

The Final Frontier of Logistics: Artificial Intelligence in the Last Mile Delivery

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Abstract— Last-mile delivery (LMD), the most critical segment of the modern supply chain (SC), plays a vital role in shaping customer satisfaction but also accounts for the highest cost among all supply chain activities. Particularly in the context of e-commerce, it serves as a key differentiator while grappling with challenges such as rising customer expectations, urban traffic congestion, adverse weather, and sustainability concerns. This article explores how Artificial Intelligence (AI) and its subset, Machine Learning (ML), can be leveraged to optimize last-mile delivery. With the growing wave of digital transformation across the globe, this area is gaining increased attention. The article adds to the relatively limited body of research on this topic and concludes that AI and ML have the potential to significantly enhance supply chain efficiency, especially in last-mile delivery, by reducing costs, accelerating delivery speeds, and ultimately improving customer satisfaction.

Keywords— Artificial Intelligence, AI, Machine Learning, ML, Last-mile Delivery, LMD, Supply Chain, SC, Optimization.

1. Introduction

The significance of last-mile delivery (LMD) in modern commerce is undeniable. It stands out as a key competitive differentiator in the pursuit of customer satisfaction. Representing the final leg of a product's journey through the supply chain, LMD encompasses the movement of finished goods from a business's last dispatch point to the customer's doorstep. This crucial phase spans the entire spectrum of logistical operations, beginning at the manufacturer's final distribution hub and concluding at the consignee's delivery location. [1].

The widespread adoption of smartphones and the rapid global expansion of internet connectivity have transformed online shopping into a preferred mode

for consumers. This shift in behavior has compelled nearly every business to adopt an online presence alongside their traditional brick-and-mortar operations. With endless choices at their fingertips, today's consumers expect instant gratification, placing immense pressure on businesses to ensure fast, seamless, and reliable doorstep delivery with minimal delays.

The rise of quick commerce, which guarantees same-day or even within-hours delivery, has further amplified the demands on last-mile delivery (LMD). As a result, LMD has become the fastest-growing segment within supply chain management (SCM). [2]. According to U.S. Census data, e-commerce sales have experienced a consistent annual growth rate of 15% over the past decade, significantly outpacing the 4.4% growth rate recorded for total retail sales during the same period. [3]. In the fourth quarter of 2024 alone, U.S. retail e-commerce sales were estimated to have surpassed \$308 billion, reflecting a 2.7% increase over the previous quarter [4]. With rapid growth and expansion, the challenges associated with last-mile delivery (LMD) have also intensified and become more complex.

This article draws on real-world examples to provide meaningful insights into how businesses worldwide are navigating these challenges. The findings aim to help e-commerce companies better understand customer behavior, expectations, and preferences in an increasingly dynamic and competitive marketplace. By recognizing the critical link between customer satisfaction and LMD performance, businesses can make informed managerial decisions to enhance service quality, gain a competitive edge, and build lasting customer loyalty.

2. Literature Review

Last-mile delivery (LMD) represents the most critical phase of the supply chain in terms of influencing customer satisfaction and fostering brand loyalty. As the final stage in the logistics process, LMD directly affects key performance indicators such as operational efficiency, cost optimization, competitive positioning, and consumer experience. It functions as the concluding point of interaction between the business and the end consumer, thereby playing a pivotal role in shaping customer perceptions. This phase involves the physical transfer of goods to the customer's doorstep, underscoring its significance in achieving superior service quality and sustaining consumer loyalty. Despite its strategic importance, LMD remains the most resource-intensive segment of the supply chain and is associated with a multitude of operational and environmental challenges.

2.2 Challenges in LMD

The contemporary consumer landscape is characterized by a heightened demand for instant gratification. In response, on-demand and same-day delivery options have gained substantial traction. Both large-scale e-commerce enterprises and regional small- to medium-sized businesses are increasingly adopting expedited delivery models to accommodate time-sensitive customer expectations. This shift reflects a broader trend in consumer behavior, wherein speed and convenience are paramount, compelling businesses across the spectrum to adapt their logistics strategies accordingly. [6]. The following challenges are common to all of them.

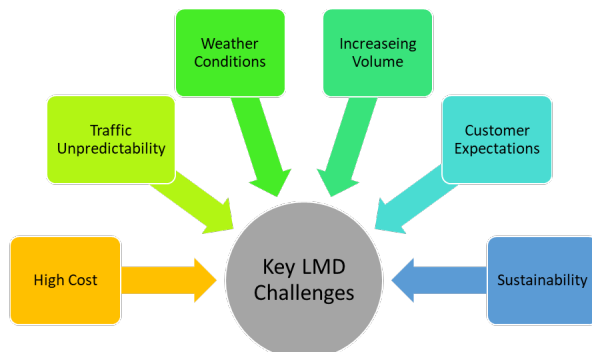


Figure 1: Key Challenges in LMD

2.2.1 High Costs:

The final leg of delivery constitutes a substantial share of overall transportation expenses, often representing more than half of the total shipping cost [7]. Specifically, last-mile delivery (LMD) is responsible for approximately 41% to 53% of the total supply chain costs [8].

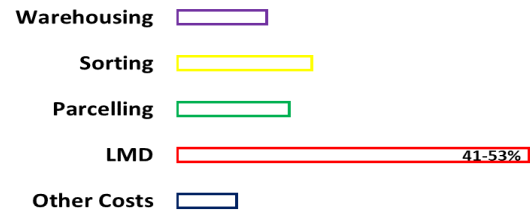


Figure 2: Breaking Up Supply Chain Cost

The rise in quick commerce has necessitated the adherence to stringent delivery schedules, such as same-day or next-day delivery, which places additional pressure on last-mile delivery (LMD) operations. This demand often overwhelms the existing vehicle fleet, resulting in time-consuming routes that frequently require driver overtime [9], leading to higher fuel consumption and, consequently, increased operational costs. Furthermore, the trucks utilized in traditional delivery models are often outdated and costly to maintain, exacerbating cost inefficiencies. Delivery expenses are further inflated by factors such as traffic congestion and limited parking availability on busy streets. Additionally, drivers face significant uncertainties regarding designated parking areas, precise customer addresses, and the availability of recipients, all of which contribute to operational inefficiencies and theft. [10]. It is crucial for corporate leaders to meticulously plan last-mile delivery (LMD) operations to prevent costs from accumulating and escalating rapidly. Urban areas present higher logistical expenses compared to rural regions, with the cost disparity becoming more pronounced when leaders fail to implement a strategic approach. For example, toll costs associated with LMD in the five boroughs of New York City can result in annual expenditures reaching six figures if shipping departments neglect to select optimal routes [5]. Moreover, traditional truck-based home delivery methods have reached their capacity in metropolitan areas and are increasingly

ineffective as a sustainable solution for urban logistics [10].

2.2.2 *Weather Conditions, Traffic Congestion, Parking & Other Issues*

Urban congestion and delivery density present significant challenges in last-mile delivery (LMD) planning. Traffic congestion, in particular, can severely affect delivery efficiency, leading to delays, missed delivery deadlines, and increased transportation costs [11]. The frequent navigation of unfamiliar neighborhoods by LMD drivers also increases the likelihood of route deviations or the risk of getting lost, further extending delivery times and exacerbating delays [12]. Delivery locations themselves are diverse, ranging from rural areas to residential buildings and urban commercial spaces, each posing its own unique set of challenges. For example, delivering goods to high-rise buildings often requires navigating complex security protocols and limited access points, adding to operational complexity. In contrast, deliveries to remote, suburban, or rural areas are hindered by greater distances and substandard infrastructure [6]. Additionally, adverse weather conditions, such as extreme heat, heavy snowfall, or prolonged rain, can serve as significant deterrents to timely deliveries, resulting in delays that drive up both storage and transportation costs [13].

2.2.3 *Unpredictability & Reverse Logistics*

A major challenge in last-mile delivery (LMD) is ensuring the availability of the customer at the designated delivery location on the scheduled date or time. If the recipient is unavailable for any reason or requests a rescheduling or re-attempt, additional costs related to storage and transportation are incurred. In cases where a delivery is cancelled at the last moment or the customer refuses to accept the package, the transportation costs are effectively doubled, with no corresponding sale. Depending on the seller's policies, a refund may also be issued to the customer. Furthermore, reverse logistics, which involves retrieving goods from the customer's doorstep and returning them to the warehouse, also incurs significant costs [14].

2.2.4 *Delivery Failures*

Incorrect or incomplete address information frequently leads to delays in the delivery process. These delivery failures can result in dissatisfied customers, potentially leading to reputational damage and additional costs for the business [15]. Additionally, delivery failures often arise when drivers face difficulties in completing deliveries on time due to restricted accessibility, such as in walled or gated communities, residential buildings, or remote rural areas [16]. Furthermore, distribution volumes can exhibit significant variability, influenced by factors such as seasonality, day of the week, or specific events, all of which require careful planning and resource allocation to ensure timely and efficient product delivery [17].

2.2.5 *Customer Expectations*

Consumers increasingly demand faster, more precise deliveries, with real-time tracking capabilities. They expect products to be delivered from fulfillment centers to their doorsteps with minimal delay following the placement of an order. Achieving such rapid delivery speeds requires meticulous and strategic last-mile planning [5]. While online shopping began gaining traction prior to the pandemic, it saw an exponential surge during the COVID-19 crisis, and post-pandemic growth has remained robust. Amazon's introduction of free two-day delivery in 2005 for its Prime subscribers has now evolved into one-day delivery for a select range of items. These exemplary customer services have significantly altered and elevated global customer expectations, making them more demanding [18]. Today, the cost, speed, and quality of delivery are pivotal factors influencing purchase decisions, establishing them as critical differentiators in the modern retail landscape [7].

2.2.6 *Sustainability*

Transportation plays a pivotal role in global carbon emissions, and the transportation industry is a key contributor to this environmental challenge. Consumer decisions are increasingly influenced by the availability of eco-friendly delivery options, which have become a critical determinant when selecting a business from which to purchase. The responsibility of balancing the demand for faster delivery with environmental sustainability falls

upon online retailers [19]. Companies must find ways to reconcile the need for speed with the imperative to reduce environmental impact while maintaining cost efficiency. Concerns regarding the environmental consequences of fast and free delivery options have escalated in tandem with the rapid growth in demand for last-mile delivery (LMD) services [20].

Conventional internal combustion engine (ICE) delivery vehicles are significant contributors to environmental pollution, emitting CO₂ and particulate matter that adversely affect both the environment and human health, and are key drivers of climate change and global warming. Additionally, the increased number of delivery vehicles, particularly in urban areas, exacerbates traffic congestion, leading to higher levels of idling and further emissions. Packaging waste also compounds the environmental challenges associated with the final-mile delivery sector. However, a positive shift is emerging, as a growing number of consumers, now more conscious of environmental issues, are willing to incur additional costs for eco-friendly delivery options. This trend places increasing pressure on businesses to adopt more sustainable delivery methods. Companies are now exploring ways to implement processes and policies that facilitate a green transition while striving to maintain profitability and operational efficiency [8].

3. AI & ML Solutions for Last-Mile Optimization

Logistics providers have come to realize that the mere ability to deliver the right product at the right time is no longer sufficient to meet the evolving demands of consumers. Online retailers now seek an additional attribute: clean delivery. In response to the myriad challenges associated with last-mile delivery (LMD), it has become essential for modern logistics providers to adopt and implement innovative strategies and solutions.

In the digital era, where technology permeates every facet of life, the adoption of Artificial Intelligence (AI) has emerged as a dominant trend across various business sectors [21]. The exponential growth in demand for doorstep delivery, particularly for small packages, poses a significant challenge for contemporary businesses [22]. To address these emerging issues, novel approaches are required to

overcome the difficulties inherent in last-mile logistics. Companies such as Amazon, DHL, Starship Technologies, and JD.com are investing heavily in AI technologies, including Machine Learning (ML), in order to develop and implement sustainable logistics and supply chain solutions more effectively.

Artificial Intelligence (AI), initially introduced as a means of automating complex business processes, has become integral to enhancing productivity, thereby fostering business growth and contributing to broader economic development. AI refers to machines capable of performing labor-intensive tasks traditionally conducted by humans, simulating human intelligence to some extent. These machines can replicate cognitive functions that are typically associated with human intellect, such as problem-solving, decision-making, and pattern recognition, making mundane tasks more efficient and error-free. From a human perspective, AI can be described as the "simulation of human intelligence by machines" that have been programmed to replicate human thinking processes, enabling them to perform tasks that once required human intervention [23, p. 2].

To address the challenges associated with last-mile delivery (LMD) discussed earlier, companies are increasingly adopting AI-driven algorithms, which are transforming last-mile logistics in several significant ways. The application of Artificial Intelligence (AI) and Machine Learning (ML) offers numerous advantages for LMD operations. This phase of the supply chain generates vast amounts of valuable data related to delivery operations, customer preferences, and various factors that influence the delivery process. By analyzing this data, businesses can derive actionable insights that enable them to predict consumer demand, optimize delivery routes, and enhance overall delivery efficiency.

The primary value of AI in LMD lies in its ability to manage even the most complex data sets effectively. AI facilitates the use of advanced data systems to generate datasets that can then be employed to monitor patterns and predict events within the delivery process. The most significant advantage of applying AI to LMD is its ability to develop predictive data models that leverage predictive analytics [24]. Through the powerful computational capabilities of AI, LMD operations can benefit from

more effective machine learning applications, optimizing processes and enhancing overall operational performance [23].

3.2 Dynamic Route Optimization

By leveraging AI and Machine Learning (ML) algorithms, logistics providers and enterprises can anticipate traffic patterns, identify the most time-efficient and cost-effective routes, and adapt to dynamic conditions in real-time. Route optimization algorithms and real-time data analysis are thus pivotal in providing advanced solutions for last-mile delivery (LMD). In simple terms, Machine Learning (ML) refers to computational techniques that enable systems to link a set of inputs to a predicted set of outputs by extracting knowledge from relevant data [25]. ML models analyze vast volumes of real-time data to generate valuable insights into traffic patterns, reveal trends, and predict delivery windows, allowing companies to plan the most accurate and efficient delivery routes [26]. These ML algorithms take into account factors such as customer preferences, traffic conditions, and delivery volumes to minimize travel distance and optimize delivery routes, thereby contributing to a reduction in overall delivery time.

Optimizing LMD operations has been particularly beneficial where third-party logistics (3PL) solutions have not produced the desired results. Enterprises often rely on 3PL providers to outsource various logistics functions, including distribution, warehousing, and fulfillment services [27]. The adoption of 3PL allows businesses to reduce their investment in fleet management while maintaining service quality. These providers typically handle a variety of tasks, such as picking up finished goods from warehouses or distribution centers, booking containers for transportation, and managing LMD operations. Service providers typically secure long-term contracts to cover long-distance transportation with carriers [28]. A key decision within this framework involves determining the volume of bins to book for transportation, which is heavily influenced by demand uncertainty and the potential for supply delays [29].

3.3 Real-time Data Analysis

Machine Learning (ML) enables real-time data analysis by allowing models to continuously learn, update, and adapt based on new data inputs. This dynamic process generates insights that assist in expediting decision-making [30]. The increasing accessibility of streaming data, although often not without cost, coupled with the growing demand for rapid decision-making, has contributed to the rise of real-time machine learning as a pivotal technology. Unlike traditional batch learning, which is confined to offline data processing, real-time machine learning advances by enabling systems to process data as it arrives, learn from it, and act accordingly. This capability facilitates the timely prediction of optimal moments and appropriate responses, paving the way for efficient decision-making [31]. Furthermore, real-time machine learning allows for spontaneous adjustments, enabling enterprises to adapt to fluctuating conditions, thereby optimizing operational efficiency.

AI and ML technologies also play a critical role in enhancing LMD by facilitating the use of advanced machines, such as autonomous vehicles, robots, and drones. These innovations help increase delivery speed while reducing reliance on human drivers. Additionally, AI and ML technologies enable customers to track their deliveries through real-time data, providing them with accurate delivery-time estimates. Notifications regarding expected delivery times, sent via email, SMS, or mobile applications, improve communication between customers and logistics providers, reducing uncertainty and enhancing transparency [32].

3.4 Predictive Analysis for Demand Prediction and LMD Time Estimation

Predictive analytics encompasses a broad range of algorithms and methodologies that enable AI to forecast delivery times based on historical data and external variables, thereby improving both customer communication and operational efficiency for enterprises [26]. Additionally, predictive analytics aids in demand forecasting and production planning, ensuring that production levels are aligned with demand. This helps prevent surplus inventory accumulation while also mitigating the risk of production shortfalls during periods of heightened demand. Machine learning models are particularly

effective at predicting demand fluctuations, such as the increased demand for goods during peak seasons like Christmas or Halloween, allowing logistics companies to optimize workforce allocation and fleet utilization accordingly [33]. Furthermore, AI facilitates personalized deliveries by integrating customer preferences, including preferred delivery times and locations (e.g., home or office), which significantly enhances customer satisfaction.

3.5 Sustainable LMD Solutions

According to forecasts by the World Economic Forum, e-commerce demand has experienced a significant surge, and to accommodate this remarkable growth, the number of e-commerce delivery vehicles operating within modern cities is projected to rise by 36% by the end of this decade [34]. In response to this rapid expansion, there is an increasing demand for last-mile delivery (LMD) solutions that prioritize environmental sustainability. These solutions are typically assessed based on their contributions to reducing carbon footprints and promoting social welfare. In order to satisfy consumer expectations while minimizing environmental impact, modern businesses are increasingly adopting delivery strategies that incorporate sustainability metrics, such as reducing carbon emissions, implementing ethical labor practices, and supporting local communities [35]. AI and ML are playing a pivotal role in driving supply chain sustainability through optimization processes, which help reduce waste, improve resource efficiency, and ultimately contribute to the creation of greener and more resilient supply chains [36].

4. Discussion

Last-mile delivery (LMD) is crucial to the success of e-commerce businesses, particularly within the realm of quick commerce. Artificial Intelligence (AI) provides essential solutions to transform LMD by optimizing routes, forecasting demand, and supporting autonomous delivery systems. These advancements result in faster, more efficient, and cost-effective solutions for businesses, while simultaneously enhancing customer experiences [37]. AI's capabilities extend to predicting customer demand, optimizing inventory levels, and anticipating potential challenges, enabling businesses to proactively adjust operations and improve efficiency.

It is evident why major enterprises such as UPS, FedEx, and Amazon have integrated AI-powered route optimization platforms. In addition to being cost-effective, these AI-driven solutions reduce emissions and provide faster, more efficient product delivery. Amazon, a pioneer in same-day delivery, employs an AI system that processes vast amounts of data to identify the most efficient and economical delivery routes, avoiding traffic congestion to ensure timely deliveries. AI-powered route optimization is revolutionizing logistics and transportation by enabling businesses to enhance supply chain efficiencies and streamline product deliveries, from food and beverages to other consumer goods [38]. Therefore, it is clear that AI-based route optimization (AIRO) not only accelerates delivery speed and reduces costs but also contributes to greater customer satisfaction, ultimately driving business growth.

4.1 Real Life Instances – Success Stories

United Parcel Service (UPS) has invested significantly in AI to enhance their operations, improve efficiency, and provide better customer service.

4.1.1 UPS's AI Initiatives:

In 2023, United Parcel Service (UPS) started using generative AI to help modernize and rationalize its customer service operations.

Message Response Automation & Language Translation: UPS has already seen tangible benefits from its Message Response Automation (MeRA) project, which it developed in-house to improve operational efficiency and customer interaction [39]. In the context of rapid technological advancements, UPS has positioned itself as a pioneer in utilizing AI to reshape the logistics sector. With a vast global footprint and millions of deliveries per day, the company faces unique challenges, requiring the integration of cutting-edge solutions to enhance both operational efficiency and customer satisfaction while maintaining sustainability.

By leveraging AI, UPS has transformed its Last-Mile Delivery (LMD) operations, focusing on key areas such as optimizing delivery routes, improving package sorting systems, and refining fleet maintenance practices. These technological advancements have not only streamlined operations but also addressed environmental challenges by incorporating more sustainable practices into their

logistics model [40].

Moreover, UPS's Languages Across Logistics (LAL) platform, powered by AI, translates over 20 languages, enabling better communication among its diverse global workforce. This technology helps bridge language barriers, fostering a more inclusive and harmonious work environment. The LAL platform supports the recruitment of employees from numerous countries, reinforcing UPS's commitment to diversity and inclusivity in its workforce [41].

Route Optimization: UPS's AI-powered On-Road Integrated Optimization and Navigation (ORION) system is a groundbreaking tool that has revolutionized the logistics industry by applying advanced data analytics and dynamic optimization techniques. By streamlining operations and reducing costs, ORION not only enhances the efficiency of delivery routes but also makes them more environmentally friendly [42].

ORION utilizes AI and sophisticated algorithms to analyze a massive volume of data, such as traffic patterns, package destinations, and delivery deadlines. This allows the system to generate the most efficient delivery routes in real-time, minimizing redundant mileage and optimizing the sequence of stops for drivers. One of the system's key advantages is its ability to make dynamic adjustments to routes during the day, helping drivers avoid traffic congestion and respond to last-minute delivery requests, ensuring minimal disruptions.

The impact of ORION has been substantial. The system has reduced the annual distance traveled by UPS delivery trucks by 100 million miles, resulting in an approximate annual savings of \$300 million. Furthermore, ORION has helped reduce CO₂ emissions by over 100,000 metric tons per year, making UPS's operations more sustainable [43]. Beyond route optimization, ORION plays a pivotal role in improving customer satisfaction and

supporting UPS's growth by enabling more reliable and efficient deliveries.

Automated Facilities: The UPS Velocity facility represents a cutting-edge model in the logistics and e-commerce sector, harnessing over 700 AI-driven robots to streamline package handling and storage, thus enhancing operational efficiency and the overall quality of services. The facility integrates a variety of advanced technologies, including artificial intelligence, machine learning, and smart automation, which significantly boost UPS's ability to meet the increasing demands of modern e-commerce [44].

One of the standout technologies employed in the Velocity facility is the Goods-to-Person technology, which optimizes space and speeds up activities by bringing inventory directly to the worker, reducing handling time and improving productivity. Additionally, Rack-to-Person technology enhances storage efficiency by allowing UPS to achieve 30% more storage optimization compared to facilities lacking this innovation. As one of the largest and most technologically sophisticated facilities in UPS's network, Velocity exemplifies the future of e-commerce logistics, offering a blueprint for scalable and efficient operations.

Despite global trade disruptions, the e-commerce market continues to experience significant growth. Global retail e-commerce sales are projected to exceed \$4.3 trillion, with the global e-commerce market size in terms of revenue expected to reach \$28.02 trillion by 2028, up from \$11.04 trillion in 2021 [45]. This represents a projected annual growth rate of around 15% from 2022 to 2028 [46], underscoring the expanding role of e-commerce and logistics in the global economy.

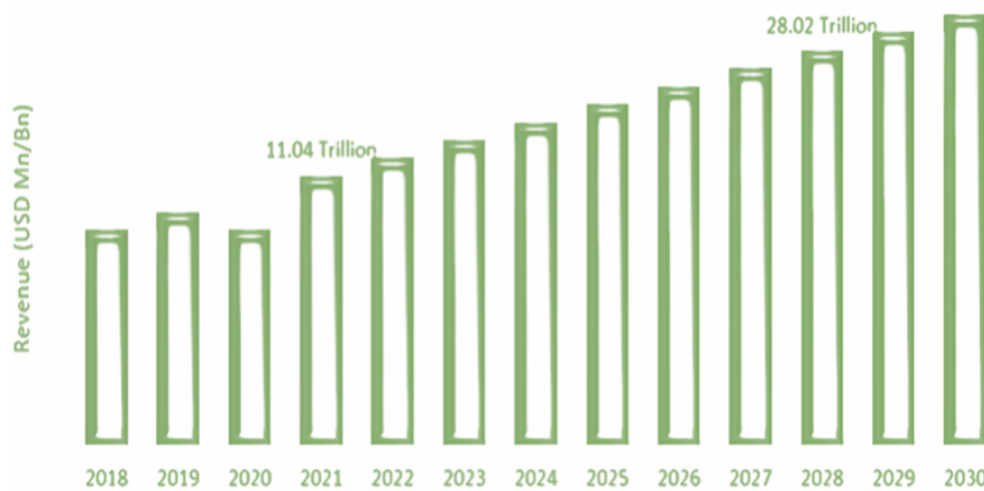


Figure 3: Global e-commerce market to grow at a CAGR of nearly 14.8% over the period from 2022 to 2028 [45]

UPS Velocity was specifically designed to meet the growing demands of the e-commerce market and to position UPS for future growth. With its ability to process over 350,000 items per day, the facility is a significant leap forward compared to traditional, non-automated warehouses. This impressive processing capacity enables UPS to fulfill orders with much higher speed and efficiency, which is crucial to meeting the fast-paced expectations of today's customers.

The integration of automation and AI at UPS Velocity ensures that the company remains competitive in a rapidly evolving logistics landscape, providing timely deliveries while reducing operational costs and increasing overall capacity. This facility is not only a response to current market demands but also a strategic investment to tap into future growth in the e-commerce sector [47].

Real-Time Data Integration: The On-Road Integrated Optimization and Navigation (ORION) system is a cornerstone of UPS's operational efficiency and environmental sustainability efforts. By continuously processing real-time data from GPS devices, traffic monitoring systems, weather updates, and other sources, ORION generates optimized delivery routes that adapt dynamically to changing road conditions. This adaptability ensures that UPS can consistently meet its delivery promises while significantly reducing inefficiencies such as idle driver time and fuel consumption.

The AI platform's ability to analyze vast amounts of real-time data allows it to optimize routes in real-time, accounting for factors like traffic patterns, construction zones, and regional delivery trends. The result is not only reduced fuel consumption but also lower emissions and a more efficient delivery process. Each year, the ORION system shortens delivery routes by millions of miles, leading to substantial cost savings on fuel and labor.

Furthermore, this optimization boosts UPS's delivery speed and reliability, improving both financial and operational efficiencies. By continuously refining its approach to route optimization through AI, UPS enhances its ability to meet customer expectations while maintaining sustainability goals [48].

AI-Powered Predictive Analysis: The dynamic nature of global markets means that consumer demands can shift rapidly, creating both challenges and opportunities for logistics companies. UPS leverages predictive analytics to anticipate these fluctuations, ensuring that the company is prepared for peak demand periods, such as during holidays or festive seasons. By utilizing AI to analyze historical data, UPS can forecast delivery volumes and make the necessary logistical adjustments ahead of time. This predictive capability helps the company optimize resource allocation, ensuring that it has the right number of vehicles, drivers, and warehouses in place to meet demand. It also minimizes potential delays, reduces the risk of interruptions, and

prevents overloading during times of heightened demand. As a result, UPS can maintain operational efficiency and uphold service quality, even during the busiest times of the year [40].

Sustainability & Security Enhancements: A critical benefit of UPS's AI-driven logistics is its significant reduction in carbon footprint. By eliminating unnecessary miles and optimizing vehicle loads, ORION helps the company reduce fuel consumption and lower carbon emissions. UPS further strengthens its commitment to sustainability by integrating electric vehicles (EVs) and alternative-fuel vehicles into the routes optimized by its AI initiatives. Thanks to AI and machine learning (ML) technologies, UPS saves more than 10 million gallons of fuel annually and reduces carbon emissions by over 100,000 metric tons each year. These impressive savings underscore the substantial economic and environmental benefits that UPS achieves through the application of AI-driven route optimization in the logistics sector [49].

The surge in online shopping, fueled by the growth of e-commerce and the widespread use of internet-enabled smart devices, has led to a significant increase in doorstep package deliveries. This, in turn, has contributed to a rise in package theft. In response, UPS has implemented the DeliveryDefense system, which uses artificial intelligence (AI) and machine learning (ML) to assess various factors, such as location, frequency of shipment losses, and the number of delivery attempts. By analyzing this data, the system predicts the likelihood of successful deliveries while also enhancing package security [50].

Additionally, UPS integrates Striim's real-time data streaming technology with Google BigQuery's analytics capabilities to further enhance delivery security. Striim's platform allows real-time ingestion and integration of data from multiple sources, enabling real-time risk assessments. This helps UPS to make proactive decisions that improve the security and reliability of its deliveries [51].

4.1.2 *FedEx's AI Initiatives*

Federal Express, or "FedEx," is a U.S.-based multinational conglomerate with an impressive annual turnover of \$94 billion. The company offers a broad range of transportation, e-commerce, and business services to customers and businesses

worldwide [52]. Headquartered in Memphis, FedEx is renowned for its flagship service, FedEx Express, which is recognized for its investments in express transportation and its commitment to providing fast and reliable shipping solutions globally. FedEx has become a major player in the logistics and supply chain industry, continuously innovating to meet the evolving demands of its customers.

Supply Chain Optimization: The optimization of various aspects of its supply chain (SC) involves the use of AI technology by FedEx, particularly in areas such as real-time shipment routing and last-mile delivery (LMD). These efforts contribute to substantial cost reductions while simultaneously improving service quality. In a significant collaboration with Microsoft, FedEx has developed an innovative package analytics system known as FedEx Surround [53].

FedEx, one of the largest global express transportation companies, provides reliable and fast delivery services to over 220 countries and territories worldwide. With its extensive air-and-ground network, the company ensures time-sensitive shipments are delivered with precision and speed. FedEx is leveraging data-driven, intelligent solutions to build smarter logistics for its customers, and the introduction of FedEx Surround is a testament to that vision.

FedEx Surround is a cutting-edge, AI-powered solution designed to revolutionize supply chain management by offering businesses superior control over their shipments and enhanced visibility [54]. The use of AI tools extends beyond tracking to provide real-time interventions in logistics management. This smart solution actively manages shipments as part of a strategy for risk mitigation, rather than merely monitoring them. By utilizing AI and machine learning, FedEx Surround can predict potential delays and disruptions in LMD, enabling businesses to make quicker, more informed decisions.

Investment in Nimble: To enhance its e-commerce fulfillment services, FedEx has made a strategic financial investment in autonomous e-commerce technology, particularly AI-driven robotics, through its partnership with the technology company Nimble [55]. This collaboration aims to streamline FedEx's supply chain operations, improve inventory management, and boost its efficiency in order

handling [56]. Through this alliance, FedEx plans to leverage Nimble's fulfillment centers to expand its FedEx Fulfillment services, which focus on order fulfillment and inventory management for small- and medium-sized enterprises (SMEs) [57].

FedEx's comprehensive approach helps omnichannel brands and e-commerce companies make smarter supply chain decisions more quickly [58]. The company operates over 130 warehouses and fulfillment centers across North America, processing 475 million returns annually. FedEx Supply Chain supports brands by consolidating functions, improving agility, and accelerating the click-to-door speed, which ultimately helps e-commerce companies maximize value throughout their supply chain [55].

This investment in Nimble is expected to further enhance FedEx's supply chain capabilities across North America by integrating Nimble's automated third-party logistics (3PL) solutions. The strategic partnership and investment are designed to expand FedEx's e-commerce footprint and scale up its FedEx Fulfillment offering across the continent [59].

Robotic Automation: FedEx's collaboration with companies like Berkshire Grey has enabled the integration of AI-powered robotic systems into its package handling operations, enhancing both safety and efficiency in sorting and processing packages [60]. FedEx Ground, a subsidiary of FedEx Corp, has partnered with Berkshire Grey to deploy Robotic Product Sortation and Identification (RPSi) systems, which are designed to automatically organize small-sized packages that arrive daily for distribution.

The initial installations of RPSi systems have been carried out at eight sortation facilities, including locations in Las Vegas, Nevada, Queens, New York, and Columbus, Ohio. FedEx Ground has expanded the deployment to other select facilities within its supply chain network [60]. These systems are specifically designed to automate tasks traditionally performed by human labor, such as picking, identifying, sorting, collecting, and containerizing individual packages like polybags, padded mailers, tubes, and other small items that were conventionally handled manually [61].

The application of AI and machine learning in this context significantly accelerates the sorting process

and reduces human error, ultimately improving efficiency and accuracy in FedEx's operations. This innovation plays a crucial role in scaling up the company's operations to meet the increasing demands of e-commerce.

5 Other Emerging Solutions

A critical consideration when relying on predictive analytics is that while historical data can provide valuable insights into patterns of consumer behavior and traffic conditions, it is not foolproof. Predictive models are based on past data, and there is no guarantee that future events will unfold in the same way. This reliance on historical data means that any unforeseen disruption—such as a sudden market shift, an unforeseen crisis, or an event that has never occurred in the past—may not be adequately predicted or prepared for. This limitation can leave companies vulnerable, potentially leading to significant operational and financial setbacks.

As a result, businesses are exploring alternative delivery methods to adapt to these challenges. Autonomous vehicles and drones have gained attention as potential solutions for last-mile delivery (LMD), offering advantages like avoiding traffic congestion and efficiently accessing remote or hard-to-reach areas. While these technologies are still evolving, they hold promise to improve delivery efficiency. As adoption and technology progress, these methods are expected to become more cost-effective, providing significant advantages in logistics.

Another viable strategy gaining traction is collaboration. Several companies are exploring partnerships and alliances to optimize LMD. Crowdsourcing platforms, for instance, enable local couriers or independent delivery service providers to connect quickly with nearby pickup and delivery requests. This approach leverages existing resources, reducing costs for logistics providers while allowing greater flexibility and speed in deliveries.

Micro-fulfillment centers (MFCs) also present a powerful solution to address the growing demands of e-commerce. These small-scale warehouses, strategically located close to urban areas, allow for faster deliveries by reducing the distance between inventory and customers. By decentralizing storage

and placing products closer to where customers live, companies can reduce delivery time, cut transportation costs, and improve overall efficiency.

Together, these strategies—autonomous vehicles, crowdsourcing, and micro-fulfillment centers—represent promising alternatives that complement predictive analytics and could help companies mitigate risks, overcome disruptions, and stay competitive in the evolving logistics landscape.

6 Conclusion

As the logistics ecosystem continues to evolve both domestically and internationally, businesses are increasingly developing in-house technologies or partnering with specialists to create innovative supply chain (SC) solutions. The focus is on accelerating delivery times and enhancing customer satisfaction, with last-mile delivery (LMD) being a key success driver in this process. The growing demand for efficient LMD solutions presents both opportunities and challenges for companies, as they look to optimize operations while addressing the complexities of urban congestion and remote delivery needs.

To meet these challenges, many companies are leveraging sophisticated AI and machine learning (ML) technologies to enhance their LMD operations. For instance, outsourcing delivery to third-party logistics (3PL) providers or engaging local delivery services with established networks allows businesses to fulfill orders more quickly. However, these options also require the use of advanced technologies for route optimization, especially in congested urban areas or challenging remote terrains, where delivery times can be unpredictable and resource allocation can be tricky.

In addition to technology-driven solutions, there is a growing interest in eco-friendly alternatives, such as electric vehicles (EVs) and bicycles for urban deliveries. EVs, for instance, significantly reduce carbon emissions and cut down on noise pollution while ensuring efficient deliveries. However, challenges such as the initial cost of adoption, range anxiety, and the need for charging infrastructure still hinder widespread adoption. EVs also don't address all LMD challenges, particularly when it comes to route optimization, demand prediction, and inventory management. This is where AI and ML

come into play, helping to address these issues by providing data-driven insights and solutions.

In summary, as logistics companies strive to meet the growing demand for efficient and eco-friendly LMD solutions, the integration of AI and ML technologies is becoming indispensable. These technologies not only enable smarter route optimization and demand forecasting but also support the adoption of sustainable practices, such as EVs and bicycles, without compromising on operational efficiency or customer satisfaction.

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