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## International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

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# Challenges and Innovations in Sustainable Last-Mile Delivery Technologies

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**ABSTRACT:** Last-mile delivery is the final stage of the logistics process in which goods are transferred from a distribution center to the end consumer, typically within an urban area. This phase is not only important for customer satisfaction, but it also has a substantial impact on logistics costs and the environment. As e-commerce expands, traditional last-mile delivery systems' inefficiencies and environmental repercussions, such as traffic congestion and increasing carbon emissions, become more apparent. Sustainable last-mile delivery aims to mitigate these environmental impacts through innovations such as electric vehicles (EVs), self-driving delivery systems, and urban consolidation centers. It seeks to strike a balance between operational efficiency and environmental responsibility by lowering carbon emissions, reducing energy consumption, and optimizing route efficiency. This study will look at the obstacles of attaining sustainability in last-mile delivery, specifically in India. Using secondary data from research articles and industry case studies, the study investigates the primary impediments, such as high costs, limited infrastructure, and regulatory restraints, while also showcasing advancements in sustainable technologies.

**KEYWORDS:** Last-mile delivery, sustainability, logistics, electric vehicles

## I. INTRODUCTION

The rapid expansion of e-commerce has highlighted the importance of last-mile delivery, which transports goods from a distribution hub to the end consumer. This stage is not just the most resource-intensive, but also the most critical to assuring client satisfaction. However, last-mile delivery confronts substantial obstacles, such as road congestion, rising fuel costs, and inefficiencies that result in increased emissions, particularly in highly populated urban areas. These concerns are particularly acute in India, where urbanization is rising and online shopping is booming.

Sustainable last-mile delivery seeks to address these issues by incorporating eco-friendly techniques and technologies. From the adoption of electric vehicles (EVs) to the creation of smart urban consolidation centers, the logistics sector is looking for new ways to minimize its carbon footprint while preserving delivery efficiency.

This research paper will examine the major problems and advances in sustainable last-mile delivery systems, concentrating on how they are affecting the future of logistics. The study attempts to uncover practical and scalable methods for attaining sustainability in last-mile logistics by examining existing literature as well as industry practices.

### 1.1 Importance of Last-mile delivery in logistics

Last-mile delivery is the last stage in transporting goods to customers. It is also one of the crucial component in the logistics process. It is an important point where the operational efficiency of a company meets customer satisfaction. The importance of last-mile delivery can be inferred from the following factors:

**1. Customer satisfaction:** The last-mile delivery is the point of direct contact between the companies and their customers. Therefore, a fast, reliable and cost-effective delivery is vital for meeting the customer expectations, especially with the growth of e-commerce and the demand for same-day or next-day delivery. Delays in the delivery can lead to dissatisfaction among customers, proving detrimental to the company's reputations.



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**2. Cost efficiency:** A large portion of costs of a company is tied to the last-mile delivery of the company. Last-mile delivery is the most expensive and time-consuming part of the logistics chain, often accounting to 50% of total delivery cost. So naturally, ensuring cost efficiency in last-mile delivery becomes very important for a company.

**3. Environmental Impact and considerations:** As urban populations grow and online shopping increases, it is accompanied by increasing awareness among customers about traffic congestion and environmental degradation due to the vehicle emissions. Sustainable last-mile delivery solutions are therefore becoming more and more popular and vital in mitigating the adverse effects caused by the emissions on the environment.

### 1.2 Growing demand for sustainability and technological innovation

The global push for sustainability and technological innovation is gaining pace across industries, as businesses, governments, and consumers acknowledge the importance of addressing climate change and environmental degradation. From energy to transportation and agriculture, technical developments are critical to lowering carbon emissions, encouraging renewable energy, and increasing efficiency. Global investments in green technologies are anticipated to require around \$7.2 trillion by 2050 to satisfy the decarbonization goals.

Given India's fast urbanization and economic progress, there is a strong demand for sustainability. The country is already a global leader in renewable energy, generating 42% of its power from sustainable sources. India's ambitious target of achieving 500 GW of renewable energy capacity by 2030 demonstrates its commitment to sustainability. Government measures like the "National Green Hydrogen Policy" and a record \$14.5 billion investment in renewable energy in 2021-2022 highlight the country's concentration on low-emission fuels and green technologies.

The increasing demand for eco-friendly products, corporate social responsibility standards, and increasingly rigorous environmental regulations around the world, all contribute to the growing need for sustainable practices. This transition creates a major potential for innovation in energy and mobility sector like logistics.

### 1.3 Purpose of this Analysis

The goal of this analysis is to investigate the problems and advances in sustainable last-mile delivery technology, specifically in the Indian setting. With rising urbanization and the rise of e-commerce in India, last-mile delivery is critical for logistics, but it also adds considerably to pollution and congestion. This analysis incorporates real-time Indian case studies, including Amazon India's electric fleet program, Flipkart's EV adoption, and Zyp Electric's last-mile EV solutions, as well as Indian government regulations such as the Shooonya campaign. The analysis's goal in evaluating these case studies is to provide insights into how various stakeholders are solving infrastructure issues, legislative constraints, and technological improvements to produce more sustainable urban logistics. The results will help inform plans for balancing environmental responsibility and operational efficiency in India's growing last-mile delivery sector.

### 1.4 OBJECTIVES

1. Identify the primary hurdles to establishing sustainable last-mile delivery solutions in India, such as high costs, inadequate infrastructure, and regulatory constraints.
2. Explore and assess the effectiveness of sustainable technologies and initiatives, such as electric vehicles (EVs), self-driving delivery systems, and urban consolidation hubs, in reducing environmental consequences.
3. Showcase recent breakthroughs and case studies in sustainable last-mile delivery systems, emphasizing their relevance and potential advantages in India.

## II. REVIEW OF LITERATURE

**1. Techane Bosona (2020):** "Urban Freight Last Mile Logistics—Challenges and Opportunities to Improve Sustainability: A Literature Review" highlights several challenges and opportunities for enhancing sustainability. Bosona (2020) cites three important drivers of urban freight growth: population growth, urbanization, and e-commerce. The primary obstacles in LML are technological, infrastructure, and cost-related, resulting in inefficiencies like as delivery failures and increasing emissions. However, sustainable transportation options include electric vehicles, cargo cycles, and urban consolidation hubs. These methods strive to lessen the environmental and economic implications of urban logistics while also improving delivery efficiency.





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**2. Wassen AM Mohammad et.al :** The study "Innovative solutions in last mile delivery: concepts, practices, challenges, and future directions" examines the most recent changes in last-mile logistics, which are fueled by the advent of e-commerce. It investigates alternatives to traditional delivery methods such as drones, autonomous robots, smart parcel lockers, and crowdsourcing. These inventions seek to improve delivery efficiency and sustainability. The study, which analyzes over 80 papers, cites important hurdles such as regulatory concerns, cost-effectiveness, and infrastructure integration, while emphasizing the growing relevance of smart, sustainable delivery systems.

**3. Karaoulanis Andreas (2024):** This study provides a literature analysis of urban last-mile logistics in the context of smart cities, with an emphasis on novel technologies such as robotics, drones, and the Internet of Things (IoT) to promote sustainability. Following the SALSA approach and CASP checklist, the evaluation reveals the positive influence of Industry 4.0 technologies while also highlighting new initiatives such as dark stores and micro-fulfillment centers as essential contributors to more sustainable urban living. This novel literature review combines several critical features to provide new insights into last-mile logistics, making it a valuable resource for future academics studying this quickly growing topic.

**4. Thomas Maxner (2022):** In "Identifying the Challenges to Sustainable Urban Last-Mile Deliveries: Perspectives from Public and Private Stakeholders," Thomas Maxner and colleagues investigate the complex interactions between public and private organizations in urban freight systems. The report identifies significant obstacles such as insufficient leadership, a lack of resources, and the need for effective public-sector policy instruments through stakeholder interviews. Private organizations, on the other hand, confront technological and financial challenges when it comes to managing worker dynamics. The report emphasizes the importance of collaboration amongst sectors to effectively cut CO2 emissions and improve urban logistics sustainability.

**5. Vasco Silva et.al (2023) :** The research you cited conducts a systematic literature analysis of sustainable urban last-mile logistics, examining 102 studies to identify significant themes and potential solutions. It categorizes the findings into six thematic clusters: supply chain dynamics, delivery methods, novel vehicles, logistical infrastructures, operational optimization, and developing business models. The study stresses that there is no one-size-fits-all approach for last-mile logistics due to varied constraints and situations. Instead, it calls for a comprehensive approach that combines numerous concepts and encourages stakeholder engagement to address economic, environmental, and social concerns in last-mile delivery.

**6. Mohammed A Awwal et.al (2018):** This study "Sustainable Last-Mile Logistics Operation in the Era of E-Commerce" underlines the critical need for sustainable last-mile logistics operations, especially in light of expanding e-commerce. It explores a variety of options, including optimizing delivery routes with sophisticated technologies, deploying electric cars, and utilizing autonomous systems. The authors emphasize that smart fleet management and novel solutions, such as reception boxes and collection locations, can dramatically reduce carbon emissions and operating costs. Finally, the report recommends switching to greener logistical approaches to suit consumer demands while minimizing environmental impact.

**7. Shahryar Sorooshian (2022):** The paper "Toward a Modern Last-Mile Delivery: Consequences and Obstacles of Intelligent Technology" conducts a narrative literature analysis to investigate the impact of AI-powered technologies on optimizing last-mile delivery (LMD). It divides technologies into tangible (robots, drones, autonomous vehicles) and intangible (decision support tools, operating systems). The findings demonstrate that modern LMD may increase productivity and sustainability while satisfying changing consumer demands. However, difficulties that limit these gains are recognized, giving insights for practitioners and policymakers to improve supply chain performance.

**8. Sergio Maria Patella et.al (2021):** The paper titled "The Adoption of Green Vehicles in Last Mile Logistics: A Systematic Review" by Patella et al. conducts a systematic literature review focusing on the integration of green vehicles in urban freight, particularly e-commerce. It analyzes 159 articles, categorizing them into optimization and scheduling, policy, and sustainability. Key findings suggest that while green vehicles can excel in urban deliveries with frequent stops, their current adoption remains low, necessitating incentives. Autonomous vehicles are identified as a promising yet challenging solution for enhancing last-mile logistics efficiency



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9. **C. Nagadeepa et.al (2024):** This study "Last-Mile Delivery Innovations: The Future of E-commerce Logistics" delves into the essential difficulties of last-mile delivery in e-commerce. It emphasizes the revolutionary potential of upcoming technologies like self-driving cars, drones, smart lockers, and IoT. The study underlines that these innovations improve delivery speed and minimize operating costs while also increasing customer satisfaction through real-time tracking. Finally, it proposes a vision for a future marked by efficiency, transparency, and improved customer experience in logistics.

10. **H.D.Yoo et.al(2024):** The study "Drone-delivery Using Autonomous Mobility: An Innovative Approach to Future Last-mile Delivery Problems" by H.D. Yoo et al. offers a revolutionary delivery concept known as Drone-delivery using Autonomous Mobility (DDAM). This concept combines drone technology with self-driving trucks to address three major difficulties in urban logistics: rising delivery demand, shortening lead times, and lowering traffic congestion. Using Design Science Research methodology, the study assesses the DDAM idea through expert interviews, suggesting its practicality as an alternative delivery mode, particularly during peak demand periods, and underlining the potential of autonomous mobility in improving last-mile delivery.

### III. KEY CHALLENGES IN LAST-MILE DELIVERY

Last-mile delivery, particularly in terms of sustainability, has various challenges that limit efficiency and scalability. Companies must overcome a number of barriers to lessen their environmental effect, including infrastructural gaps such as a lack of charging stations, high costs, and legal challenges.

**1. Inadequate Charging Infrastructure:** One of the most significant obstacles to electrifying last-mile deliveries is a lack of broad charging infrastructure. Companies that have embraced electric fleets, such as Flipkart and Amazon India, struggle with few charging outlets, especially in semi-urban and rural locations.

**2. High Initial Costs of Electric Vehicles (EVs):** Electric vehicles (EVs) have high initial costs. While electric vehicles help to reduce pollutants, their initial costs remain a substantial obstacle. Small logistics organizations and startups confront difficulties in funding electric fleets due to their higher purchase price compared to traditional vehicles.

**3. Last-Mile Delivery Cost:** The cost of last-mile delivery remains expensive due to the added logistics required in metropolitan areas, particularly when EVs and drones are used. EVs can be cost-effective in the long run, but they demand a considerable initial investment. Furthermore, operational inefficiencies and infrastructural limitations raise last-mile delivery costs, making scale difficult.

**4. Fragmented Supply Chain Ecosystem:** India's logistics and supply chain environment is highly fragmented, with numerous small firms participating. This fragmentation causes inefficiencies in coordination, data sharing, and standardization, making it difficult to implement uniform sustainable practices throughout the entire ecosystem.

**5. Customer Expectations for Speedy Delivery:** With the rise of e-commerce, customers are increasingly expecting same-day or next-day deliveries, putting enormous pressure on businesses to prioritize speed above sustainability. Meeting such needs while attempting to implement environmentally responsible solutions remains a serious challenge.

**6. Lack of Standardization in Charging Solutions:** The absence of standardized EV charging stations or battery swapping infrastructure causes logistical difficulties. distinct EV models sometimes require distinct charging arrangements, limiting compatibility and slowing mainstream adoption.

**7. Resistance to Change from Traditional Practices:** Many logistics organizations have established rigid practices that are difficult to change. Resistance to implementing new technologies and approaches for sustainability might originate from company culture, fear of the unknown, or perceived dangers connected with innovation.

**8. Lack of Consumer Awareness:** Many consumers remain unaware of the environmental impacts of their delivery choices, leading to a lack of demand for sustainable delivery options. This gap in awareness can slow down the adoption of eco-friendly practices

### IV. SUSTAINABLE LOGISTICS IN LAST-MILE DELIVERY

**Electric Vehicles (EVs):** Major e-commerce players are adopting electric vehicles (EVs). Amazon India and Flipkart are switching their fleets to electric vehicles. Amazon wants to have 10,000 EVs in its fleet by 2025, with an emphasis on decreasing carbon emissions from its delivery operations. Startups such as Zypp Electric are making progress in this area by using electric two-wheelers for urban logistics, demonstrating a viable strategy for decreasing delivery emissions.



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**Battery Swapping and Fast Charging:** Exponent Energy has created methods for rapid charging and battery switching, which considerably solve concerns about EVs' limited range. Their technology permits rapid recharges, allowing delivery vehicles to remain operating while reducing downtime.

**Non-Motorized Delivery Solutions:** Cargo bikes and electric rickshaws are becoming increasingly popular as last-mile delivery options in congested urban areas. These modes of transportation lower emissions and are more maneuverable in traffic.

**Integrated Multimodal Transport:** Logistics organizations are implementing multimodal transport plans, which combine road, rail, and other modes of transportation to optimize delivery routes and reduce overall emissions. Collaboration between train networks and logistics firms is crucial in building effective delivery systems.

**Smart Logistics Technologies:** The combination of technology like IoT, AI, and big data analytics allows businesses to optimize routes, manage inventories, and forecast demand. This data-driven method reduces waste and improves the efficiency of last-mile deliveries.

**Sustainable Packaging Practices:** Companies are increasingly using eco-friendly packaging options, such as biodegradable and recyclable materials, to reduce waste. This endeavor coincides with the overall goal of sustainable logistics by decreasing the environmental footprint of the packaging process.

**Consumer Engagement and Awareness:** Educating consumers about the environmental impact of their delivery choices is crucial. Many companies are launching campaigns to promote sustainable delivery options, encouraging responsible consumer behavior.

### V. INNOVATIONS IN LAST-MILE DELIVERY TECHNOLOGIES

**Delivery Drones:** Drone technology is fast evolving, altering the logistics industry. Drones will be employed for a variety of logistical applications by 2024, including delivery and inventory management. Companies like Amazon and UPS are pioneering drone deliveries, intending to accelerate package delivery to consumers by flying autonomously and over traffic, dramatically lowering delivery times.

**Delivery Robots:** Robotic delivery solutions are being deployed in urban environments to handle small package deliveries autonomously. Companies like Starship Technologies and Nuro are pioneering this approach, providing cost-effective delivery options.

**In-app delivery tracking:** In-app delivery tracking is an innovative feature that improves the consumer experience in the logistics and e-commerce industries. It enables users to track their orders in real time, ensuring transparency and peace of mind throughout the delivery process.

**Blockchain for Transparency:** Blockchain technology is being investigated to improve transparency in the supply chain by allowing stakeholders to follow the movement of commodities in real time. This improves confidence between customers and suppliers.

**Mobile Warehousing:** The concept of mobile warehousing is to use cars as temporary storage units to fulfill orders closer to clients. This minimizes transportation expenses and expedites the delivery process. Companies such as Locus are incorporating this paradigm into their logistics strategy.

**Artificial Intelligence in Route Optimization:** AI algorithms are now being used to monitor traffic patterns and weather conditions in real time, recommending the best delivery routes. This technique improves delivery times and decreases fuel use.

**Advanced Analytics for Demand Forecasting:** Companies use advanced analytics and machine learning to increase demand forecasting accuracy. This enables them to improve inventory levels and cut delivery times by predicting consumer requirements.

**Warehouse management using Robots:** Amazon's warehouse management system uses Kiva robots to increase the efficiency of its fulfillment facilities. Kiva robots are designed to optimize inventory movement by autonomously transferring shelves or "pods" containing merchandise to human workers for picking and packing. This unique strategy dramatically lowers the time staff spend walking to get products, allowing them to focus on more productive duties such as assembling orders.



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### VI. GLOBAL CASE STUDIES AND EXAMPLES

#### Amazon's Struggle with Delivery Costs in Rural Areas

Amazon's last-mile delivery network confronts significant hurdles in rural regions due to the high expense of transporting products to sparsely populated areas. Costs increase due to a lack of infrastructure, longer distances, and fewer delivery volumes. Amazon has experimented with drone deliveries and collaborated with local carriers to cut costs. Despite these efforts, rural delivery remains a costly enterprise.

#### India's E-commerce Delivery Challenges

In India, the last-mile distribution sector faces infrastructure challenges, particularly in semi-urban and rural areas. E-commerce behemoths such as Flipkart and Amazon India have faced poor road conditions, uneven address systems, and security issues. To overcome these issues, they collaborated with local logistics providers and invested in hyperlocal fulfillment centers. Nonetheless, delivery delays and botched deliveries are still prevalent.

#### DHL's Struggles with Delivery Density

DHL has faced issues with delivery density, particularly in suburban and rural areas. The lower the delivery density, the less cost-effective the operation, because delivery people must travel greater distances between stops. To address this, DHL has adopted data-driven route optimization solutions and invested in micro-distribution centers to increase efficiency.

#### DHL's "Parcelcopter" Initiative

DHL has been testing drone technology as part of its "Parcelcopter" effort, which aims to overcome obstacles in remote deliveries. This initiative successfully tested drone deliveries in rural Germany, resulting in much shorter delivery times and lower prices. Drones may transfer items rapidly, avoiding traffic and difficult terrain. This innovation emphasizes the potential of drones to improve last-mile delivery efficiency, particularly in locations that are difficult to reach with traditional vehicles.

#### Walmart's Automated Fulfillment Centers

Walmart has deployed automated fulfillment centers, which use robotic technologies to streamline the picking and packing procedures. Walmart has increased the speed and accuracy of order fulfillment by combining autonomous robots with human workers. This case study demonstrates how automation in warehousing and last-mile delivery can contribute to operational efficiencies and a reduction in environmental impact through streamlined logistics.

#### FedEx's Same-Day Delivery Service

FedEx has introduced same-day delivery in select urban areas, utilizing a network of distribution facilities and modern tracking systems. This service promises to address growing demand for speedier deliveries while reducing carbon emissions. FedEx has invested in electric trucks and updated routing algorithms to improve the environmental sustainability of its delivery operations. This example emphasizes the significance of responding to consumer expectations and addressing environmental concerns.

#### IKEA's Use of Electric Vehicles

IKEA has incorporated electric vehicles into its last-mile delivery service to lessen its carbon footprint. This program supports IKEA's commitment to sustainability and lowering greenhouse gas emissions throughout its supply chain. By using electric delivery vans, IKEA not only improves its operating efficiency but also sets a model for other businesses to adopt sustainable logistics techniques.

#### Zipline's Drone Delivery in Healthcare

Zipline has transformed healthcare logistics by employing drones to transport medical supplies, blood, and vaccinations to remote locations in Rwanda and Ghana. This case study demonstrates how drone technology can help healthcare organizations overcome crucial logistical obstacles, particularly in areas with inadequate infrastructure. The Zipline model highlights the potential for drones to improve delivery speed and dependability in life-saving scenarios.





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### VII. CONCLUSION

Last-mile delivery has emerged as one of the most crucial and problematic components of modern logistics, particularly with the rapid rise of e-commerce and rising consumer expectations for speed and reliability. The difficulties addressed in this study, such as urban transportation congestion, rural delivery inefficiencies, and the critical requirement for sustainable operations, show the complications that businesses face.

Innovative technologies such as drone deliveries, electric vehicles, autonomous robotics, and improved warehouse management systems have enormous promise to address these difficulties. Specific difficulties in India, such as poor infrastructure, inconsistent addressing systems, and delivery inefficiencies in semi-urban and rural areas, are being addressed through hyperlocal fulfillment centers, electric delivery vehicles, and partnerships with local logistics companies. Globally, technologies such as route planning software, AI-driven data analysis, and warehouse automation are critical in modernizing last-mile delivery processes.

Sustainable last-mile solutions are critical not only for operational efficiency, but also for decreasing logistics' environmental impact. The industry is transitioning to greener, more cost-effective processes, but more innovation and scalability are needed to fulfill expanding demand while remaining sustainable. As technological advancements continue, the future of last-mile delivery appears bright, with the ability to balance cost, efficiency, and environmental footprint.

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