International Journal of Multidisciplinary Research and Growth Evaluation.

Last- mile challenges and recommended solution

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Article Info

ISSN (online): 2582-7138
Volume: 06
Issue: 02
March-April 2025
Received: 09-02-2025
Accepted: 10-03-2025
Page No: 1814-1818

Abstract
The last-mile delivery segment is the most expensive component of the supply chain, accounting for approximately 53% of total logistics costs. This is because of inefficiencies such as fragmented routing, lack of real-time tracking, delivery failures, and increasing consumer expectations for same-day or next-day deliveries which are implemented by ecommerce giants like Amazon. This paper presents an innovative approach leveraging AI for route optimization, micro-fulfillment centers, and crowd-sourced delivery models leading to reduction in last-mile costs while at the same time maintaining service quality. By integration of advanced analytics and automation, this solution improves operational efficiency, minimizes delivery lead times, and improves overall supply chain performance due to its heavy revenue contributing towards end o end supply chain.

DOI: https://doi.org/10.54660/.IJMRGE.2025.6.2.1814-1818

Keywords: Last-mile delivery, supply chain optimization, logistics cost reduction, artificial intelligence, micro-fulfillment, crowd-sourced delivery, logistics

Introduction

The last-mile delivery segment of the supply chain represents the final stage of product transportation from a distribution center to the end consumer. Following diagram shows last mile in traditional supply chain (Fig 1).

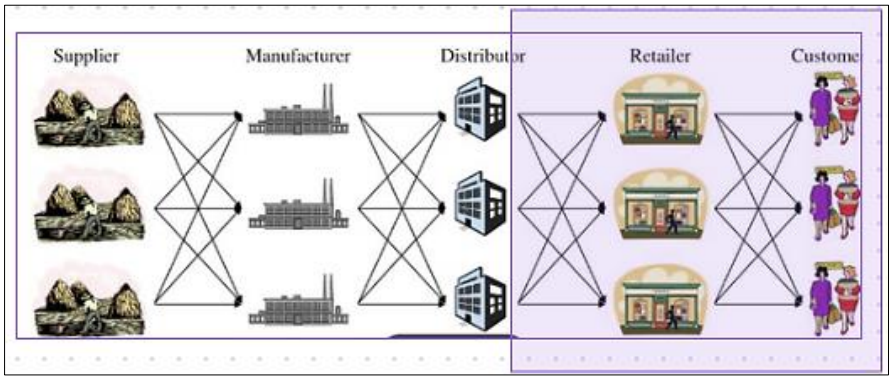

Fig 1

Distribution center is a generic term which is called differently based on the organization, example in modern supply chain like Amazon, last building is called Delivery Station and last mile is from Delivery Station to end customer. Studies indicate that last-mile delivery costs have surged by 20% over the past five years due to increasing e-commerce penetration and evolving consumer expectations [2].

This paper shows, data-driven approach to last-mile optimization using artificial intelligence (AI), micro-fulfillment centers, and crowd-sourced delivery models. The proposed solution aims to significantly reduce costs while enhancing the overall efficiency of supply chain operations. The discussion encompasses problem identification, detailed solutions, practical use cases and impact.

Last Mile Challenges

Out of multiple challenges faced by last mile, following are some important and high impact issues:

A.) High Cost: Usually the cost of running last mile is high and main factors contributing to it are:

- **Labor Cost**: Price of paying driver ages, Warehouse Staff wages and customer service is high.
- **Fuel Cost**: Fuel is important and ongoing expense in last mile.
- **Vehicle maintenance and depreciation**: Expense related to vehicle maintenance and reduction of vehicle value over the period of time is also considerably high.

B.) **Inefficient Route Planning:** Traditional routing algorithms lack the flexibility to adapt to real-time variables, resulting in suboptimal delivery performance. The key inefficiencies in route planning include:

- **Traffic Congestion**: Static route planning does not account for unpredictable traffic patterns, causing delays and increased fuel consumption.
- **Weather Disruptions**: Adverse weather conditions, such as heavy rainfall or snowstorms, impact delivery times and increase the risk of missed deliveries.
- **Dynamic Order Clustering**: Orders are often dispatched without intelligent grouping, leading to inefficient use of delivery resources.

Advanced route optimization technologies that incorporate machine learning, GPS tracking, and predictive analytics can address these challenges by dynamically adjusting delivery routes based on real-time data.

C.) Missed Deliveries: Studies indicate that 5-10% of last-mile deliveries fail due to customer unavailability, requiring redelivery attempts that significantly increase costs and inefficiencies [3]. The main causes of missed deliveries include:

- **Inaccurate Address Information**: Errors in address data result in misrouted or undeliverable packages.
- **Customer Absence**: Many consumers are unavailable to receive packages, particularly for time-sensitive or signature-required deliveries.
- **Lack of Real-Time Communication**: Inadequate coordination between delivery personnel and customers results in missed drop-offs.

Implementing proactive solutions such as real-time tracking, automated notifications, and flexible delivery windows can reduce missed deliveries and improve overall efficiency.

D.) Environmental Impact: The last-mile delivery process contributes significantly to carbon emissions, with urban freight accounting for nearly 30% of urban transport CO2 emissions [4]. Key factors contributing to the environmental impact include:

- **High Fuel Consumption**: Inefficient routing and missed deliveries increase fuel usage and emissions.
- **Traffic Congestion**: Increased delivery vehicle density exacerbates urban congestion and pollution.
- **Packaging Waste**: The rise of e-commerce has led to excessive packaging, further increasing the carbon footprint of deliveries.

E.) Demand for Speed: Consumer expectations for rapid delivery continue to rise, with 67% of shoppers expecting same-day or next-day delivery services [5]. This demand places immense pressure on logistics providers to enhance their capabilities while maintaining cost-effectiveness. Challenges associated with fast delivery expectations include:

- **Strain on Warehouse Operations**: Expedited shipping requires faster order fulfillment and inventory management.
- **Higher Delivery Costs**: Meeting tight delivery windows often necessitates premium shipping methods and additional labor resources.
- **Complexity in Urban Logistics**: Increased delivery frequency in congested urban areas adds to logistical complexity and operational inefficiencies.

To meet rising consumer demands, logistics providers must adopt innovative solutions such as micro-fulfillment centers, crowd-sourced delivery models, and AI-driven predictive analytics to streamline operations and ensure timely deliveries.

Consolidated Recommended Solution:

The proposed solution integrates AI-driven route optimization, micro-fulfillment centers, and a crowd-sourced delivery model to reduce costs and improve efficiency. Each of these components plays a crucial role in optimizing last-mile logistics by minimizing costs, enhancing operational effectiveness, and improving customer experience.

1. AI-Powered Route Optimization

- **Real-Time Traffic and Weather Analysis**: Advanced machine learning models continuously analyze real-time traffic conditions, weather disruptions, and roadblocks to adjust delivery routes dynamically. This ensures optimal delivery times and minimizes delays due to unforeseen circumstances.
- **Dynamic Order Clustering**: Instead of dispatching deliveries in a predetermined manner, AI-powered algorithms dynamically cluster orders based on geographical proximity and delivery urgency. This reduces unnecessary mileage, optimizes vehicle capacity, and enhances efficiency. Here is a diagram illustrating dynamic order clustering in last-mile delivery. The warehouse (WH) serves as the central hub, and AI-powered clustering dynamically groups orders based on geographical proximity (Fig 2.):

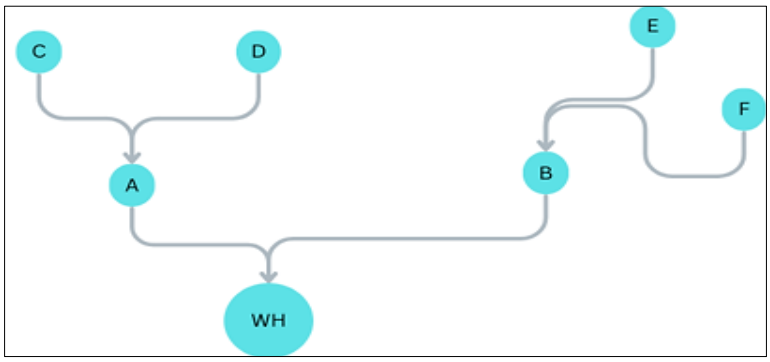

Fig 2

- **Predictive Demand Analytics**: AI models analyze historical order data, seasonal trends, and customer buying behavior to forecast demand. This enables proactive route planning and efficient resource allocation, leading to cost reductions.
- **AI-Driven Dynamic Pricing**: Machine learning models help implement variable delivery pricing, encouraging consumers to select cost-effective delivery windows. This reduces peak-hour congestion and balances logistics operations throughout the day, leading to lower operational expenses. Dummy example is as following: A logistics company, FastTrack Delivery, uses machine learning models to optimize delivery schedules for its customers. By analyzing historical data on traffic patterns, order volumes, weather conditions, and consumer behavior, the machine learning system predicts the best times for deliveries in terms of cost and efficiency. The company implements a pricing strategy where delivery costs vary depending on the time window chosen by the customer. For example:
- Deliveries requested during peak hours (e.g., between 4 p.m. and 7 p.m.) are more expensive due to the increased demand and traffic congestion.
- Deliveries scheduled during off-peak hours (e.g., 10 a.m. to 2 p.m.) are discounted, encouraging customers to select these time slots.
- Consumers are presented with these variable prices when placing their orders. The system uses machine learning algorithms to continuously refine the pricing model based on feedback, adjusting for factors like traffic patterns and delivery success rates.

Micro-Fulfillment Centers (MFCs)

1. **Localized Distribution Hubs**: Establishing small-scale, automated fulfillment centers in high-demand urban areas significantly reduces transit distances. These centers function as intermediate storage points for frequently ordered goods, expediting deliveries and reducing transportation costs.
2. **Automation and Robotics**: MFCs leverage robotics and AI-powered inventory management systems to streamline order processing. Automated order picking and sorting reduce labor costs by up to 40% and improve order accuracy [6].
3. **Reduced Delivery Distance**: Strategic placement of MFCs within densely populated areas decreases the average last-mile delivery distance by 30%, minimizing fuel consumption and optimizing resource utilization [7].
4. **Scalability and Flexibility**: MFCs provide businesses with a scalable solution to handle fluctuating demand. During peak seasons, additional fulfillment hubs can be activated to prevent bottlenecks and enhance delivery performance.

Crowd-Sourced Delivery Model

1. **Gig Economy Integration**: Utilizing freelance couriers and gig workers for last-mile deliveries reduces dependence on traditional fleet-based models. This flexible workforce allows companies to scale operations in response to varying demand, reducing fixed costs.
2. **Dynamic Driver Allocation**: AI-driven platforms match available drivers with delivery requests based on location, vehicle capacity, and real-time demand, optimizing delivery efficiency and reducing idle time.
3. **Cost Savings and Efficiency**: Studies indicate that integrating crowd-sourced delivery models reduces last-mile logistics costs by up to 25% compared to conventional fleet-based delivery methods [8]. Companies benefit from lower overhead expenses and improved service agility.
4. **Customer-Centric Delivery Options**: Crowd-sourced models enable businesses to offer same-day or on-demand delivery services at competitive rates, improving customer satisfaction and loyalty.

By combining AI-powered route optimization, micro-fulfillment centers, and a crowd-sourced delivery model, logistics providers can significantly enhance last-mile delivery efficiency, reduce operational costs, and meet growing consumer expectations. This integrated approach ensures a more agile, cost-effective, and sustainable last-mile logistics framework.

Advantages of the above consolidated model

The benefits of implementing this solution include:

- **Cost Reduction**: One of the most critical advantages of an AI-driven last-mile delivery model is its potential to significantly reduce operational costs. Traditional delivery models often suffer from inefficiencies such as suboptimal routing, unnecessary mileage, and excessive fuel consumption, all of which drive up costs. By utilizing AI-powered predictive analytics, real-time traffic data, and dynamic route optimization, companies can streamline their fleet operations, minimize idle time, and reduce delivery expenses. Studies indicate that AI-driven route optimization and automated dispatching can lower last-mile delivery costs by up to 30% [9].

  As shown in Table 1, AI-optimized delivery fleets can bring the average cost per delivery down from $10.00 to

$7.00, demonstrating a 30% reduction in expenses. Similarly, crowd-sourced delivery models, which leverage gig-economy drivers and decentralized networks, can reduce costs by 25%, offering an alternative cost-effective solution.

- **Improved Customer Experience**: With the rise of e-commerce and on-demand services, customers now expect faster, more transparent, and reliable deliveries. Delays, missed delivery windows, and lack of real-time tracking can lead to customer dissatisfaction and negative brand perception. By integrating AI-powered logistics management systems, companies can enhance delivery speed, improve tracking accuracy, and ensure higher fulfillment rates. According to research, implementing AI-driven delivery optimization and real-time tracking has led to a 20% increase in customer satisfaction [10]. Features such as precise estimated arrival times (ETA), automated notifications, and customer preference-based delivery scheduling improve the overall experience, leading to higher retention rates and brand loyalty
- **Sustainability**: Sustainability is becoming a top priority for modern supply chains, with regulatory bodies and consumers pushing for greener logistics solutions. Traditional last-mile delivery fleets contribute significantly to CO2 emissions, particularly in urban environments where fuel inefficiencies and congestion-related delays further increase carbon footprints.
- By leveraging AI to optimize delivery routes, reduce mileage, and promote eco-friendly transportation methods, companies can lower CO2 emissions by 15-20% [11]. Strategies such as route clustering, EV (electric vehicle) fleet integration, and hybrid delivery models contribute to more sustainable last-mile operations.
- **Operational Efficiency**: Efficiency in last-mile delivery is directly linked to speed, accuracy, and cost-effectiveness. The integration of micro-fulfillment centers, AI-based demand forecasting, and real-time fleet management can significantly improve warehouse-to-customer delivery times.

By reducing the distance between storage hubs and customers, micro-fulfillment centers enable quicker dispatch and better inventory availability. AI-driven models improve sorting, package handling, and order consolidation, leading to a 35% reduction in delivery times compared to traditional warehouse fulfillment models [12].

Table 1: Cost Comparison of Traditional vs. Optimized Last-Mile Delivery Models

Delivery Model	Average Cost per Delivery ($)	Reduction (%)
Traditional Fleet	10.00	0%
AI-Optimized Fleet	7.00	30%
Crowd-Sourced Delivery	7.50	25%

Application

The proposed solution is applicable across various industries, significantly enhancing efficiency, reducing costs, and improving customer satisfaction. Key industries that benefit from this approach include:

- **E-Commerce**: Online retailers rely heavily on last-mile delivery for timely and cost-effective fulfillment. AI-powered route optimization helps reduce delivery times, while micro-fulfillment centers strategically positioned near urban hubs enable faster order processing. Crowd-sourced delivery models provide flexibility during peak demand periods, ensuring scalable and efficient fulfillment solutions.
- **Grocery Delivery**: The grocery industry requires a highly efficient last-mile delivery system due to the perishable nature of products. Micro-fulfillment centers (MFCs) allow grocers to store high-demand items closer to consumers, reducing lead times and preserving product quality. AI-driven route optimization ensures that deliveries are completed efficiently, while crowd-sourced drivers enable quick, same-day fulfillment.
- **Healthcare & Pharma**: Timely delivery is critical in the healthcare sector, where pharmaceutical products and medical supplies must reach hospitals, pharmacies, and patients promptly. AI-powered logistics ensure the fastest and most reliable routes, reducing delays. MFCs enhance supply chain efficiency by storing critical inventory in strategic locations. Crowd-sourced models provide an additional layer of flexibility, particularly for urgent medical deliveries.
- **B2B Logistics**: Businesses involved in intra-city deliveries benefit from AI-driven route optimization, which improves scheduling efficiency and reduces transportation costs. Micro-fulfillment centers provide localized storage for essential supplies, ensuring just-in-time inventory management. Crowd-sourced delivery models offer a cost-effective alternative to traditional fleet operations, reducing dependency on dedicated delivery infrastructure.

By implementing these solutions across industries, companies can streamline operations, reduce costs, and enhance overall supply chain efficiency.

Conclusion

Optimizing last-mile delivery is imperative for reducing supply chain costs and improving operational efficiency. High delivery costs, inefficient routing, missed deliveries, and environmental impact necessitate innovative solutions. The proposed integration of AI-powered route optimization, micro-fulfillment centers, and crowd-sourced delivery models significantly reduces costs while enhancing service levels.

The use of AI-driven routing reduces unnecessary mileage and improves delivery speed. Micro-fulfillment centers enhance inventory management and shorten delivery times. Crowd-sourced delivery models lower labor costs while maintaining service quality. These innovations lead to cost reductions of up to 30%, improved customer satisfaction, and a more sustainable supply chain.

Future advancements in autonomous delivery and blockchain technology will further revolutionize last-mile logistics, ensuring continued cost savings and efficiency gains. The integration of AI, automation, and decentralized delivery models represents the future of logistics, promising an agile and cost-effective supply chain.

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