INTERNATIONAL MULTI DISCIPLINARY JOURNAL FOR RESEARCH & DEVELOPMENT

eISSN 2394-6334 Impact factor: 7,854 Volume 12, issue 08 (2025)

AI-Driven Intelligence in Last-Mile Logistics: Integrating Autonomous Fleet Management, Predictive Maintenance, and Urban Delivery Ecosystems

Dr. Lucas André Moreau

Department of Mechanical and Industrial Engineering University of Toronto, Canada

Abstract: The rapid acceleration of urbanization, the exponential growth of e-commerce, and increasing consumer expectations for speed, transparency, and reliability have collectively transformed last-mile logistics into one of the most complex and strategically critical segments of contemporary supply chains. Within this evolving landscape, artificial intelligence has emerged not merely as a supportive technological tool but as a foundational paradigm reshaping how fleets are managed, how vehicles are maintained, and how autonomous systems interact with dynamic urban environments. This research article undertakes a comprehensive and theoretically grounded examination of AI-driven fleet management and predictive maintenance within the broader context of last-mile delivery systems, with a particular emphasis on autonomous and semi-autonomous vehicles operating in dense metropolitan settings.

The study situates AI-enhanced fleet intelligence at the intersection of data science, machine learning, cyber-physical systems, and logistics theory, arguing that predictive maintenance and real-time decision-making are no longer discrete operational functions but integral components of an interconnected, adaptive logistics ecosystem. Drawing extensively on recent scholarly contributions, including foundational work on AI-enhanced fleet management and predictive maintenance for autonomous vehicles (Patil & Deshpande, 2025), the article explores how algorithmic foresight enables a shift from reactive maintenance models toward anticipatory, condition-based strategies that significantly alter cost structures, safety outcomes, and asset lifecycles. In parallel, the research contextualizes these developments within the expanding global last-mile delivery market, where urban congestion, sustainability pressures, and labor constraints intensify the need for intelligent automation (Statista Inc., 2023; Boysen et al., 2021).

Methodologically, the article adopts an integrative qualitative research design grounded in systematic literature synthesis, comparative conceptual analysis, and interpretive evaluation of industry reports, policy frameworks, and academic models. Rather than relying on empirical datasets or mathematical formalism, the study emphasizes deep theoretical elaboration and critical discourse, aligning with calls in logistics and systems engineering scholarship for more conceptually robust examinations of AI adoption (Masorgo et al., 2024; Giuffrida et al., 2022). The results section synthesizes emergent patterns across the literature, demonstrating how AI-enabled telemetry, real-time route optimization, and predictive diagnostics collectively redefine operational visibility and strategic control in fleet-based logistics (Drozdov, 2024; Microsoft Azure, 2024).

The discussion extends beyond technical efficiency to interrogate broader implications, including human–machine collaboration in Industry 5.0 contexts, ethical governance of autonomous decision-making, and the socio-technical resilience of urban delivery infrastructures (Tóth et al., 2023; Yahya et al., 2021). By critically engaging with counter-arguments concerning data dependency, algorithmic bias, and infrastructural inequality, the article contributes a nuanced perspective on both the promises and limitations of AI-driven fleet intelligence. Ultimately, this research positions AI-enhanced fleet management and predictive maintenance not as incremental innovations but as transformative forces capable of reshaping the future of last-mile logistics in increasingly complex urban ecosystems.

Keywords: Artificial intelligence; last-mile logistics; autonomous vehicles; predictive maintenance; fleet management; urban delivery systems

INTRODUCTION

The The last-mile segment of logistics has long been recognized as the most resource-intensive, operationally complex, and customer-sensitive component of the supply chain. Historically, this phase—defined as the final movement of goods from a distribution hub to the end consumer—has accounted for a disproportionate share of total delivery costs while simultaneously exerting significant influence on customer satisfaction and brand perception (Boysen et al., 2021). As global e-commerce volumes have surged and urban populations have expanded, the structural inefficiencies embedded within traditional last-mile delivery models have become increasingly visible and unsustainable (Statista Inc., 2023). These pressures have catalyzed a profound transformation in how logistics systems are designed, governed, and optimized, with artificial intelligence emerging as a central driver of change.

Urbanization trends provide a critical backdrop for understanding the urgency of innovation in last-mile logistics. According to global urban development projections, a steadily increasing proportion of the world's population now resides in cities, intensifying congestion, environmental externalities, and infrastructural strain (United Nations Human Settlements Programme, 2023). Within such environments, conventional fleet management approaches—characterized by static routing, scheduled maintenance, and fragmented data silos—are ill-equipped to respond to real-time disruptions or long-term asset degradation. The limitations of these legacy systems have prompted both scholars and practitioners to explore AI-enabled alternatives capable of sensing, learning, and adapting within complex urban ecosystems (Giuffrida et al., 2022).

At the core of this transformation lies the integration of AI into fleet management and vehicle maintenance functions. Fleet management, traditionally focused on vehicle allocation, route planning, and compliance monitoring, has evolved into a data-intensive discipline that leverages continuous streams of telemetry, geospatial information, and behavioral analytics (RishabhSoft, 2024). Predictive maintenance, once reliant on heuristic schedules and reactive repairs, has similarly undergone a paradigm shift toward condition-based and prognostic models that anticipate failures before they manifest (Kaluvakuri, 2023). The convergence of these domains is particularly evident in the context of autonomous vehicles, where operational safety, system reliability, and algorithmic decision-making are inextricably linked (Patil & Deshpande, 2025).

Despite the growing body of literature addressing AI applications in logistics, significant gaps remain in the theoretical integration of fleet management, predictive maintenance, and last-mile delivery under a unified analytical framework. Existing studies often treat these domains as discrete areas of inquiry, focusing narrowly on optimization techniques, technological architectures, or market trends without sufficiently interrogating their interdependencies (Masorgo et al., 2024). Moreover, much of the current discourse emphasizes efficiency gains and cost reduction, while underexploring broader systemic implications such as human–machine collaboration, ethical governance, and urban resilience (Tóth et al., 2023).

This article seeks to address these gaps by offering a comprehensive, theory-driven examination of AI-enhanced fleet management and predictive maintenance within last-mile logistics ecosystems. Building on recent foundational research in autonomous fleet intelligence (Patil & Deshpande, 2025), the study situates AI not merely as an optimization tool but as a socio-technical catalyst reshaping decision-making structures, organizational capabilities, and urban delivery paradigms. By synthesizing insights from logistics theory, data science, and systems engineering, the article aims to contribute a more holistic understanding of how AI-driven intelligence reconfigures the operational and strategic contours of last-mile delivery.

The introduction proceeds by first tracing the historical evolution of last-mile logistics and fleet management, highlighting key inflection points that have shaped contemporary challenges. It then examines the theoretical foundations of AI and predictive analytics as applied to transportation systems, situating current developments within broader debates on automation and digital transformation (Yahya et al., 2021). Finally, the section articulates the central research problem and objectives, emphasizing the need for integrative frameworks that capture the complexity of AI-enabled logistics in urban environments (Moradi et al., 2024). Through this extensive contextualization, the article establishes a robust foundation for the methodological, analytical, and interpretive discussions that follow.

METHODOLOGY

The methodological orientation of this research is grounded in an interpretive, qualitative, and theory-building approach designed to accommodate the complexity and multidimensionality of AI-driven fleet management and predictive maintenance in last-mile logistics. Rather than employing empirical experimentation or quantitative modeling, the study adopts a systematic conceptual synthesis methodology, which is particularly well-suited to domains characterized by rapid technological change, heterogeneous data sources, and evolving theoretical constructs (Masorgo et al., 2024). This methodological choice aligns with contemporary calls in logistics and operations research for deeper theoretical integration and critical reflection beyond purely algorithmic performance evaluations (Giuffrida et al., 2022).

The primary data sources for this study consist of peer-reviewed journal articles, industry reports, policy documents, and authoritative technical publications focusing on artificial intelligence, fleet management, predictive maintenance, autonomous vehicles, and last-mile delivery systems. Particular emphasis is placed on recent contributions that explicitly address AI-enhanced fleet intelligence, including the work of Patil and Deshpande (2025), which provides a comprehensive examination of predictive maintenance architectures and data-driven decision-making in autonomous vehicle fleets. These sources are complemented by macro-level market analyses and urbanization reports that contextualize technological developments within broader economic and demographic trends (Statista Inc., 2023; United Nations Human Settlements Programme, 2023).

The research process unfolds through three interrelated stages. The first stage involves thematic mapping, wherein key concepts, terminologies, and theoretical perspectives are identified across the literature. This mapping process enables the identification of recurring themes such as real-time telemetry, machine learning-based failure prediction, route optimization, and human–machine interaction in logistics systems (Drozdov, 2024; Microsoft Azure, 2024). By systematically cataloging these themes, the study establishes a conceptual vocabulary that facilitates cross-disciplinary dialogue and comparative analysis.

The second stage consists of analytical synthesis, during which the identified themes are examined in relation to one another to uncover patterns, complementarities, and tensions. For instance, predictive maintenance models are analyzed not only in terms of technical accuracy but also in relation to fleet-level decision-making, organizational workflows, and urban infrastructure constraints (Kaluvakuri, 2023). This stage is particularly attentive to the ways in which AI-enabled insights traverse organizational boundaries, influencing strategic planning, operational control, and policy compliance (RishabhSoft, 2024).

The third stage involves critical interpretation, wherein the synthesized findings are situated within broader theoretical debates on automation, Industry 4.0 and 5.0, and socio-technical systems (Tóth et al., 2023). This interpretive lens enables the study to move beyond descriptive accounts of technological adoption and toward a more nuanced understanding of power relations, ethical considerations, and long-term sustainability implications. Throughout this process, attention is given to counter-arguments and limitations identified in the literature, including concerns regarding data privacy, algorithmic opacity, and infrastructural inequities (Yahya et al., 2021).

While the qualitative and literature-driven nature of this methodology offers significant strengths in terms of theoretical depth and integrative insight, it also entails certain limitations. The absence of primary empirical data constrains the ability to generalize findings across specific operational contexts or geographic regions. Additionally, reliance on secondary sources introduces potential biases related to publication trends and industry narratives (Effigy Consulting, 2024). These limitations are acknowledged not as deficiencies but as contextual boundaries within which the study's contributions should be interpreted.

By foregrounding conceptual rigor and critical synthesis, the chosen methodology enables a comprehensive exploration of AI-enhanced fleet management and predictive maintenance as interconnected components of last-mile logistics ecosystems. This approach lays the groundwork for the subsequent results and discussion sections, which elaborate the emergent insights and their implications for theory, practice, and future research (Patil & Deshpande, 2025).

RESULTS

The results of this integrative analysis reveal a set of interconnected patterns that collectively illustrate how artificial intelligence reshapes fleet management and predictive maintenance within last-mile logistics systems. Rather than presenting discrete findings in isolation, this section interprets the outcomes as emergent properties of complex socio-technical interactions, consistent with contemporary systems-oriented perspectives in logistics research (Masorgo et al., 2024). Across the reviewed literature, AI-driven intelligence consistently appears as a unifying mechanism that enhances visibility, anticipatory control, and adaptive responsiveness in fleet-based delivery operations (Giuffrida et al., 2022).

One of the most salient results concerns the transformation of maintenance practices from reactive or schedule-based models toward predictive and prognostic paradigms. Studies examining AI-enhanced fleet systems demonstrate that continuous monitoring of vehicle health through sensor data and machine learning algorithms enables early detection of component degradation and failure risks (Patil & Deshpande, 2025). This shift fundamentally alters maintenance decision-making, allowing organizations to align interventions with actual asset conditions rather than arbitrary time intervals. The literature consistently associates this approach with reduced downtime, improved safety margins, and extended vehicle lifecycles, particularly in autonomous fleets where system reliability is paramount (Kaluvakuri, 2023).

A second key result pertains to the integration of real-time route optimization with predictive maintenance insights. AI-enabled routing systems leverage dynamic data streams—such as traffic conditions, weather patterns, and delivery constraints—to continuously adjust routes in response to changing environments (Drozdov, 2024). When combined with predictive maintenance data, these systems can proactively reroute vehicles to avoid conditions that may exacerbate mechanical stress or accelerate component wear. This integrative capability represents a departure from siloed optimization approaches and underscores the value of holistic fleet intelligence architectures (Microsoft Azure, 2024).

The analysis also reveals that AI-driven fleet management contributes to strategic-level decision-making beyond day-to-day operations. Predictive analytics enable fleet operators to forecast long-term maintenance costs, assess asset replacement cycles, and evaluate the financial implications of adopting autonomous technologies (RishabhSoft, 2024). These capabilities support more informed capital allocation and risk management strategies, aligning operational data with organizational planning processes. The literature suggests that such strategic integration is particularly critical in the last-mile context, where narrow margins and high service expectations amplify the consequences of inefficiencies (Statista Inc., 2023).

From an organizational perspective, the results highlight evolving roles and competencies within fleet management functions. As AI systems assume greater responsibility for monitoring and decision support, human operators increasingly transition toward supervisory, interpretive, and exception-handling roles (Tóth et al., 2023). This reconfiguration reflects broader trends associated with Industry 5.0, emphasizing human–machine collaboration rather than full automation. However, the literature also notes challenges related to trust, skill gaps, and the interpretability of AI outputs, which can constrain effective adoption if not adequately addressed (Yahya et al., 2021).

Finally, the results underscore the contextual sensitivity of AI-enhanced fleet management outcomes. Urban density, regulatory frameworks, and infrastructural maturity significantly influence the effectiveness of predictive maintenance and autonomous delivery systems (Moradi et al., 2024). In highly congested cities, for example, the benefits of real-time optimization and predictive diagnostics are magnified, while in less developed contexts, data availability and connectivity constraints may limit system performance (Effigy Consulting, 2024). These findings suggest that AI-driven fleet intelligence cannot be understood in abstraction from its operational and institutional environments.

Collectively, these results illustrate that AI-enhanced fleet management and predictive maintenance function as interdependent elements of a broader transformation in last-mile logistics. Rather than yielding isolated efficiency gains, their integration produces systemic effects that reshape operational practices, organizational structures, and strategic orientations (Patil & Deshpande, 2025). These outcomes provide a foundation for the subsequent discussion, which critically interprets their theoretical and practical implications within the evolving landscape of urban logistics.

DISCUSSION

The findings of this study invite a deeper theoretical and critical examination of artificial intelligence as a transformative force within last-mile logistics, particularly through its integration into fleet management and predictive maintenance systems. Rather than treating AI as a neutral technological enhancement, the discussion situates it within broader socio-technical, organizational, and urban contexts that shape both its capabilities and its limitations (Giuffrida et al., 2022). This section elaborates on the implications of the results by engaging with competing scholarly perspectives, addressing counter-arguments, and exploring future trajectories for research and practice.

A central theoretical implication concerns the reconceptualization of maintenance and fleet management as anticipatory systems. Traditional logistics theory has largely framed maintenance as a support function subordinate to routing and delivery performance. However, the emergence of AI-driven predictive maintenance challenges this hierarchy by positioning asset health as a strategic variable that directly influences service reliability, safety, and cost efficiency (Patil & Deshpande, 2025). From a systems theory perspective, predictive maintenance can be understood as a feedback mechanism that enhances system resilience by reducing uncertainty and enabling preemptive intervention. This reframing aligns with broader discussions in operations management that emphasize robustness and adaptability over narrow efficiency metrics (Masorgo et al., 2024).

At the same time, the literature reveals ongoing debate regarding the extent to which predictive models can reliably capture the complexity of real-world operating conditions. Critics argue that machine learning algorithms are inherently dependent on historical data, which may not fully represent future disruptions or novel failure modes, particularly in rapidly evolving autonomous vehicle technologies (Kaluvakuri, 2023). While proponents counter that continuous learning architectures mitigate this limitation by updating models in real time, the tension underscores the importance of human oversight and hybrid decision-making frameworks (Tóth et al., 2023). This debate reflects a broader epistemological question concerning the limits of algorithmic foresight in complex socio-technical systems (Yahya et al., 2021).

Another critical dimension involves the integration of AI-driven fleet intelligence within urban delivery ecosystems. The results suggest that AI-enabled optimization is most effective when embedded within supportive infrastructural and regulatory environments (Moradi et al., 2024). This observation resonates with urban studies scholarship emphasizing the co-evolution of technology and city governance. For instance, dynamic routing and autonomous delivery systems may exacerbate congestion or inequity if deployed without coordination with urban planning and public policy (United Nations Human Settlements Programme, 2023). Conversely, when aligned with smart city initiatives and sustainable mobility strategies, AI-enhanced logistics can contribute to reduced emissions, improved traffic flow, and more equitable access to services (Tan, 2025).

The discussion also highlights ethical and governance challenges associated with AI-driven fleet management. Issues of data privacy, algorithmic transparency, and accountability become particularly salient in autonomous and semi-autonomous systems, where decision-making authority is partially delegated to machines (RishabhSoft, 2024). Scholars caution that opaque predictive models may obscure the rationale behind maintenance decisions or routing choices, complicating responsibility attribution in the event of failures or accidents (Yahya et al., 2021). Addressing these concerns requires not only technical solutions, such as explainable AI, but also institutional frameworks that define standards, oversight mechanisms, and stakeholder roles (Patil & Deshpande, 2025).

From an organizational standpoint, the transition toward AI-enhanced fleet intelligence necessitates significant cultural and structural adaptation. While the literature emphasizes efficiency gains, it also documents resistance stemming from skill mismatches, trust deficits, and fears of job displacement (Tóth et al., 2023). The Industry 5.0 perspective offers a constructive lens by framing AI as a collaborator that augments human capabilities rather than replacing them. In this view, fleet managers evolve into system integrators and strategic analysts who interpret AI-generated insights and make contextual judgments that machines alone cannot (Masorgo et al., 2024).

Looking forward, the discussion identifies several avenues for future research. One promising direction involves longitudinal studies that examine how AI-enhanced predictive maintenance influences fleet performance and organizational learning over time. Another area concerns cross-city comparative analyses that explore how differing urban contexts shape the outcomes of AI-driven logistics interventions (Moradi et al., 2024). Additionally, interdisciplinary research integrating logistics, ethics, and urban governance could yield more holistic frameworks for responsible AI deployment in last-mile delivery systems (Giuffrida et al., 2022).

In synthesizing these perspectives, the discussion underscores that AI-enhanced fleet management and predictive maintenance represent not merely technical innovations but profound shifts in how logistics systems are conceptualized and governed. Their transformative potential is contingent upon thoughtful integration with human expertise, institutional frameworks, and urban infrastructures (Patil & Deshpande, 2025). By engaging critically with both the promises and the challenges of AI-driven intelligence, this study contributes to a more nuanced and theoretically grounded understanding of the future of last-mile logistics.

CONCLUSION

The comprehensive analysis presented in this article demonstrates that artificial intelligence has become a foundational force reshaping last-mile logistics through its integration into fleet management and predictive maintenance systems. By synthesizing insights from a diverse body of scholarly and industry literature, the study reveals that AI-driven intelligence enables a transition from reactive, fragmented operational models toward anticipatory, adaptive, and systemically integrated logistics ecosystems (Patil & Deshpande, 2025). This transformation is particularly consequential in urban contexts, where congestion, sustainability pressures, and service expectations intensify the need for real-time decision-making and asset reliability (Statista Inc., 2023).

The findings underscore that predictive maintenance is no longer a peripheral support function but a strategic capability that directly influences safety, cost efficiency, and service continuity in autonomous and semi-autonomous fleets (Kaluvakuri, 2023). When coupled with real-time route optimization and advanced data analytics, AI-enhanced fleet management generates synergistic effects that extend beyond operational efficiency to inform strategic planning and organizational learning (Drozdov, 2024; Microsoft Azure, 2024). At the same time, the analysis highlights critical challenges related to data dependency, algorithmic transparency, and human–machine collaboration, emphasizing that technological sophistication alone is insufficient to guarantee positive outcomes (Tóth et al., 2023).

By engaging deeply with theoretical debates and counter-arguments, this article contributes a nuanced perspective that situates AI-driven fleet intelligence within broader socio-technical and urban systems. The study argues that the future of last-mile logistics depends not only on technological innovation but also on thoughtful governance, ethical oversight, and interdisciplinary collaboration (Yahya et al., 2021; Moradi et al., 2024). In doing so, it offers a robust conceptual foundation for scholars, practitioners, and policymakers seeking to navigate the complexities of AI adoption in logistics.

Ultimately, the article positions AI-enhanced fleet management and predictive maintenance as transformative capabilities with the potential to redefine the structure and performance of last-mile delivery systems. By moving beyond narrow optimization narratives and embracing a holistic, theory-driven approach, this research advances understanding of how intelligent systems can be responsibly and effectively integrated into the logistics networks that underpin contemporary urban life (Patil & Deshpande, 2025).

REFERENCES

1. Effigy Consulting. CEP Market. In Courier, Express and Parcel (CEP) Market Volume in Europe from 2015 to 2022; Statista: London, 2024.

2. Patil, A. A.; Deshpande, S. AI-Enhanced Fleet Management and Predictive Maintenance for Autonomous Vehicles. International Journal of Data Science and Machine Learning 2025, 5(01), 229–249. https://doi.org/10.55640/ijdsml-05-01-21

3. Drozdov, A. Real-Time Route Optimization with AI Solutions. 2024.

4. United Nations Human Settlements Programme. World Cities Report 2022: Envisaging the Future of Cities; Statista: London, 2023.

5. 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.

6. Kaluvakuri, V. P. K. The Impact of AI and Cloud on Fleet Management and Financial Planning: A Comparative Analysis. 2023.

7. Tan, E. AI, Circular Supply Chains and More: Top Logistics Trends in Singapore and Beyond. 2025.

8. Boysen, N.; Fedtke, S.; Schwerdfeger, S. Last-mile delivery concepts: A survey from an operational research perspective. OR Spectrum 2021, 43, 1–58.

9. Yahya, M.; Breslin, J. G.; Ali, M. I. Semantic web and knowledge graphs for Industry 4.0. Applied Sciences 2021, 11, 5110.

10. Statista Inc. Size of the Global Last Mile Delivery Market from 2020 to 2027 (in Billion U.S. Dollars). Technical Report; Statista: London, 2023.

11. Moradi, N.; Wang, C.; Mafakheri, F. Urban air mobility for last-mile transportation: A review. Vehicles 2024, 6, 1383–1414.

12. Masorgo, N.; Dobrzykowski, D. D.; Fugate, B. S. Last-Mile Delivery: A Process View, Framework, and Research Agenda. Journal of Business Logistics 2024, 45, e12397.

13. RishabhSoft. AI and Machine Learning in Fleet Management. 2024.

14. Tóth, A.; Nagy, L.; Kennedy, R.; Bohuš, B.; Abonyi, J.; Ruppert, T. The human-centric Industry 5.0 collaboration architecture. MethodsX 2023, 11, 102260.

15. Microsoft Azure. Data analytics for automotive test fleets. 2024.

16. Mahajan, G. Artificial Intelligence in Transportation Market Size and Share Analysis – Growth Trends and Forecasts (2025–2032). 2025.

17. Confluent. Building a Scalable Real-Time Fleet Management IoT Data Tracker with Kafka Streams and gRPC. 2024.