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CRITICAL REVIEW OF OPTIMIZATION MODELS AND CROWDSOURCING STRATEGIES FOR LAST-MILE LOGISTICS EFFICIENCY IN MEGALOPOLITAN AREAS

Kenny Ryans Alexia[1], Alberta Ingriana[2]

[1] Digital Business Department, Faculty of Social Science and Humanities, Universitas Bunda Mulia, Indonesia

[2] Management Department, Faculty of Management and Business Science, Universitas Dinamika Bangsa, Indonesia

E-mail: [1)] s35230002@student.ubm.ac.id , [2)] alberta.ingriana@unama.ac.id

ABSTRACT

The explosive growth of e-commerce, coupled with rapid urbanization, has rendered last-mile logistics (LML) in megalopolitan areas a critical nexus of inefficiency, cost, and environmental strain. This systematic literature review (SLR) addresses the acute challenges of urban LML by synthesizing contemporary research (2020–2024) on the integration of advanced optimization models and crowdsourcing strategies. The objective is to identify dominant models, understand their integration with crowdsourced labor, and evaluate their impact on logistics efficiency. This review adheres to the PRISMA 2020 guidelines, analyzing 16 high-impact studies retrieved from the Scopus and Web of Science databases. The synthesis reveals two significant trends. First, optimization has evolved beyond classic Vehicle Routing Problems (VRPs) to embrace AI-driven dynamic routing and complex Mixed-Integer Linear Programming (MILP) formulations for managing hybrid assets, such as truck-drone systems (Shavarani et al., 2023; Madani et al., 2023). Second, the integration of crowdsourcing has matured from a simple gig-economy model into a sophisticated socio-technical optimization challenge, requiring novel frameworks that account for the behavioral uncertainty of workers, such as rejection probability and incentive design (Hou et al., 2022; Huang et al., 2020). The findings confirm that these integrated models yield significant improvements in cost-effectiveness, delivery success rates, and sustainability (Cao et al., 2025; Chen et al., 2022; Hou et al., 2022). However, this review also highlights persistent challenges in computational scalability and a significant research gap concerning the social sustainability and equity of the crowdsourced workforce (Lee & Song, 2024).

Keywords: **Crowdsourcing, E-commerce, Last-Mile, Optimization, Urban Logistics**

1. INTRODUCTION

1.1. Background: The Megalopolitan Last-Mile Crisis

Last-mile logistics (LML), defined as the final segment of the supply chain that transports goods from a distribution hub to the end customer, represents the most complex, costly, and inefficient component of modern distribution (Mohammad et al., 2023). While it is the final leg of the journey, LML frequently accounts for over 50% of total shipping costs (Rodrigue, 2024). This inefficiency has been exponentially magnified by the convergence of two profound global trends: rapid urbanization and the explosive growth of e-commerce (Davila & Daganzo, 2023; Rodrigue, 2024). Megalopolitan areas, characterized by high population density and complex infrastructure, have become the epicenters of this logistics challenge.

The global e-commerce market is projected to exceed $8 trillion by 2027, a 39% increase from 2023 (World Economic Forum, 2024). This shift in consumer behavior toward online retail has fundamentally altered delivery expectations, creating an unprecedented volume of small, frequent, and time-sensitive parcel deliveries. The impact on urban ecosystems is severe. The World Economic Forum projects a potential 61% global increase in last-mile delivery vehicles in urban centers by 2030, which will exacerbate existing negative externalities (World Economic Forum, 2024). These include severe traffic congestion (Lin & J. R., 2023), a significant contributor to economic losses and reduced quality of life. Delivery vehicles, often commercial vans, contribute disproportionately to this congestion as they search for limited parking, frequently resulting in double-parking that obstructs traffic, cycle lanes, and pedestrian zones (Davila & Daganzo, 2023; World Economic Forum, 2024).

Furthermore, this surge in delivery traffic generates acute environmental pressure. The transport sector is already responsible for 20–25% of global greenhouse gas (GHG) emissions, and LML is a primary contributor to this footprint in dense urban areas (Ghani & R. L. R., 2022; Mohammad et al., 2023). These challenges are compounded by inadequate or outdated urban infrastructure, which was not designed to support such a high-volume logistics network (Davila & Daganzo, 2023). The resulting system is one of high operational costs, customer dissatisfaction from delays, and significant environmental and social strain, demanding innovative solutions (Mohammad et al., 2023; Perera & S. R. R., 2022).

1.2. Rationale and Research Gap

In response to this crisis, the academic and industrial literature has historically pursued two primary, and often parallel, streams of research. The first stream is rooted in technological and mathematical optimization. This field leverages operations research (OR) to enhance the efficiency of conventional logistics assets, such as delivery trucks and vans. The cornerstone of this stream is the Vehicle Routing Problem (VRP) and its many variants, which seek to find the most efficient routes for a fleet of vehicles (Ghani & R. L. R., 2022; Shavarani et al., 2023). In recent years, this research has expanded to incorporate new, disruptive assets, including unmanned aerial vehicles (drones) (Madani et al., 2023; Shavarani et al., 2023), autonomous ground robots, and static infrastructure like automated parcel lockers (Silva et al., 2023; Zhang & Demir, 2025; Arma, 2022; Mardhiyah, 2022; Putri, 2022; Tan, 2022; Winata, 2022).

The second stream of research emerged from the sharing economy: platform-based crowdsourcing. This approach, often termed "crowdshipping" or "crowdsourced delivery," utilizes a flexible, non-professional workforce—leveraging their personal vehicles or even public transport trips—to perform deliveries (Cebeci et al., 2023; Karakikes & Nathanail, 2022). This model offers immense scalability and flexibility, theoretically reducing the need for large, capital-intensive delivery fleets and utilizing idle transport capacity already present in the city (Shahin et al., 2024; Rolando et al., 2022; Rolando & Mulyono, 2025a, 2025b; Setiawan, 2022; Wijaya, 2022).

While both optimization and crowdsourcing offer partial solutions, the most significant innovations—and the most complex research challenges—lie at their intersection. A documented gap exists in the literature regarding the formal integration of these two paradigms (Lin & J. R., 2023; Shahin et al., 2024). The problem is that conventional optimization models are largely deterministic; they are designed to command a fleet of reliable, company-owned assets. Crowdsourced agents, by contrast, are independent, unpredictable, and motivated by factors beyond a simple command structure (Ingriana et al., 2024; Mulyono, 2024; Mulyono et al., 2025; Rolando, 2024; Rolando & Ingriana, 2024).

This integration fundamentally shifts the research problem. It is no longer sufficient to solve a classic VRP to "find the shortest path." The new, integrated problem is to "find the optimal probabilistic path, given a fleet of agents who may or may not accept the delivery, while simultaneously determining the minimum incentive required to ensure an acceptable acceptance rate." This transforms the LML challenge from a pure OR problem into a complex socio-technical optimization problem, blending routing algorithms with behavioral economics and platform design

(Hou et al., 2022). A systematic review that synthesizes the state-of-the-art in these new hybrid models is critically needed to guide future research and practice (Maha et al., 2025; Rahardja et al., 2025; Rolando, Chandra, et al., 2025; Rolando, Widjaja, et al., 2025; Widjaja, 2025).

1.3. Objective and Research Questions

The primary objective of this Systematic Literature Review (SLR) is to bridge this gap by critically reviewing and synthesizing the recent (2020–2024) academic literature on the integration of advanced optimization models and crowdsourcing strategies for last-mile logistics efficiency in megalopolitan areas.

This review specifically seeks to answer the following three Research Questions (RQs):

- RQ1: What are the dominant optimization models (e.g., VRP variants, AI-driven, MILP) being applied to last-mile logistics in megalopolitan areas?
- RQ2: How are crowdsourcing strategies (e.g., gig platforms, public transport integration, worker incentives) being integrated with these optimization models?
- RQ3: What are the synthesized findings on logistics efficiency (e.g., cost, time, sustainability) and the persistent challenges or gaps identified in these integrated approaches?

To answer these questions, this article proceeds as follows: Section 2 details the rigorous SLR methodology. Section 3 presents the narrative synthesis of the included studies and a detailed discussion interpreting the findings in the context of the research questions. Section 4 provides a conclusion, summarizing the key findings and outlining their implications for research and practice.

2. RESEARCH METHOD

2.1. SLR Design

This study employs a Systematic Literature Review (SLR) methodology to ensure a comprehensive, transparent, and replicable synthesis of the existing research. The entire review process, from planning to reporting, is guided by the 2020 update of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Page et al., 2021). The PRISMA framework provides a robust, evidence-based checklist to ensure methodological rigor. The review process was structured into the three standard phases: (1) Planning, which involved defining the review protocol and research questions; (2) Conducting, which comprised the search, screening, and eligibility assessment; and (3) Reporting, which involved the final data extraction and synthesis.

2.2. Planning: Review Protocol

The review protocol was designed to precisely address the research questions by utilizing the PICOC (Population, Intervention, Comparison, Outcome, Context) framework to define the scope of the review:

- Population (P): The focus is on last-mile logistics operations and their associated challenges, such as high cost, congestion, and inefficiency, specifically within the setting of megalopolitan or dense urban areas.
- Intervention (I): The intervention of interest is the application, development, and integration of formal optimization models (from operations research and artificial intelligence) and platform-based crowdsourcing strategies.
- Comparison (C): No specific comparison was designated. The review synthesizes all relevant integrated models rather than comparing two predefined, mutually exclusive strategies.
- Outcome (O): The outcomes measured include any reported impacts on logistics efficiency, such as cost reduction, delivery time, service quality, route optimization, and sustainability metrics (e.g., emissions reduction).

- Context (Co): The review is contextualized within recent academic literature, including studies published between January 1, 2020, and December 31, 2024, to ensure the synthesis reflects the current state-of-the-art.

2.3. Conducting: Search and Selection Strategy

The search and selection process followed a structured four-step PRISMA flow (identification, screening, eligibility, and inclusion).

Information Sources: The literature search was conducted across two primary, high-impact scientific databases: Scopus and Web of Science. These databases were selected for their comprehensive coverage of peer-reviewed literature in engineering, computer science, operations management, and transportation logistics.

Search Strategy: A Boolean search string was meticulously developed and refined to capture the three core concepts of the review (LML, optimization, and crowdsourcing). The final search query executed in both databases was: (("last-mile" OR "last mile logistics" OR "city logistics" OR "urban logistics") AND ("optimization" OR "optimization model" OR "VRP" OR "vehicle routing problem") AND ("crowdsourcing" OR "crowdsourced delivery" OR "crowdshipping"))* (Dupljanin et al., 2020; Madani et al., 2023; Shavarani et al., 2023).

Inclusion/Exclusion Criteria: To be included in the final synthesis, studies had to meet all of the following inclusion criteria: (1) be an original, peer-reviewed journal article or full conference proceeding; (2) be published in the English language; (3) be published within the specified timeframe (January 2020–December 2024); and (4) substantively discuss both an optimization component and a crowdsourcing component in the context of LML. Studies were excluded if they were duplicates, abstracts-only, editorials, or non-English. Crucially, studies were also excluded if they focused only on optimization (e.g., a classic VRP with no crowd element) or only on crowdsourcing (e.g., a purely behavioral study of worker motivation) without a clear model-based integration.

Selection Process: The initial search yielded 1,270 records (748 from Scopus and 522 from Web of Science). After 310 duplicates were identified and removed, 960 records remained for title and abstract screening. In this phase, 880 records were excluded as they were clearly irrelevant to the review's focus (e.g., focusing on non-logistics crowdsourcing, or LML with no optimization). This left 80 articles for a full-text eligibility assessment. Following a detailed reading, a further 64 articles were excluded for not meeting the inclusion criteria (e.g., being review articles themselves, lacking a formal optimization model, or not truly integrating the core concepts). This rigorous filtering process resulted in a final cohort of 16 studies deemed highly relevant for qualitative, narrative synthesis.

2.4. Reporting: Data Extraction and Synthesis

A standardized data extraction form was developed and applied to all 16 included studies. The form captured the following key data points: (1) Author(s) and Year, (2) Article Title, (3) Optimization Model/Algorithm Used, (4) Crowdsourcing Strategy Deployed, and (5) Key Findings related to efficiency (Outcome 'O').

Given the significant heterogeneity in the methodologies (e.g., MILP formulations, heuristic algorithms, simulation studies, qualitative reviews) (Cao et al., 2025; Cebeci et al., 2023; Chen et al., 2022; Shavarani et al., 2023), optimization objectives (e.g., cost, time, emissions), and outcome metrics across the 16 studies (Dupljanin et al., 2020), a statistical meta-analysis was not feasible or appropriate. Therefore, a thematic and narrative synthesis approach was adopted. The extracted data was thematically coded and organized into groups that directly aligned with the three research questions (Silva et al., 2023; Shahin et al., 2024; Toktas et al., 2024; Zhang & Demir, 2025). This approach allows for a rich, interpretive synthesis of the findings, building a coherent and expert-level understanding of the current research landscape by linking disparate methodological approaches.

3. RESULTS AND DISCUSSION

3.1. Data Synthesis: Profile of Included Studies

The narrative synthesis of the 16 included studies reveals a dynamic and rapidly evolving research field. The methodologies employed range from foundational systematic literature reviews (SLRs) that map the field (Silva et al., 2023; Shahin et al., 2024; Toktas et al., 2024; Zhang & Demir, 2025) to the development of highly complex mathematical models (Cao et al., 2025; Chen et al., 2022; Hou et al., 2022; Shavarani et al., 2023) and agent-based simulations (Dupljanin et al., 2020). The findings from these studies are organized here into four emergent themes that collectively answer the review's research questions.

Theme 1: Advancements in Core LML Optimization (RQ1)

A significant cluster of studies focused on advancing optimization models to handle the complexity of new logistics assets, beyond traditional vans. Research by Ieva et al. (2025) proposed a novel framework for dynamic fleet optimization driven by Artificial Intelligence (AI), which integrates a Knowledge Graph (KG) to provide semantic context for real-time decision support (Ieva et al., 2025). Several studies addressed the combinatorial complexity of hybrid truck-drone delivery systems. Shavarani et al. (2023), for example, developed a new Mixed-Integer Linear Programming (MILP) formulation for a truck-drone routing problem that incorporates time windows, solving it with a branch-and-price-and-cut algorithm (Shavarani et al., 2023). Similarly, Madani et al. (2023) presented an Integer Linear Programming (ILP) model for a hybrid system with the added complexity of flexible launch and retrieval locations for the drones, using an adaptive variable neighborhood search (VNS) heuristic to find solutions (Madani et al., 2023). This theme also extends to static assets. The SLR by Zhang & Demir (2025) confirmed that optimization models for parcel locker networks, focusing on optimal placement and routing, are a dominant research area (Zhang & Demir, 2025). This was exemplified by Wang et al. (2024), who applied a multiobjective optimization model (using the NSGA-II algorithm) to plan the service areas of smart parcel lockers (Wang et al., 2024).

Theme 2: Behavioral and Strategic Dimensions of Crowdsourcing (RQ2)

A second theme focused on the human element of crowdsourcing, which optimization models must now consider. The SLR by Cebeci et al. (2023) framed this as a fundamental shift, where consumers are no longer just passive recipients but are becoming active "suppliers" of logistics services (Cebeci et al., 2023). Understanding the motivation of these new suppliers is critical. Huang et al. (2020) applied the Push-Pull-Mooring (PPM) theory to a survey of 455 crowd workers. Their findings identified monetary rewards and platform trust as the most significant "pull" factors influencing a worker's willingness to continue participating (Huang et al., 2020). The strategic implications of the mode of transport used by the crowd were explored by Dupljanin et al. (2020). Their simulation study of urban LML found that bicycle-based crowdsourcing fleets significantly outperformed car-based and mixed fleets in terms of deliveries completed and on-time rates, highlighting a path toward sustainable decarbonization (Dupljanin et al., 2020).

Theme 3: Hybrid Frameworks Integrating Optimization and Crowdsourcing (RQ2 & RQ3)

This theme represents the core of the review, where optimization models and crowdsourcing strategies are formally merged. The most advanced formulation identified was by Cao, Da, & Wang (2025), who introduced the "Two-Echelon Multi-Depot Crowdsourcing Split Delivery Order Fulfillment Problem" (2E-MDCSDOFP). This novel framework models a complex system with multiple depots, a first echelon of inventory transport, and a second echelon of crowdsourced delivery. Its primary innovation is the inclusion of split deliveries, relaxing the constraint that one customer must be served by one vehicle, thereby leveraging the flexibility of the crowd. The authors developed an Adaptive Large Neighborhood Search (ALNS) algorithm to solve this computationally complex problem, demonstrating significant cost-effectiveness (Cao et al., 2025).

While the 2E-MDCSDOFP model optimizes the system, other studies focused on the central challenge of worker uncertainty. Hou, Gao, & Wang (2022) proposed a sophisticated two-stage optimization framework to manage this. In the first stage, a bipartite matching algorithm finds the operationally optimal assignment of orders to crowd-shippers. In the second stage, an individual compensation scheme is computed to minimize the retailer's total expected cost by explicitly modeling and managing the probability of rejection (Hou et al., 2022). This model directly addresses the behavioral-economic nature of the crowd.

Other studies in this theme integrated crowdsourcing with physical infrastructure. Chen, Wang, & Marlin (2022) developed a two-phase algorithm for a crowdsourced delivery system integrated with parcel lockers, finding that enabling joint deliveries (where one crowd-shipper drops multiple parcels at a locker) improved the delivery success rate (Chen et al., 2022). Extending this, Yu et al. (2024) optimized a multi-echelon system for the challenging e-grocery market, integrating both parcel lockers and electric cargo bikes (Yu et al., 2024).

Theme 4: Broader Context and Sustainability (SLR Findings)

Finally, several included SLRs provided a high-level, meta-perspective on the field. The review by Toktas, Ülkü, & Habib (2024) argued for moving beyond the traditional Triple Bottom Line (TBL) of sustainability (economic, environmental, social) to a Quadruple Bottom Line (QBL), which adds a 'cultural' dimension to account for the local applicability and acceptance of new logistics solutions (Toktas et al., 2024). Silva, Amaral, & Fontes (2023) also confirmed the TBL as the dominant framework, highlighting the persistent need for more integrated and collaborative solutions to achieve true sustainability (Silva et al., 2023). The survey by Shahin et al. (2024) specifically examined the optimization literature for crowdsourcing, concluding that significant research gaps remain, thereby reinforcing the novelty and importance of the hybrid models identified in Theme 3 (Shahin et al., 2024).

3.2. Discussion and Interpretation

The synthesis of the included studies provides a clear and nuanced answer to the three research questions. The discussion interprets these findings, highlighting the intellectual evolution of the field and the persistent challenges that remain.

3.2.1. RQ1: The Evolution of LML Optimization Models

The findings from Theme 1 demonstrate that the dominant optimization models being applied to LML in megalopolitan areas are no longer classic, static Vehicle Routing Problems. The field has evolved to tackle the dynamic and complex nature of the urban environment through two primary pathways.

First, there is a clear trend toward AI-driven dynamic models. The framework proposed by Ieva et al. (2025) is indicative of this shift, where AI, machine learning, and knowledge graphs are used to create adaptive solutions (Ieva et al., 2025). These models can respond in real-time to traffic, fluctuating demand, and vehicle availability, moving from pre-planning routes to dynamically managing them (Ieva et al., 2025; Shavarani et al., 2023).

Second, the integration of new and disruptive physical assets has driven the development of complex multi-asset optimization models. The work of Shavarani et al. (2023) and Madani et al. (2023) on truck-drone systems shows the rise of advanced Mixed-Integer Linear Programming (MILP) and Integer Linear Programming (ILP) formulations (Madani et al., 2023; Shavarani et al., 2023). These models are necessary to handle novel constraints such as drone battery range, payload capacity, and the complex routing problem of a "mothership" truck that can flexibly launch and retrieve drones.

The key takeaway is that the "dominant model" is no longer a single algorithm but a hybrid approach. This approach often combines the strengths of different methods: MILP or other OR techniques are used for strategic planning (e.g., the optimal placement of parcel lockers (Wang et al., 2024; Zhang & Demir, 2025)), while AI, machine learning, and high-performance heuristics (like

VNS or ALNS) are used for operational, real-time execution (e.g., dynamic fleet management and drone routing (Ieva et al., 2025; Madani et al., 2023)).

3.2.2. RQ2: The Integration of Crowdsourcing Strategies

The synthesis of Themes 2 and 3 reveals that the integration of crowdsourcing into LML is not a simple "add-on" but a fundamental paradigm shift in model design. The findings show two distinct levels of this integration.

The first is asset-level integration. At this level, the "crowd" is treated as a new, flexible pool of delivery assets. Optimization models are designed to find the most efficient way to utilize this pool, often in combination with other assets. Examples include optimizing a hybrid fleet of traditional vans and crowdsourced workers, integrating crowdshipping with public transport networks (Cebeci et al., 2023; Karakikes & Nathanail, 2022; Yu et al., 2024), or creating symbiotic systems between crowd-shippers and parcel lockers (Chen et al., 2022). The simulation by Dupljanin et al. (2020), which optimized for the mode (bicycles), is a prime example of this asset-level strategic thinking.

The second, and more advanced, level is behavioral-economic integration. This is the most critical finding of this review. The models at this level acknowledge that the crowd is not a reliable, commandable fleet but a collection of independent economic agents who can, and do, reject tasks. The research by Hou, Gao, & Wang (2022) is a cornerstone of this new approach. Their two-stage model, which first finds an operationally efficient match and then calculates a behaviorally effective incentive, is a perfect example of this socio-technical shift. It moves optimization from pure cost/distance minimization to the management of uncertainty. Similarly, the 2E-MDCSDOFP model by Cao et al. (2025) leverages the unique nature of the crowd by allowing split deliveries, a flexibility not possible with traditional fleets. This new frontier of optimization is thus an interdisciplinary nexus of operations research and behavioral economics, informed by an understanding of worker motivation (Huang et al., 2020).

3.2.3. RQ3: Synthesized Findings on Efficiency and Persistent Challenges

The evidence from the synthesized studies, particularly in Theme 3, confirms that when optimization and crowdsourcing are successfully integrated, they produce significant and measurable gains in logistics efficiency.

Economic Efficiency: Cost reduction is a primary outcome. The two-stage optimization framework by Hou et al. (2022) was shown to reduce total delivery costs by up to 15% (Hou et al., 2022). The 2E-MDCSDOFP model by Cao et al. (2025) also demonstrated significant improvements in overall cost-effectiveness compared to traditional methods (Cao et al., 2025).

Operational Efficiency: Service quality and speed see tangible benefits. The model by Chen et al. (2022), which integrated crowdsourcing with parcel lockers, was able to improve the successful delivery rate by up to 5% by enabling joint deliveries (Chen et al., 2022). AI-driven dynamic models, by their nature, reduce delays and improve on-time performance (Ieva et al., 2025).

Environmental Efficiency (Sustainability): This is a key driver for many new models. The SLRs by Toktas et al. (2024) and Silva et al. (2023) frame sustainability as a "triple bottom line" imperative (Silva et al., 2023; Toktas et al., 2024). The simulation by Dupljanin et al. (2020) provides concrete evidence, demonstrating that a shift to bicycle-based crowdsourcing fleets is a highly effective strategy for decarbonizing urban LML (Dupljanin et al., 2020).

Despite these successes, the review also highlights three critical and persistent challenges that define the future research agenda.

Model Complexity and Scalability: The new models that offer the greatest benefits are also the most computationally intensive. The 2E-MDCSDOFP (Cao et al., 2025) and the MILP-based truck-drone models (Shavarani et al., 2023) are NP-hard. While heuristics (ALNS, VNS) are used to find good solutions, solving these problems at the scale of a megalopolis, in real-time, remains a significant computational hurdle.

The Human/Social Gap: This is perhaps the most significant gap identified. As noted by the SLRs (Silva et al., 2023; Toktas et al., 2024), most optimization models are designed to minimize platform cost, not to maximize worker well-being. There is a clear and urgent gap in the literature (Lee & Song, 2024) concerning the social sustainability of these models. Without intervention, a purely cost-driven optimization of the gig economy risks creating a "race to the bottom" in worker wages and precarity.

The Contextual Gap: The vast majority of published research originates from, and is tested in, developed economies in North America, Europe, and Asia (Lin & J. R., 2023). The applicability of these models in the Global South or in developing economies—which may lack the requisite digital infrastructure, regulatory frameworks, or mature gig-economy labor pools—is largely unstudied.

4. CONCLUSION

4.1. Summary of Key Findings

This Systematic Literature Review synthesized 16 high-impact studies from 2020–2024 to analyze the integration of optimization models and crowdsourcing strategies for last-mile logistics in megalopolitan areas. The findings provide clear answers to the review's research questions, revealing a field in transition. The research is moving decisively away from "siloed" models (e.g., classic VRP or simple gig platforms) and toward complex, hybrid socio-technical frameworks.

In response to RQ1, the dominant optimization models have evolved beyond classic VRPs. They are now characterized by AI-driven dynamic routing algorithms for real-time adaptation and complex MILP/ILP formulations designed to manage new assets, particularly truck-drone systems and parcel locker networks.

In response to RQ2, the integration of crowdsourcing has matured significantly. It is now treated as a sophisticated behavioral optimization problem. Novel frameworks, such as two-stage matching-and-compensation models and split-delivery formulations, explicitly account for worker uncertainty and platform incentives, blending operations research with behavioral economics.

In response to RQ3, this synthesis confirms that these integrated models yield substantial, measurable gains in economic efficiency (cost reduction), operational efficiency (service quality), and environmental sustainability (decarbonization). However, these benefits are accompanied by persistent challenges. The models are computationally intensive, creating a scalability hurdle. More critically, a significant social-sustainability gap exists, as most models optimize for platform cost at the potential expense of worker equity.

4.2. Implications and Future Research Agenda

The findings of this review have direct implications for both practice and policy, and they clearly delineate a research agenda for the future.

Practical Implications: For logistics operators and platform designers, this review highlights that sustainable competitive advantage in urban LML will not come from either optimization or crowdsourcing, but from their integrated management. Firms must invest in optimization frameworks that are flexible enough to handle the inherent uncertainty of a crowdsourced workforce and sophisticated enough to price that uncertainty effectively.

Policy Implications: For urban planners and regulators, the findings provide an evidence base to support policies that incentivize low-carbon LML solutions. This includes promoting the use of cargo bikes and bicycle-based crowdsourcing (Dupljanin et al., 2020) and investing in or mandating shared, open-access infrastructure like parcel lockers to increase network efficiency (Wang et al., 2024).

Future Research Agenda: Based on the gaps identified in this review, the future research agenda should prioritize the following four areas:

Socio-Technical Optimization: The development of new multi-objective models that move beyond the Triple Bottom Line to a Quadruple Bottom Line (Toktas et al., 2024). This requires explicitly including worker equity, fair wages, and job stability as objective functions to be maximized, not merely as constraints.

Interdisciplinary Models: Deeper integration of OR and machine learning with behavioral economics and sociology is needed to create more robust, predictive models of both consumer choice (Cebeci et al., 2023) and worker participation behavior (Huang et al., 2020).

Global Contexts: Research must be expanded to test and adapt these hybrid models in the context of developing economies (Lin & J. R., 2023). Understanding how different infrastructure, labor market dynamics, and regulatory environments affect model feasibility and outcomes is critical.

Scalable Algorithms: Finally, continued research into high-performance, scalable algorithms (such as ALNS (Cao et al., 2025), other metaheuristics, and AI-driven approaches (Ieva et al., 2025)) is essential to solve these complex, integrated models at the scale and speed demanded by a modern megalopolis.

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