between urban planners, government bodies, and logistics providers [40,41]. Autonomous vehicles (A_3) and drones (A_4) represent cutting-edge innovations with the potential to greatly enhance delivery efficiency and reduce human error, but their relative immaturity and unresolved legal and social acceptance issues limit current deployment [43,44]. For example, drones circumvent urban congestion to provide rapid delivery services but face challenges related to noise pollution, safety risks, and lack of comprehensive regulations, unlike e-bikes or cargo bikes that operate within existing traffic frameworks [45]. Meanwhile, autonomous ground vehicles require sophisticated infrastructure and high digital literacy among users, which can hinder scalability. Electric freight vehicles (A_5) and eTrolleys (A_6) stand out for their environmental advantages by significantly reducing emissions and noise pollution, yet they are constrained by high upfront costs, limited battery range, and the need for extensive charging infrastructure [46,47]. Compared to more established solutions like e-bikes, these electric options often rely heavily on supportive policies and investments, highlighting the gap between environmental potential and practical feasibility. In sum, these alternatives exhibit distinct strengths and limitations across technical, operational, environmental, and social dimensions. While e-bikes offer immediate flexibility and cost benefits, cargo bikes and electric freight vehicles excel in sustainability but require complex organizational and infrastructural support. Autonomous vehicles and drones promise transformative impacts but remain in early adoption stages with considerable barriers to overcome. Recognizing these nuanced contrasts is essential to develop realistic and context-sensitive evaluations. It ensures that decision-makers understand the trade-offs involved and can design LML systems that balance efficiency, sustainability, and safety effectively.

4.1.2. Criteria Description

As cities continue to grow, there is an urgent need to improve citizens' quality of life while simultaneously addressing challenges such as increasing demand for urban freight deliveries and environmental sustainability goals. The study by Corti et al. [48] examines how sustainability is addressed when decision-makers and stakeholders evaluate alternative solutions using MCDM methods across various city logistics contexts. This study conducted a multi-stage systematic review to investigate the application of MCDM in the specific multidisciplinary field of city logistics, as well as how sustainability is defined and operationalized. In doing so, the selection of actors and sources, and the chosen criteria are approached holistically, respecting the goal of selecting sustainable LML solutions.

In this paper, the evaluation of alternatives will be carried out based on nine criteria selected from previous research [48–55]. The criteria are defined to reflect all aspects of sustainability, social, economic, and environmental.

***Cost* (C_1)** refers to the financial investments required for the implementation and operation of LML initiatives or solutions. Investment costs are often one of the main barriers to developing and deploying quality solutions. ***CO_2 Emission* (C_2)** focuses on reducing the negative environmental impact of logistics activities and processes through LML solutions. Primarily, this concerns the reduction of fuel consumption by transportation vehicles. ***Congestion* (C_3)** relates to changes in urban traffic congestion due to LML activities.

***Quality of Service* (C_4)**, from a marketing and service management perspective, refers to the evaluation of last-mile service quality by the end users. For instance, when users experience failure in face-to-face service delivery, they may boycott such services or provide negative feedback. ***Delivery Speed* (C_5)** has become increasingly important due to the growth of e-commerce. Consumer preferences have shifted in the previously business-oriented parcel delivery market. Major e-commerce players and various startups have identified last-mile services as a key differentiator. The variety of delivery options and perceived delivery quality are crucial decision-making criteria for online customers, directly impacting the success of e-commerce players. Therefore, vendors strive to offer the best possible customer experience, especially by improving delivery times. An increasing number of consumers are willing to pay significant premiums for same-day or instant delivery privileges. ***Delivery Flexibility* (C_6)** is often required to meet rigid delivery deadlines, such as next-day delivery after an order is placed. However, due to the inherent temporal stochasticity in customer orders, this practice may overload the available fleet with long routes and require drivers to work overtime. Potential benefits exist in customer flexibility, where distributors can select delivery days from predefined delivery windows spanning two or more consecutive days. ***Traffic Safety* (C_7)** involves improvements in traffic conditions resulting from a reduction in the number of delivery vehicles deployed. By decreasing the number of transport units participating in urban traffic, congestion is reduced and safety is enhanced. ***Delivery Security* (C_8)** has become increasingly important with rising online shopping demand and a shortage of delivery personnel. Timely home delivery is becoming more challenging. The use of autonomous delivery robots in urban LML is a promising solution to meet these needs. In such an unpredictable environment, ensuring human safety is paramount. Security encompasses the integrity, availability, and confidentiality of location and environmental data, as well as the parcel contents. Both parcel content and robot movements (e.g., collisions with humans) can pose risks to people. Therefore, human safety must be prioritized in this environment. ***Infrastructure Availability* (C_9)** denotes that reduced availability of transportation infrastructure significantly affects highly dependent LML activities, leading to modal shifts in the short term. In such cases, the adoption of alternative transport modes and technologies in distribution becomes justified.

4.1.3. Description of Stakeholders

Stakeholders or participants in LML include all those involved in or affected by the execution of goods flows within a city. Identifying all actors and stakeholder groups, especially those with an indirect impact on urban freight flows, is a complex task. Besides the direct participants in logistics chains (shippers, receivers, and logistics providers), recent research increasingly emphasizes the role and involvement of local authorities as policy makers and decision-makers, as well as end consumers, residents, and city visitors. Each group may hold different perceptions of the problems, objectives, constraints, and opportunities that must be balanced. An additional challenge is the variability of their roles over time [56]. Freight transport is an activity involving multiple stakeholders. Successful approaches to creating sustainable LML solutions are achieved through the inclusion of all stakeholders, i.e., by developing consensus-based strategies. No single stakeholder can find the best solutions to address the various issues influencing the movement of goods in cities. This implies that the engagement of multiple stakeholders in the decision-making process regarding the future direction of LML is essential [29].

Delivery person is a vital but increasingly challenged role in LML due to an aging workforce in many industrialized countries, making recruitment for physically demanding tasks harder. Although automation and alternatives like parcel lockers, drones, or autonomous robots show promise, the final handover by delivery personnel remains crucial for customer satisfaction and trust. This human element is often overlooked in evaluations of last-mile strategies despite its impact on service quality. The typical delivery chain, from depot to van to delivery person to customer, highlights this key role. To ease urban congestion and optimize staffing, two-tier systems with micro-depots and cargo bikes are growing in cities, while parcel lockers reduce the need for attended deliveries [57]. Understanding delivery personnel's tasks is essential to avoid miscommunication and strengthen the system. Maravić et al. [58] showed that market segmentation can improve delivery efficiency by optimizing routes, vehicle loads, and services like parcel insurance aligned with customer behavior. However, while automation can boost efficiency, it risks losing the human touch crucial for customer loyalty, making it necessary to balance technology with human-based strategies for a holistic LML approach.

Transport company plays a central role in managing complex e-commerce distribution, where logistics require time, resources, and costs. Companies must decide whether to handle distribution internally or outsource to logistics service providers [59]. These providers, including third-party logistics companies, freight forwarders, and in-house logistics systems, are responsible for urban goods flows, aiming to reduce costs while maximizing service reliability and sales. To stay competitive, providers expand services and improve delivery quality through demand consolidation, route optimization, and cost reduction. However, they face significant challenges like traffic congestion, access restrictions, narrow streets, parking issues, and regulations that limit service improvements. Large fleets are often underutilized and delayed by unpredictable urban traffic, increasing costs and pushing prices up, which may cause customer dissatisfaction. Moreover, these operations create negative externalities such as pollution and traffic hazards, leading to calls for internalizing these costs in pricing. Still, despite these issues, there is potential for optimization through collaboration and innovative logistics focused on efficiency and sustainability [56]. The reliance on extensive vehicle fleets and cost pressures may limit transport companies' ability to fully embrace more sustainable or socially responsible practices, pointing to the need for integrated approaches that balance operational efficiency with broader environmental and social concerns.

Customers living, working, and shopping in urban areas often view the presence of delivery vehicles in residential and commercial zones as undesirable. They want convenient access to products and services while minimizing traffic congestion, noise, air pollution, and safety risks near their homes and workplaces. Freight transport significantly contributes to congestion, extending travel times and causing dissatisfaction. Deliveries scheduled during off-peak hours, especially at night, introduce noise disturbances, further aggravating residents. Additionally, delivery vehicles can degrade the visual quality of urban environments. Health organizations highlight that transport-related impacts, especially from freight traffic, reduce quality of life and life expectancy in some cities. As end-users generating demand for deliveries, customers may express discontent to local authorities when negative externalities of LML exceed acceptable limits [56]. This tension reveals the challenge in balancing efficient delivery services with urban livability, underscoring the need for last-mile strategies that respect both consumer convenience and community well-being.

Local authorities are responsible for improving residents' quality of life while promoting economic and environmental development. They should coordinate urban logistics and mediate stakeholder conflicts by developing strategies that balance various interests. This requires dedicated sectors to monitor and supervise logistics activities, ideally working with experts and academia to propose effective solutions. However, many administrations lack the expertise and organizational structures needed, with few having specialized officers for urban freight planning, which weakens cooperation and limits their role mostly to handling complaints [56]. At the same time, digital platforms enable companies to outsource logistics tasks to individuals, tapping into private resources for transportation and warehousing needs. Although promising, these models are still emerging and require stronger regulatory frameworks. Therefore, local authorities must actively develop policies, standards, and support systems to fully realize the potential of these innovative logistics solutions [60,61].

4.2. Results

In the following section, the results of the model application will be presented. These results will be shown from the perspective of four previously defined stakeholders. This approach allows a clear insight into the preferences among the stakeholders during the decision-making process.

4.2.1. Results of Model Application—Delivery Person Perspective

As mentioned earlier, the FAHP method was applied to determine the weights of the defined criteria. Table 3 provides the input data used in this process. It is important to emphasize that the perspective of the delivery person was respected in this analysis. Regarding the input data, the criteria were pairwise compared in terms of importance/significance using a linguistic scale (Table 2). The consistency of the pairwise comparison matrix was verified, yielding a maximum eigenvalue (Z_{max}) of approximately 9.2043, a CI of 0.0280, and a CR of 0.0193, which is well below the acceptable threshold of 0.1, confirming the reliability of the comparisons.

Table 3. Input data for the FAHP (Delivery Person Perspective).

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	VP	SP	QP	MP	QP	SP	QP	SP
C_2		1	PP	MP	QP	RP	QP	MP	EI
C_3			1	RP	QP	MP	QP	QP	BP
C_4				1	SP	PP	MP	MP	VP
C_5					1	RP	MP	RP	BP
C_6						1	QP	MP	MP
C_7							1	QP	RP
C_8								1	QP
C_9									1

Using Equations (1)–(9), the criteria weights were calculated from the delivery person's perspective (Table 4). Among all the criteria, Cost (C_1) emerged as the most significant. On the other hand, Traffic Safety (C_7), Delivery Security (C_8), and Infrastructure Availability (C_9) were assigned relatively low weights, indicating that these factors are considered less important from this particular viewpoint.

Table 4. Criteria weights (Delivery Person Perspective).

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Weights	0.372	0.167	0.123667	0.1285	0.06	0.058667	0.036333	0.0305	0.023333

Since the criteria weights have been determined using the FAHP method, the next step involves applying the EDAS method to rank the predefined alternatives. This process begins with the construction of the initial decision matrix (Equation (11)). Based on expert evaluations (from five industry experts), the decision matrix has been developed specifically from the delivery person's perspective (Table 5).

Table 5. Initial decision-making matrix (Delivery Person Perspective).

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	2	2	2	6	6	9	6	6	7
A_2	1	1	1	5	5	8	7	5	6
A_3	6	5	5	4	8	3	8	8	3
A_4	5	3	2	4	9	7	3	7	4
A_5	7	5	6	7	7	5	7	8	8
A_6	3	3	3	5	5	5	7	6	6

By applying Equations (11) and (12), the average solution (AV) was first calculated from the delivery person's perspective (Table 6). The highest AV values were recorded for Delivery Speed (C_5) and Delivery Security (C_8), indicating their strong performance relative to other criteria. On the other hand, the lowest AV values were associated with CO_2 Emissions (C_2) and Congestion (C_3), highlighting their comparatively poor performance in this context.

Table 6. Average solution (Delivery Person Perspective).

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
AV	4.00	3.17	3.17	5.17	6.67	6.17	6.33	6.67	5.67

After calculating the AV, the next step in the EDAS method involves determining the Positive Distance from Average (PDA) from the delivery person's perspective. This was done using Equation (13). It is important to note that the nature of each criterion (i.e., whether it is to be maximized or minimized) was taken into account in this step. Accordingly, Equations (15) and (16) were applied for benefit-type criteria, while Equations (17) and (18) were used for cost-type criteria. The results of this phase are presented in Table 7.

Table 7. Positive distance from average (PDA) (Delivery Person Perspective).

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.50	0.37	0.37	0.16	0.00	0.46	0.00	0.00	0.24
A_2	0.75	0.68	0.68	0.00	0.00	0.30	0.11	0.00	0.06
A_3	0.00	0.00	0.00	0.00	0.20	0.00	0.26	0.20	0.00
A_4	0.00	0.05	0.37	0.00	0.35	0.14	0.00	0.05	0.00
A_5	0.00	0.00	0.00	0.35	0.05	0.00	0.11	0.20	0.41
A_6	0.25	0.05	0.05	0.00	0.00	0.00	0.11	0.00	0.06

Similar to the previous step, the Negative Distance from Average (NDA) was determined from the delivery person's perspective, using Equation (14). As before, it was necessary to account for the type of each criterion (maximization/minimization), and accordingly, Equations (15) and (16) were applied for benefit criteria and Equations (17) and (18) for cost criteria. The obtained results are presented in Table 8.

The next phase of the EDAS method involves calculating the Weighted Sum of PDA (SP) and the Weighted Sum of NDA (SN), again from the delivery person's perspective. These were calculated using Equations (19) and (20), respectively. The results are shown in Table 9.

Table 8. Negative distance from average (NDA) (Delivery Person Perspective).

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.00	0.00	0.00	0.00	0.10	0.00	0.05	0.10	0.00
A_2	0.00	0.00	0.00	0.03	0.25	0.00	0.00	0.25	0.00
A_3	0.50	0.58	0.58	0.23	0.00	0.51	0.00	0.00	0.47
A_4	0.25	0.00	0.00	0.23	0.00	0.00	0.53	0.00	0.29
A_5	0.75	0.58	0.89	0.00	0.00	0.19	0.00	0.00	0.00
A_6	0.00	0.00	0.00	0.03	0.25	0.19	0.00	0.10	0.00

Table 9. Weighted sum of PDA and weighted sum of NDA (Delivery Person Perspective).

Alternatives	SP	SN
A_1	0.35	0.01
A_2	0.50	0.03
A_3	0.03	0.42
A_4	0.08	0.15
A_5	0.07	0.50
A_6	0.11	0.03

After computing SP and SN, the following step includes their normalization, resulting in the Normalized SP and SN values, calculated using Equations (21) and (22). These values are presented in Table 10.

Table 10. Normalized SP and SN (Delivery Person Perspective).

Alternatives	NSP	NSN
A_1	0.69	0.98
A_2	1.00	0.95
A_3	0.06	0.15
A_4	0.17	0.70
A_5	0.14	0.00
A_6	0.23	0.93

The final output of the EDAS method is the Appraisal Score (AS), which is used to rank the previously defined alternatives from the delivery person's perspective. The AS was computed using Equation (23). According to the results, the manual cargo bike (A_2) emerged as the best-rated alternative, followed by the electric bike (A_1), while the electric freight vehicle (A_5) received the lowest score (Table 11).

Table 11. Appraisal score and ranking (Delivery Person Perspective).

Alternatives	AS	Ranking
A_1	0.83	2
A_2	0.97	1
A_3	0.10	5
A_4	0.44	4
A_5	0.07	6
A_6	0.58	3

4.2.2. Results of Model Application—Transport Company Perspective

As previously stated, in order to determine the criteria weights, the FAHP method needs to be applied. The input data for this process, based on the transport company's perspective, are presented in Table 12. Again, the criteria were compared pairwise in terms of their relative importance using the linguistic scale shown in Table 2. The consistency of the pairwise comparison matrix was verified, yielding a maximum eigenvalue (Z_{max}) of approximately 9.2557, a CI of 0.0320, and a CR of 0.0221, which is well below the acceptable threshold of 0.1, confirming the reliability of the comparisons.

Table 12. Input data for the FAHP (Transport Company Perspective).

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	SP	VP	PP	QP	QP	VP	SP	SP
C_2		1	MP	MP	RP	RP	BP	BP	RP
C_3			1	BP	RP	RP	BP	RP	QP
C_4				1	PP	QP	PP	PP	SP
C_5					1	QP	SP	PP	SP
C_6						1	PP	SP	PP
C_7							1	MP	MP
C_8								1	MP
C_9									1

By applying Equations (1)–(9), the criteria weights from the transport company's perspective were obtained and are presented in Table 13. Among all, Cost (C_1) was identified as the most significant criterion. In contrast, Traffic Safety (C_7), Delivery Security (C_8), and Infrastructure Availability (C_9) received similarly low weights.

Table 13. Criteria weights (Transport Company Perspective).

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Weights	0.395	0.1365	0.101167	0.132167	0.090667	0.063667	0.037667	0.027167	0.016

After determining the criteria weights using the FAHP method, the process continues with the application of the EDAS method to rank the defined alternatives. This begins with the construction of the initial decision matrix, based on Equation (11). The matrix, developed using expert evaluations, reflects the transport company's perspective and is shown in Table 14.

Table 14. Initial decision-making matrix (Transport Company Perspective).

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	2	2	2	7	6	8	7	6	7
A_2	1	1	1	6	5	7	7	5	6
A_3	5	5	6	8	9	6	6	8	3
A_4	4	3	2	7	9	9	4	7	4
A_5	6	5	6	8	7	6	7	8	8
A_6	3	3	3	6	5	5	6	6	6

By applying Equations (11) and (12), the average solution (AV) was first calculated from the transport company's perspective (Table 15). The highest AV value was recorded for Quality of Service (C_4), indicating its strong relative performance. In contrast, the lowest AV values were observed for CO_2 Emissions (C_2) and Congestion (C_3).

Table 15. Average solution (Transport Company Perspective).

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
AV	3.50	3.17	3.33	7.00	6.83	6.83	6.17	6.67	5.67

Following the determination of the average values, the next step of the EDAS method involves calculating the positive distance from average (PDA) from the transport company's perspective. Equation (13) was used for this purpose. It is important to emphasize that the nature of the criteria (i.e., whether they are of maximization or minimization type) must be respected. Accordingly, Equations (15) and (16) or (17) and (18) were applied where appropriate. The resulting values are presented in Table 16.

Table 16. Positive distance from average (PDA) (Transport Company Perspective).

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.43	0.37	0.40	0.00	0.00	0.17	0.14	0.00	0.24
A_2	0.71	0.68	0.70	0.00	0.00	0.02	0.14	0.00	0.06
A_3	0.00	0.00	0.00	0.14	0.32	0.00	0.00	0.20	0.00
A_4	0.00	0.05	0.40	0.00	0.32	0.32	0.00	0.05	0.00
A_5	0.00	0.00	0.00	0.14	0.02	0.00	0.14	0.20	0.41
A_6	0.14	0.05	0.10	0.00	0.00	0.00	0.00	0.00	0.06

In a similar manner, the negative distance from average (NDA) was calculated from the transport company's perspective, this time using Equation (14). Once again, the criterion type was taken into account, and Equations (15) and (16) or (17) and (18) were used as appropriate. The results are summarized in Table 17.

Table 17. Negative distance from average (NDA) (Transport Company Perspective).

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.10	0.00
A_2	0.00	0.00	0.00	0.14	0.27	0.00	0.00	0.25	0.00
A_3	0.43	0.58	0.80	0.00	0.00	0.12	0.03	0.00	0.47
A_4	0.14	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.29
A_5	0.71	0.58	0.80	0.00	0.00	0.12	0.00	0.00	0.00
A_6	0.00	0.00	0.00	0.14	0.27	0.27	0.03	0.10	0.00

The next step of the EDAS method involves calculating the weighted sum of PDA (SP) and the weighted sum of NDA (SN) from the transport company's perspective. Accordingly, Equations (19) and (20) were applied. The obtained results are presented in Table 18.

Table 18. Weighted sum of PDA and weighted sum of NDA (Transport Company Perspective).

Alternatives	SP	SN
A_1	0.28	0.01
A_2	0.45	0.05
A_3	0.05	0.35
A_4	0.10	0.07
A_5	0.04	0.45
A_6	0.07	0.06

After determining the SP and SN values, the process continues with the normalization step, where the normalized SP and SN values are calculated from the transport company's perspective. This was done using Equations (21) and (22), and the results are shown in Table 19.

The final output of the EDAS method is the Appraisal Score (AS), which serves to rank the previously defined alternatives from the transport company's perspective. The AS values were determined using Equation (23), and the final ranking is presented in

Table 20. The manual cargo bike (A_2) emerged as the top-rated alternative, followed by the electric bike (A_1). On the other hand, the electric freight vehicle (A_5) was ranked as the least favorable option.

Table 19. Normalized SP and SN (Transport Company Perspective).

Alternatives	NSP	NSN
A_1	0.62	0.97
A_2	1.00	0.89
A_3	0.12	0.23
A_4	0.22	0.83
A_5	0.08	0.00
A_6	0.16	0.86

Table 20. Appraisal score and ranking (Transport Company Perspective).

Alternatives	AS	Ranking
A_1	0.79	2
A_2	0.94	1
A_3	0.17	5
A_4	0.53	3
A_5	0.04	6
A_6	0.51	4

4.2.3. Results of Model Application—Customer Perspective

As previously stated, in order to determine the weights of the defined criteria, the Fuzzy AHP method was applied. The input data used in the method's application are provided in Table 21, and the customer perspective was taken into account. When it comes to input data, the criteria were compared pairwise based on their importance, using the linguistic scale presented in Table 2. The consistency of the pairwise comparison matrix was verified, yielding a maximum eigenvalue (Z_{max}) of approximately 9.1859, a CI of 0.0232, and a CR of 0.0160, which is well below the acceptable threshold of 0.1, confirming the reliability of the comparisons.

Table 21. Input data for the FAHP (Customer Perspective).

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	QP	PP	RP	RP	RP	QP	RP	QP
C_2		1	QP	MP	MP	MP	QP	PP	SP
C_3			1	RP	RP	BP	BP	RP	MP
C_4				1	PP	QP	SP	SP	SP
C_5					1	QP	PP	SP	SP
C_6						1	PP	PP	SP
C_7							1	QP	MP
C_8								1	MP
C_9									1

By applying Equations (1)–(9), the criteria weights from the customer perspective were calculated and presented in Table 22. The most important criterion was identified as CO_2 Emission (C_2). In contrast, Infrastructure Availability (C_9) and Delivery Security (C_8) received the lowest weights.

Table 22. Criteria weights (Customer Perspective).

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Weights	0.20916	0.26952	0.11638	0.15723	0.09869	0.06999	0.03729	0.02279	0.01895

With the criteria weights defined using the FAHP method, the process continues with the EDAS method to rank the predefined alternatives. The procedure begins with the construction of the initial decision matrix, based on expert assessments and corresponding to Equation (11). This matrix was developed from the customer's perspective, and is shown in Table 23.

Table 23. Initial decision-making matrix (Customer Perspective).

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	6	2	2	8	6	8	6	7	7
A_2	8	1	1	7	5	6	6	6	6
A_3	5	5	6	9	9	7	7	9	5
A_4	4	3	2	8	9	9	5	8	4
A_5	3	5	6	9	7	6	7	9	8
A_6	7	3	3	7	5	5	6	7	6

By applying Equations (11) and (12), the average solution (AV) was first calculated from the customer perspective (Table 24). The highest AV value was observed for quality of service (C_4), while the lowest values were found for CO_2 Emission (C_2) and Congestion (C_3).

Table 24. Average solution (Customer Perspective).

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
AV	5.5	3.17	3.33	8.00	6.83	6.83	6.17	7.67	6.00

The next step of the EDAS method involved calculating the positive distance from average (PDA) from the customer's perspective, using Equation (13). It is essential to account for the nature of the criteria (i.e., benefit or cost), which determined the use of Equations (15) and (16) or (17) and (18), accordingly. The results of customer perspective are shown in Table 25.

Table 25. Positive distance from average (PDA) (Customer Perspective).

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.00	0.37	0.40	0.00	0.00	0.17	0.00	0.00	0.17
A_2	0.00	0.68	0.70	0.00	0.00	0.00	0.00	0.00	0.00
A_3	0.09	0.00	0.00	0.13	0.32	0.02	0.14	0.17	0.00
A_4	0.27	0.05	0.40	0.00	0.32	0.32	0.00	0.04	0.00
A_5	0.45	0.00	0.00	0.13	0.02	0.00	0.14	0.17	0.33
A_6	0.00	0.05	0.10	0.00	0.00	0.00	0.00	0.00	0.00

Similar to the previous step, the negative distance from average (NDA) was then calculated, this time using Equation (14), again considering the nature of each criterion. The corresponding results are provided in Table 26.

Table 26. Negative distance from average (NDA) (Customer Perspective).

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.09	0.00	0.00	0.00	0.12	0.00	0.03	0.09	0.00
A_2	0.00	0.00	0.00	0.13	0.27	0.12	0.03	0.22	0.00
A_3	0.00	0.58	0.80	0.00	0.00	0.00	0.00	0.00	0.17
A_4	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.33
A_5	0.00	0.58	0.80	0.00	0.00	0.12	0.00	0.00	0.00
A_6	0.00	0.00	0.00	0.13	0.27	0.27	0.03	0.09	0.00

Subsequently, the weighted sums of PDA and NDA were determined, denoted as SP and SN, respectively, from the customer's perspective. These were computed using Equations (19) and (20), with results summarized in Table 27.

Table 27. Weighted sum of PDA and weighted sum of NDA (Customer Perspective).

Alternatives	SP	SN
A_1	0.28	0.05
A_2	0.42	0.11
A_3	0.12	0.44
A_4	0.32	0.04
A_5	0.17	0.45
A_6	0.05	0.12

The process then moved to the normalization phase, in which Normalized SP and SN were determined based on Equations (21) and (22). The results are presented in Table 28.

Table 28. Normalized SP and SN (Customer Perspective).

Alternatives	NSP	NSN
A_1	0.67	0.89
A_2	1.00	0.76
A_3	0.28	0.03
A_4	0.76	0.91
A_5	0.40	0.00
A_6	0.11	0.73

The final output of the EDAS method is the Appraisal Score (AS), used to rank the evaluated alternatives from the customer's perspective. The AS values were computed using Equation (23), and the ranking results are shown in Table 29. The manual cargo bike (A_2) was identified as the top-ranked alternative, followed by the drone (A_4) and the electric bike (A_1). In contrast, the autonomous vehicle (A_3) received the lowest score.

Table 29. Appraisal score and ranking (Customer Perspective).

Alternatives	AS	Ranking
A_1	0.78	3
A_2	0.88	1
A_3	0.15	6
A_4	0.83	2
A_5	0.20	5
A_6	0.42	4

4.2.4. Results of Model Application—Local Authorities' Perspective

As previously stated, in order to determine the weights of the defined criteria, the FAHP method was applied. The input data used for its implementation are presented in Table 30, and the local authorities' perspective was taken into account. The criteria were compared in pairs with respect to their importance using the linguistic scale shown in Table 2. The consistency of the pairwise comparison matrix was verified, yielding a maximum eigenvalue (Z_{max}) of approximately 9.1321, a CI of 0.0165, and a CR of 0.0114, which is well below the acceptable threshold of 0.1, confirming the reliability of the comparisons.

Table 30. Input data for the FAHP (Local Authorities' Perspective).

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	PP	QP	PP	PP	PP	QP	PP	QP
C_2		1	PP	QP	QP	QP	PP	QP	QP
C_3			1	MP	MP	MP	QP	QP	QP
C_4				1	PP	QP	QP	QP	PP
C_5					1	MP	MP	RP	MP
C_6						1	QP	QP	SP
C_7							1	QP	QP
C_8								1	QP
C_9									1

By applying Equations (1)–(9), the criteria weights were calculated from the local authorities' perspective, and the results are presented in Table 31. The most important criteria identified were Cost (C_1) and CO_2 Emission (C_2). On the other hand, Infrastructure Availability (C_9), Delivery Security (C_8), and Traffic Safety (C_7) received relatively low weights.

Table 31. Weights of criteria (Local Authorities' Perspective).

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Weights	0.338	0.218333	0.135833	0.109833	0.063	0.055167	0.036167	0.026333	0.017333

With the criteria weights determined using the FAHP method, the evaluation process proceeded with the application of the EDAS method in order to rank the predefined alternatives. The starting point was the initial decision matrix, constructed based on expert evaluations from the local authorities' perspective and defined in accordance with Equation (11). The matrix is shown in Table 32.

Table 32. Initial decision-making matrix (Local Authorities' Perspective).

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	2	2	2	7	6	8	8	6	7
A_2	1	1	1	6	5	7	8	6	6
A_3	6	5	5	8	9	6	6	8	3
A_4	4	3	2	7	9	9	3	7	4
A_5	7	5	6	8	7	6	7	8	8
A_6	3	3	3	6	5	5	7	6	6

Using Equations (11) and (12), the average solution (AV) was first determined from the local authorities' perspective (Table 33). The highest AV value was observed for Quality of Service (C_4), whereas the lowest AV values were associated with CO_2 Emission (C_2) and Congestion (C_3).

Table 33. Average solution (Local Authorities' Perspective).

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
AV	3.83	3.17	3.17	7.00	6.83	6.83	6.50	6.83	5.67

The next step of the EDAS method involved the calculation of the positive distance from average (PDA) using Equation (13). It is crucial to take into account the nature of each criterion (i.e., benefit or cost), and accordingly, Equations (15) and (16) or (17) and (18) were applied. The results from the local authorities' perspective are shown in Table 34.

Table 34. Positive distance from average (PDA) (Local Authorities' Perspective).

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.48	0.37	0.37	0.00	0.00	0.17	0.23	0.00	0.23
A_2	0.74	0.68	0.68	0.00	0.00	0.02	0.23	0.00	0.06
A_3	0.00	0.00	0.00	0.14	0.32	0.00	0.00	0.17	0.00
A_4	0.00	0.05	0.37	0.00	0.32	0.32	0.00	0.02	0.00
A_5	0.00	0.00	0.00	0.14	0.02	0.00	0.08	0.17	0.41
A_6	0.22	0.05	0.05	0.00	0.00	0.00	0.08	0.00	0.06

Similarly, the negative distance from average (NDA) was calculated using Equation (14), again with careful consideration of each criterion's nature. The results of this step are presented in Table 35.

Table 35. Negative distance from average (NDA) (Local Authorities' Perspective).

Alternatives/Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.12	0.00
A_2	0.00	0.00	0.00	0.14	0.27	0.00	0.00	0.12	0.00
A_3	0.57	0.58	0.58	0.00	0.00	0.12	0.08	0.00	0.47
A_4	0.04	0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.29
A_5	0.83	0.58	0.89	0.00	0.00	0.12	0.00	0.00	0.00
A_6	0.00	0.00	0.00	0.14	0.27	0.27	0.00	0.12	0.00

The subsequent step involved calculating the weighted sums of PDA and NDA, denoted as SP and SN, from the local authorities' perspective. This was done using Equations (19) and (20), with the results provided in Table 36.

Table 36. Weighted sum of PDA and weighted sum of NDA (Local Authorities' Perspective).

Alternatives	SP	SN
A_1	0.31	0.01
A_2	0.50	0.04
A_3	0.04	0.41
A_4	0.10	0.04
A_5	0.03	0.53
A_6	0.10	0.05

Following this, the values of SP and SN were normalized using Equations (21) and (22) to obtain the Normalized SP and SN, also from the local authorities' perspective. The corresponding results are presented in Table 37.

Table 37. Normalized SP and SN (Local Authorities' Perspective).

Alternatives	NSP	NSN
$\mathbf{A_1}$	0.62	0.98
$\mathbf{A_2}$	1.00	0.93
$\mathbf{A_3}$	0.08	0.23
$\mathbf{A_4}$	0.20	0.93
$\mathbf{A_5}$	0.06	0.00
$\mathbf{A_6}$	0.19	0.91

The final output of the EDAS method is the Appraisal Score (AS), which enables the ranking of the evaluated alternatives from the local authorities' perspective. The AS values were calculated using Equation (23), and the resulting rankings are shown in Table 38. The manual cargo bike (A_2) was ranked as the most favorable alternative, followed by the electric bike (A_1). Conversely, the electric freight vehicle (A_5) was evaluated as the least favorable option.

Table 38. Appraisal score and ranking (Local Authorities' Perspective).

Alternatives	AS	Ranking
$\mathbf{A_1}$	0.80	2
$\mathbf{A_2}$	0.97	1
$\mathbf{A_3}$	0.15	5
$\mathbf{A_4}$	0.56	3
$\mathbf{A_5}$	0.03	6
$\mathbf{A_6}$	0.55	4

4.3. Sensitivity Analysis

Although the solution demonstrates a high level of stability across different stakeholder perspectives, it is essential to conduct a sensitivity analysis focusing specifically on changes in the criteria weights. This analysis is particularly important as it provides insights into how shifts in the relative importance of factors can affect the ranking of alternatives. Given the critical role of criteria weighting in LML, such analysis is invaluable for selecting the most appropriate logistics strategy that aligns with the varying priorities of stakeholders.

In the context of sensitivity analysis, four distinct scenarios will be examined to assess the robustness of the ranking results under varying criteria weight distributions. Scenario 1 assumes equal weights for all criteria, serving as a baseline to evaluate the impact of uniform importance across factors. Scenario 2 adopts a logistics-oriented approach, where criteria directly related to logistics performance, specifically delivery speed (C_5), delivery flexibility (C_6), and delivery security (C_8), are assigned higher weights. This scenario aims to explore how emphasizing operational logistics indicators influences alternative rankings. Scenario 3 focuses on transport-oriented factors, granting greater significance to congestion (C_3), traffic safety (C_7), and infrastructure availability (C_9), which are critical from the perspective of transport companies and local authorities. Finally, Scenario 4 prioritizes service quality (C_4) and environmental criteria, such as CO_2 emissions (C_2), highlighting the growing importance of sustainability and customer satisfaction in last-mile logistics decisions.

The analysis of results obtained using the EDAS method from the perspectives of different stakeholder groups demonstrates a high degree of solution stability. This can especially be observed when considering the ranking of the best and worst alternatives. Alternative A_2 consistently holds the first position across all stakeholder groups, indicating its superiority compared to other options. Conversely, alternative A_5 is almost uniformly ranked last, confirming its inferiority. This consistency in the extreme positions provides strong evidence of the reliability of the applied methods and the clarity of the obtained results.

However, the analysis of the middle rankings reveals certain variations, suggesting that different criteria and specific needs of stakeholder groups influence the evaluation of alternatives differently. For instance, alternative A_4 occupies a high position among customers but is ranked somewhat lower by other groups. A similar pattern is observed for alternatives A_1 and A_6, which hold mid-range positions but vary in ranking across the groups. These differences indicate that certain characteristics of the alternatives are valued differently depending on the perspective. This is important for a deeper understanding of the preferences and priorities of each stakeholder group.

From the standpoint of local authorities, who are primarily focused on regulatory compliance, infrastructure compatibility, and safety standards, it is evident that highly ranked alternatives align well with these requirements. The low position of alternative A_5 may result from its inadequacy regarding legislative or infrastructural frameworks, which is critical for decision-making at the public policy level. In contrast, transport companies mainly prioritize cost-effectiveness and operational efficiency, reflected in their preference for alternative A_2, which offers the best balance between price and service quality. The low ranking of A_5 also indicates potentially unfavorable costs or lower reliability of this option.

Customer perception, including evaluations of service quality, availability, and ease of use, significantly influences the positioning of alternatives. The high ratings of alternatives A_2 and A_4 suggest that these options are the most favored among end-users, likely due to their accessibility and quality of experience. On the other hand, alternatives A_3 and A_5 are rated relatively low, which may indicate lower customer satisfaction or inadequacy in meeting user needs. Additionally, delivery personnel, as key service providers, particularly value practicality, safety, and working conditions, which is reflected in their ranking where alternative A_2 dominates as the most suitable option, while A_3 and A_5 are considered less favorable due to potential operational difficulties.

In conclusion, the results reveal stable solutions with clear leading and trailing alternatives, while variations in intermediate rankings reflect stakeholders' diverse priorities and evaluative perspectives. This highlights the importance of considering multiple perspectives to fully understand the strengths and weaknesses of each alternative. Such insights are vital for balanced decisions, as they highlight key factors, regulations, infrastructure, costs, and user perception, that shape the success and acceptability of alternatives.

In line with the principles of a human-centered approach, the criteria weights determined from the customer perspective were used as universal weights (except for Scenario 1, where all criteria have equal weights.) for all stakeholder groups (Table 39). This approach ensures consistency within the ethical and value framework that places the needs of end-users at the core of the decision-making process. Moreover, this decision facilitates conducting sensitivity analysis by enabling the isolated examination of the impact of alternative criteria weight values on the final rankings, without methodological discrepancies between different stakeholder groups. Naturally, any changes regarding the criteria weights will be made according to the defined scenarios.

The results of this analysis are detailed in Table 40, which illustrates the variations in appraisal scores and rankings under each scenario. This approach underscores the complex interplay of factors influencing LML, emphasizing the necessity of adaptive strategies that accommodate diverse priorities and promote sustainable, efficient distribution solutions. Ultimately, these insights provide a valuable foundation for informed decision-making and future policy development.

Table 39. Criteria weights according to different scenarios.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Scenario 1	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111
Scenario 2	0.11638	0.09869	0.06999	0.03729	0.26952	0.20916	0.02279	0.15723	0.01895
Scenario 3	0.11638	0.09869	0.26952	0.06999	0.03729	0.02279	0.20916	0.01895	0.15723
Scenario 4	0.15723	0.26952	0.11638	0.20916	0.09869	0.06999	0.03729	0.02279	0.01895

Table 40. Ranking of alternatives according to different scenarios.

Alternative		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Delivery Person Perspective	A_1	2	2	2	2
	A_2	1	1	1	1
	A_3	6	5	6	5
	A_4	3	4	4	4
	A_5	5	6	5	6
	A_6	4	3	3	3
Transport Company Perspective	A_1	2	2	2	2
	A_2	1	1	1	1
	A_3	5	5	6	5
	A_4	3	3	4	3
	A_5	6	6	5	6
	A_6	4	4	3	4
Customer Perspective	A_1	3	2	3	3
	A_2	1	1	1	1
	A_3	6	5	6	6
	A_4	2	3	2	2
	A_5	5	6	5	5
	A_6	4	4	4	4
Local Authorities' Perspective	A_1	2	2	2	2
	A_2	1	1	1	1
	A_3	5	5	5	5
	A_4	3	3	3	3
	A_5	6	6	6	6
	A_6	4	4	4	4

The results of the sensitivity analysis conducted across four distinct scenarios indicate a high degree of stability in the ranking of the best and worst alternatives within last-mile logistics, further confirming the reliability of the applied evaluation methods. The alternatives cargo bike (A_2) and e-bike (A_1) consistently occupy leading positions across all stakeholder groups and scenarios, highlighting them as the most acceptable and efficient solutions for a wide range of requirements and conditions. Conversely, the electric freight vehicles alternative (A_5) is continuously ranked lowest, indicating its limited applicability and unfavorable perception within the context of the defined criteria and stakeholder priorities.

Variations in the mid-range rankings, particularly for alternatives such as autonomous vehicle (A_3), drones (A_4), and eTrolley (A_6), reflect differing values and priorities among stakeholders, underscoring the need for a deeper analysis of specific characteristics that certain groups consider important. The preferences of delivery personnel and transport companies are highly aligned, focusing on operational efficiency and cost-effectiveness, while customers place greater emphasis on service quality and innovation, as reflected in the higher rankings of alternatives A_4 and A_1. Local authorities, from the perspective of regulatory and infrastructural requirements, emphasize safety and compliance, which is clearly mirrored in the stable ranking of alternatives across all scenarios.

In conclusion, the sensitivity analysis confirms the robustness of the evaluation model and clearly identifies the key alternatives that satisfy diverse criteria and stakeholder interests in last-mile logistics. In this context, the cargo bike (A_2) and e-bike (A_1) represent the most efficient and acceptable solutions from the standpoint of all examined perspectives and criteria scenarios. Simultaneously, significant variations in the middle rankings highlight the importance of a flexible and tailored approach to solution selection, which must consider the specific needs and priorities of different users and actors.

It is recommended to continuously apply sensitivity analyses that monitor changes in criteria weightings to ensure the long-term relevance and adaptability of the selected solutions. Such analyses enable a better understanding of the impact of shifting priorities among different stakeholder groups and assist in identifying stable and vulnerable points in the decision-making process. Additionally, integrating the perspectives of all key actors through participatory and multidisciplinary approaches can significantly contribute to the development of balanced, sustainable, and effective last-mile logistics strategies. This approach allows for better alignment of user experience, operational efficiency, regulatory requirements, and environmental standards, thereby maximizing the overall value and acceptability of logistics solutions.

5. Theoretical and Managerial Implications

Based on the insights presented in the preceding sections, this paper offers substantial theoretical and managerial implications. The identified gap in the literature reveals a notable absence of research focused on the application of logistics strategies in LML that simultaneously accounts for the human factor. Furthermore, only a limited number of studies address this issue while incorporating a wider range of stakeholders in the evaluation of potential solutions.

The model proposed in this research adopts a fundamentally different approach to the selection of logistics strategies for LML by systematically integrating the conflicting objectives and interests of diverse stakeholder groups. By integrating multiple stakeholder perspectives, the study extends existing theoretical models in urban logistics, which traditionally focus on efficiency and cost, toward a more comprehensive view that incorporates social and regulatory dimensions. In the decision-making process, relevant indicators, comprising both the set of alternatives and evaluation criteria, were defined through a combination of insights from the literature and expert knowledge and experience. Additionally, a comprehensive, human-centered approach to LML has not yet been applied to this type of logistics problem, further emphasizing the original contribution of this study. This research lays a solid foundation for the development of future models and the continued exploration of challenges in LML through the lens of this novel approach. Also, this research extends multi-criteria decision-making frameworks by explicitly incorporating human-centered considerations and trade-offs among heterogeneous actors.

The results of this study offer clear managerial implications for those overseeing LML operations in urban environments. Managers must move beyond traditional cost- and efficiency-driven models and adopt a stakeholder-oriented approach that acknowledges the differing priorities of customers, couriers, service providers, and city authorities. This requires the use of structured decision-making tools, such as the proposed MCDM framework, to evaluate complex trade-offs and guide strategic choices. The proposed framework is intended as a decision-support tool to evaluate LML strategies, providing insights that can inform investment considerations. Given that LML is the costliest and least sustainable segment of the supply chain, managerial focus should shift toward innovations that reduce failed deliveries, improve vehicle utilization, and minimize emissions. Furthermore, logistics decision-makers must proactively engage in public–private partnerships and support the integration of smart urban infrastructure to ensure long-term operational resilience. Managers are also encouraged to communicate the value of improved LML services to end users, aligning pricing strategies with service enhancements. By incorporating multiple stakeholder perspectives and sustainability metrics into planning and control, managers can enhance competitiveness while contributing to broader urban policy goals. Although adaptable to peri-urban settings, the framework is most relevant for dense urban environments characterized by high e-commerce demand and diverse stakeholder pressures.

6. Conclusions

In recent years, LML has become increasingly complex, driven by the continual evolution of end-user expectations. On one hand, customers demand high-quality service characterized by timeliness, flexibility, reliability, and delivery security. On the other hand, they also pay close attention to how deliveries are executed, placing emphasis on the adoption of modern technologies, innovative solutions, environmentally friendly transportation modes, and the overall environmental impact of the process, including emissions, noise, and vibrations. Moreover, the presence of the "human factor," most often represented by the delivery person as the final link in the last-mile chain, can strongly influence customers' perceptions of logistics services. Against this backdrop, the competitive landscape of LML has intensified considerably. Logistics service providers are increasingly compelled to optimize both the efficiency and effectiveness of urban freight flows to secure or strengthen their market positions.

To address the growing demands for LML in urban environments, providers are implementing a wide range of logistics strategies. These strategies are highly diverse and context-specific, each offering distinct advantages and disadvantages, as well as varying levels of implementation complexity. One of the key challenges for logistics providers lies in selecting a strategy that not only meets customer requirements but also positively shapes customer perceptions. Beyond this customer-centric perspective, providers must also consider their own operational objectives, the needs of delivery personnel, and regulatory constraints imposed by local authorities.

This study proposes an MCDM model for selecting the most appropriate logistics strategy in response to the rising demand for LML in urban areas. The model integrates the FAHP and the EDAS methods. It evaluates commonly implemented logistics strategies (alternatives) against a comprehensive set of criteria reflecting the three pillars of sustainability, economic, environmental, and social, as well as key performance indicators (KPIs) of logistics service quality.

This study addresses a gap in the literature by evaluating LML strategies using well-defined criteria from the perspectives of delivery personnel, transport companies, customers, and local authorities, each with potentially conflicting objectives. The model helps logistics providers integrate diverse stakeholder interests and emphasizes the importance of the human factor in decision-making. Its simplicity and practical applicability allow managers to select strategies that are efficient, socially responsible, and environmentally sustainable. The approach also promotes transparency and stakeholder engagement through a participatory decision-making process. FAHP results showed that cost was most important for delivery personnel and transport companies, CO_2 emissions were prioritized by customers, and local authorities valued both cost and emissions, while criteria such as infrastructure availability, delivery security, and traffic safety were generally considered less critical.

In the final phase, the EDAS method was employed to rank the alternatives. The results are particularly noteworthy given that the logistics strategies were assessed from the perspectives of different stakeholders.

To validate the robustness of the model and evaluate the sensitivity of the rankings, a sensitivity analysis was conducted from each stakeholder's perspective. This capability allows decision-makers to test the impact of changes in criteria weights or priorities, which may support more informed and resilient strategic choices. A key limitation of this study lies in the contextual scope of the case analysis, as the proposed MCDM model was tested within a specific urban setting, potentially limiting the broader applicability of the results to cities with differing logistical, regulatory, or socio-economic conditions. The primary contribution of this study lies in its comprehensive approach to the examined problem, which, unlike existing research, considers all relevant stakeholder perspectives simultaneously. By doing so, the study integrates the viewpoints of all key actors, who are typically analyzed in isolation in the literature, into a unified decision-making framework. Beyond its academic significance, the study also delivers several practical contributions that can support more inclusive and effective LML strategies.

In terms of future research, the model could be extended or modified by incorporating an expanded set of alternatives or evaluation criteria, reflecting emerging technologies, regulatory changes, or evolving stakeholder expectations in the LML domain. Future research directions include the application of the proposed model to related decision-making problems, as well as the development of new, hybrid models that could further enhance the evaluation of logistics strategies in LML. In addition, field studies aimed at collecting more robust and context-specific input data, followed by a comparison with the results presented in this study, are identified as another important research avenue. Quantifying cost savings as well as emissions also represents a direction for future research. Finally, applying the proposed model to other markets in order to examine potential differences in stakeholder preferences and strategic outcomes also stands out as a relevant direction for future investigation.

Author Contributions: Conceptualization, A.M., M.A. and V.P.; methodology, A.M., M.A. and V.P.; software, A.M., M.A. and V.P.; writing—original draft preparation, A.M., M.A. and V.P.; writing—review and editing, A.M., M.A. and V.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Patella, S.M.; Grazieschi, G.; Gatta, V.; Marcucci, E.; Carrese, S. The Adoption of Green Vehicles in Last Mile Logistics: A Systematic Review. *Sustainability* **2021**, *13*, 6. [CrossRef]
2. Giuffrida, N.; Fajardo-Calderin, J.; Masegosa, A.D.; Werner, F.; Steudter, M.; Pilla, F. Optimization and Machine Learning Applied to Last-Mile Logistics: A Review. *Sustainability* **2022**, *14*, 5329. [CrossRef]
3. Ranieri, L.; Digiesi, S.; Silvestri, B.; Roccotelli, M. A Review of Last Mile Logistics Innovations in an Externalities Cost Reduction Vision. *Sustainability* **2018**, *10*, 782. [CrossRef]

4. Pahwa, A.; Jaller, M. Assessing the sustainability of last-mile distribution strategies to manage expedited shipping with dynamic and stochastic demand. *Transp. Res. E: Logist. Transp. Rev.* **2025**, *201*, 104273. [CrossRef]
5. Engesser, V.; Rombaut, E.; Vanhaverbeke, L.; Lebeau, P. Autonomous Delivery Solutions for Last-Mile Logistics Operations: A Literature Review and Research Agenda. *Sustainability* **2023**, *15*, 2774. [CrossRef]
6. Demir, E.; Syntetos, A.; van Woensel, T. Last mile logistics: Research trends and needs. *IMA J. Manag. Math.* **2022**, *33*, 549–561. [CrossRef]
7. Gevaers, R.; Van de Voorde, E.; Vanelslander, T. Characteristics of innovations in last mile logistics—Using best practices, case studies and making the link with green and sustainable logistics. In Proceedings of the European Transport Conference, Leiden, The Netherlands, 5–7 October 2009.
8. Lim, S.F.W.T.; Jin, X.; Singh Srai, J. Consumer-driven e-commerce: A literature review, design framework, and research agenda on last-mile logistics models. *Int. J. Phys. Distrib. Logist. Manag.* **2018**, *48*, 308–332. [CrossRef]
9. Guo, X.; Lujan Jaramillo, Y.J.; Bloemhof-Ruwaard, J.; Claassen, G.D.H. On integrating crowdsourced delivery in last-mile logistics: A simulation study to quantify its feasibility. *J. Clean. Prod.* **2019**, *241*, 118365. [CrossRef]
10. Andrejić, M.; Pajić, V.; Kilibarda, M. Distribution Channel Selection Using FUCOM-ADAM: A Novel Approach. *Sustainability* **2023**, *15*, 14527. [CrossRef]
11. Sangkhiew, N.; Pornsing, C.; Ohmori, S.; Watanasungsuit, A. An Integrated fuzzy AHP-TOPSIS for the Last Mile Delivery Mode Selection. *Sci. Technol. Asia* **2022**, *27*, 265–280. [CrossRef]
12. Le Pira, M.; Marcucci, E.; Gatta, V.; Inturri, G.; Ignaccolo, M.; Pluchino, A. Integrating discrete choice models and agent-based models for ex-ante evaluation of stakeholder policy acceptability in urban freight transport. *Res. Transp. Econ.* **2017**, *64*, 13–25.
13. Wang, C.N.; Nguyen, N.A.T.; Dang, T.T.; Hsu, H.P. Evaluating Sustainable Last-Mile Delivery (LMD) in B2C E-Commerce Using Two-Stage Fuzzy MCDM Approach: A Case Study from Vietnam. *IEEE Access* **2021**, *9*, 146050–146067. [CrossRef]
14. Pourmohammadreza, N.; Akbari Jokar, M.R. A Novel Two-Phase Approach for Optimization of the Last-Mile Delivery Problem with Service Options. *Sustainability* **2023**, *15*, 8098. [CrossRef]
15. Büyüközkan, G.; Uztürk, D. Smart Last Mile Delivery Solution Selection for Cities. In Proceedings of the World Congress on Engineering, WCE, London, UK, 3–5 July 2019.
16. Szmelter-Jarosz, A.; Rześny-Cieplińska, J. Priorities of Urban Transport System Stakeholders According to Crowd Logistics Solutions in City Areas. A Sustainability Perspective. *Sustainability* **2020**, *12*, 317. [CrossRef]
17. Švadlenka, L.; Simić, V.; Dobrodolac, M.; Lazarević, D.; Todorović, G. Picture Fuzzy Decision-Making Approach for Sustainable Last-Mile Delivery. *IEEE Access* **2020**, *8*, 209393–209414. [CrossRef]
18. Simić, V.; Lazarević, D.; Dobrodolac, M. Picture fuzzy WASPAS method for selecting last-mile delivery mode: A case study of Belgrade. *Eur. Transp. Res. Rev.* **2021**, *13*, 43. [CrossRef] [PubMed]
19. Gatta, V.; Marcucci, E.; Delle Site, P.; Le Pira, M.; Carrocci, C.S. Planning with stakeholders: Analysing alternative off-hour delivery solutions via an interactive multi-criteria approach. *Res. Transp. Econ.* **2019**, *73*, 53–62. [CrossRef]
20. Melkonyan, A.; Gruchmann, T.; Lohmar, F.; Kamath, V.; Spinler, S. Sustainability assessment of last-mile logistics and distribution strategies: The case of local food networks. *Int. J. Prod. Econ.* **2020**, *228*, 107746. [CrossRef]
21. Gonzalez, J.N.; Natalia Sobrino, N.; Vassallo, J.M. Considering the city context in weighting sustainability criteria for last-mile logistics solutions. *Int. J. Logist. Res. Appl.* **2025**, *28*, 380–400. [CrossRef]
22. Wang, C.N.; Chung, Y.C.; Wibowo, F.D.; Dang, T.T.; Nguyen, N.A.T. Sustainable Last-Mile Delivery Solution Evaluation in the Context of a Developing Country: A Novel OPA–Fuzzy MARCOS Approach. *Sustainability* **2023**, *15*, 12866. [CrossRef]
23. Garus, A.; Alonso, B.; Alonso Raposo, M.; Grosso, M.; Krause, J.; Mourtzouchou, A.; Ciuffo, B. Last-mile delivery by automated droids. Sustainability assessment on a real-world case study. *Sustain. Cities Soc.* **2022**, *79*, 103728. [CrossRef]
24. Kijewska, K.; Torbacki, W.; Iwan, S. Application of AHP and DEMATEL Methods in Choosing and Analysing the Measures for the Distribution of Goods in Szczecin Region. *Sustainability* **2018**, *10*, 2365. [CrossRef]
25. Harrington, T.S.; Singh Srai, J.; Kumar, M.; Wohlrab, J. Identifying design criteria for urban system 'last-mile' solutions—A multi-stakeholder perspective. *Prod. Plan. Control* **2016**, *27*, 456–476. [CrossRef]
26. Aljohani, K.; Thompson, R.G. A Stakeholder-Based Evaluation of the Most Suitable and Sustainable Delivery Fleet for Freight Consolidation Policies in the Inner-City Area. *Sustainability* **2019**, *11*, 124. [CrossRef]
27. Rześny-Cieplińska, J.; Szmelter-Jarosz, A. Assessment of the Crowd Logistics Solutions—The Stakeholders' Analysis Approach. *Sustainability* **2019**, *11*, 5361. [CrossRef]
28. Mishra, S. Industry Acceptance of Alternative Delivery Methods for Last Mile Distribution. Master's Thesis, Universidad Polytechnic de Cataluña, Barcelona, Spain, 2023.
29. Wątróbski, J.; Małecki, K.; Kijewska, K.; Iwan, S.; Karczmarczyk, A.; Thompson, R.G. Multi-Criteria Analysis of Electric Vans for City Logistics. *Sustainability* **2017**, *9*, 1453. [CrossRef]
30. Saaty, T.L. *The Analytic Hierarchy Process*; McGraw Hill: New York, NY, USA, 1980; p. 287.

31. Ecer, F. Third-party logistics (3PLs) provider selection via Fuzzy AHP and EDAS integrated model. *Technol. Econ. Dev. Econ.* **2018**, *24*, 615–634. [CrossRef]
32. Holecek, P.; Talašová, J. A free software tool implementing the fuzzy AHP method. In Proceedings of the 34th International Conference on Mathematical Methods in Economics, Liberec, Czech Republic, 6–9 September 2016; Volume 6, pp. 266–271.
33. Wang, Y.M.; Chin, K.S. Fuzzy analytic hierarchy process: A logarithmic fuzzy preference programming methodology. *Int. J. Approx. Reason.* **2011**, *52*, 541–553. [CrossRef]
34. Wind, Y.; Saaty, T.L. Marketing applications of the analytic hierarchy process. *Manag. Sci.* **1980**, *26*, 641–658. [CrossRef]
35. Keshavarz Ghorabaee, M.; Zavadskas, E.K.; Olfat, L.; Turskis, Z. Multi-criteria inventory classification using a new method of evaluation based on distance from average solution (EDAS). *Informatica* **2015**, *26*, 435–451. [CrossRef]
36. Torkayesh, A.E.; Deveci, M.; Karagoz, S.; Antucheviciene, J. A state-of-the-art survey of evaluation based on distance from average solution (EDAS): Developments and applications. *Expert Syst. Appl.* **2023**, *221*, 119724. [CrossRef]
37. Ilin, V.; Veličković, M.; Garunović, N.; Simić, D. Last-mile delivery with electric vehicles, unmanned aerial vehicles, and e-scooters and e-bikes. *J. Road Traffic Eng.* **2023**, *69*, 37–42. [CrossRef]
38. Institute for Transportation & Development Policy. As E-Bikes Surge, We Need to Address Both the Opportunities and Challenges. Available online: https://itdp.org/2025/03/04/e-bikes-surge-we-need-to-address-both-opportunities-and-challenges-stmagazine-36/ (accessed on 20 June 2025).
39. Ceccato, R.; Gastaldi, M. Last mile distribution using cargo bikes: A simulation study in Padova. *Eur. Transp. Trasp. Eur.* **2023**, *90*, 1–11. Available online: https://www.istiee.unict.it/sites/default/files/files/ET_2023_90_3.pdf (accessed on 20 June 2025). [CrossRef]
40. Llorca, C.; Moeckel, R. Assesment of the potential of cargo bikes and electrification for last-mile parcel delivery by means of simulation of urban freight flows. *Eur. Transp. Res. Rev.* **2021**, *13*, 33. [CrossRef]
41. Michalakopoulou, K.; Vann Yaroson, E.; Chatziioannou, I. Decoding cargo bikes' potential to be a sustainable last-mile delivery mode: An operations management perspective. *Transp. Plan. Technol.* **2025**, *48*, 712–734. [CrossRef]
42. Ritzer, P.; Geischberger, J.; Adeniran, I.O.; Thaller, C. Traffic impact on last mile parcel delivery with cargo bikes. *Transp. Res. Procedia* **2023**, *72*, 3656–3663. [CrossRef]
43. Dabić-Miletić, S. Autonomous vehicles as an essential component of industry 4.0 for meeting last-mile logistics requirements. *J. Ind. Intell.* **2023**, *1*, 55–62. [CrossRef]
44. Tadić, S. Inicijative city logistike za centralne urbane zone. *Teh. Menadžment* **2019**, *69*, 585–594. (In Serbian)
45. Borghetti, F.; Caballini, C.; Carboni, A.; Grossato, G.; Maja, R.; Barabino, B. The Use of Drones for Last-Mile Delivery: A Numerical Case Study in Milan, Italy. *Sustainability* **2022**, *14*, 1766. [CrossRef]
46. International Transport Forum. How Urban Delivery Vehicles can Boost Electric Mobility. © OECD/ITF 2020. Available online: https://www.itf-oecd.org/sites/default/files/docs/urban-delivery-vehicles-boost-electric-mobility.pdf (accessed on 25 May 2025).
47. Ranjan Behera, G.; Anand Babu, D.; Patil, P.N. A Review on Design of an Electric Trolley. *United Int. J. Res. Technol.* **2021**, *2*, 108–111.
48. Corti, F.; D'Alpaos, C.; Greco, L. Multicriteria evaluation of sustainability in last-mile logistics: A review. *Valori E Valutazioni* **2024**, *36*, 125–147. [CrossRef]
49. Tadić, S.; Zečević, S.; Krstić, M. Održivost inicijativa city logistike. In Proceedings of the LOGIC, 3rd Logistics International Conference, Belgrade, Serbia, 25–27 May 2017. (In Serbian).
50. Tadić, S.; Zečević, S.; Krstić, M. Assessment of the political city logistics initiatives sustainability. *Transp. Res. Procedia* **2018**, *30*, 285–294. [CrossRef]
51. Awasthi, A.; Chauhan, S.S. A hybrid approach integrating affinity diagram, AHP, and fuzzy TOPSIS for sustainable city logistics planning. *Appl. Math. Model.* **2012**, *36*, 573–584. [CrossRef]
52. Inoue, Y.; Hashimoto, M. Significance of face-to-face service quality in last mile delivery for e-commerce platforms. *Transp. Res. Interdiscip. Perspect.* **2023**, *21*, 100885. [CrossRef]
53. Izadkhah, A.; Subramanyam, A.; Lainez-Aguirre, J.M.; Pinto, J.M.; Gounaris, C.E. Quantifying the impact of delivery day flexibility on last-mile delivery costs. *Digit. Chem. Eng.* **2022**, *5*, 100057. [CrossRef]
54. Kolb, C.; Xie, L. Security and Safety in Urban Environments: Evaluating Threats and Risks of Autonomous Last-Mile Delivery Robots. In *Computer Safety, Reliability, and Security*; AFECOMP 2024, Lecture Notes in Computer Science; Ceccarelli, A., Trapp, M., Bondavalli, A., Schoitsch, E., Gallina, B., Bitsch, F., Eds.; Springer: Cham, Switzerland, 2024; Volume 14989. [CrossRef]
55. Wehrle, R.; Gast, J.; Wiens, M.; Schultmann, F. On the influence of infrastructure availability on companies decisions toward modal shift and relocation of falicities. *Transp. Res. Interdiscip. Perspect.* **2023**, *19*, 100818. [CrossRef]
56. Tadić, S. Integrated City Logistics Solutions Performance Modelling. Ph.D. Thesis, Faculty of Transport and Traffic Engineering, University of Belgrade, Belgrade, Serbia, 2014. (In Serbian).

57. Boysen, N.; Fedtke, S.; Schwerdfeger, S. Last-mile delivery concepts: A survey from an operational research perspective. *OR Spectr.* **2021**, *43*, 1–58. [CrossRef]
58. Maravić, A.; Andrejić, M.; Pajić, V. Strategic Optimization of Parcel Distribution in E-Commerce: A Comprehensive Analysis of Logistic Flows and Vehicle Selection Using SWARA-WASPAS Methods. *Int. J. Knowl. Innov. Stud.* **2024**, *2*, 190–207. [CrossRef]
59. Maravić, A.; Pajić, V.; Andrejić, M. Evaluating the Role of Couriers in E-commerce Delivery: A Performance-Based Ranking Model for Optimising Logistics Efficiency. *J. Organ. Technol. Entrep.* **2025**, *3*, 1–18. [CrossRef]
60. Nakalamić, M.; Pajić, V.; Andrejić, M. Exploring the Attitudes of Couriers in Crowdsourced Delivery Systems: A Study on Operational Challenges and Platform Dynamics. *J. Urban Dev. Manag.* **2024**, *3*, 288–309. [CrossRef]
61. Kozoderović, J.; Andrejić, M.; Pajić, V. Strategic Selection of Crowd Logistics Platforms: A Multi-Criteria Decision-Making Approach. *Mechatron. Intell. Transp. Syst.* **2024**, *3*, 235–253. [CrossRef]