ISSN 2347 - 3983
Volume 12. No.11, November 2024
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter0112112024.pdf
https://doi.org/10.30534/ijeter/2024/0112112024

Last-Mile Delivery Optimization: Balancing Cost Efficiency and Environmental Sustainability

Segbenu Zosu Ph.D. [1], Cyril Amaghionyeodiwe Ph.D. [2], Elkannah Oyetunji Ph.D.[3], Abideen Yussouf Ph.D. [4]
[1]Lagos State University of Education, Nigeria, zosujoseph@yahoo.com
[2]Micheal Okpara University of Agriculture, Nigeria, amaghionyeodiwe.cyril@mouau.edu.ng
[3]Lagos State University. Nigeria, eoyetunji@yahoo.com
[4]Lagos State University, Nigeria, abiodun.yussouf@lasu.edu.ng

Received Date: October 01, 2024 Accepted Date: October 30, 2024 Published Date : November 07, 2024

ABSTRACT

The significance of last-mile delivery in supply chains has increased due to the growth of e-commerce. Last-mile delivery (LMD) is responsible for a large amount of the environmental impact and overall logistical costs. In order to balance economic effectiveness and environmental sustainability in last-mile delivery operations, this article examines optimization options. The study used a descriptive design; collected and analyzed quantitative data. Key players in last-mile delivery, including logistics firms, online merchants, and delivery service providers, who were given surveys via Google Forms to collect primary data. The topics covered included cost structures, environmental issues, current optimization techniques, and practices. Data on current last-mile delivery strategies, optimization techniques, and environmental sustainability projects were gathered through a literature review. With a case study in Lagos, Nigeria, the study focused on metropolitan areas. Participants with substantial last-mile delivery and logistics experience were chosen using a purposive sample technique. Twenty logistics and supply chain managers, ten couriers and delivery drivers, ten owners of e-commerce businesses, thirty customers, five transportation and logistics service providers, five sustainability specialists, eight city officials and urban planners, and seven technology providers were included in the sample. The analysis with statistical methods, such as table and charts, was used to analyzed the participants opinions. The paper contributes to the growing body of literature that links supply chain efficiency with sustainability goals.

Key words: Last-Mile Delivery, Optimization, Balancing Cost Efficiency, Environmental Sustainability, E-Commerce

1. INTRODUCTION

The rise in e-commerce and urbanization has made the logistics industry—and last-mile deliveries in particular—even more crucial. A major operational difficulty is last-mile delivery, which is the last stage of the delivery process from distribution centers to end users. On the one hand, timely deliveries are essential for guaranteeing client pleasure. However, because it is expensive and increases carbon emissions, it is a field where environmental and economic objectives sometimes conflict. Cost effectiveness is given priority in traditional logistics methods, but sustainability is frequently sacrificed in the process.

.

Figure 1: The image showing things happen in Last-Mile Delivery

Last-mile distribution has become increasingly problematic in urban areas worldwide in the wake of e-commerce and its effective spread in the majority of commercial activities [9]. Figure 1 show an illustration of a Last Mile Delivery System. Customers expect instant delivery in modern food supply chains, which makes last mile logistics crucial [48]. It enables carriers to deliver more goods to customers more quickly and affordably. For the greatest number of customers who fall into the "need-it-now" category—which includes the freshness and high-quality index of the food chain—quick delivery is crucial. Over the past ten years, e-commerce has been steadily expanding. Critical logistical issues have been brought to light by the expansion of online retailing, particularly in the last distribution leg, also known as the "Last Mile" [39]. According to recent studies, traditional home delivery by truck has hit its limit in urban areas and is no longer a viable delivery option. Advances in technology have led to the

implementation of various different logistical solutions as creative substitutes for parcel delivery [39]. Last mile delivery logistics (LMD) has emerged as one of the primary competitive services offered by online retailers, according to [46]. The final leg of the delivery process to final customers is known as "last-mile delivery," and it is crucial to guaranteeing the client experience. In addition to improving the customer experience, efficient LMD has a major influence on lower transportation costs, fuel emissions, and resource usage. At the same time, it is dealing with problems including parking, unsuccessful deliveries, and rising gasoline expenses. Figure 2 shows blend of efficient delivery systems, electric vehicles, and sustainability elements like green energy.

Figure 2: An illustration depicting last-mile delivery optimization in production, featuring a blend of efficient delivery systems, electric vehicles, and sustainability elements like green energy

These days, e-commerce is spreading throughout the world along with the growing demand from consumers for online purchasing. Furthermore, although it remains at the very end of the online purchasing process, last-mile delivery (LMD) is an essential part of the complete logistical chain for e-commerce. LMD makes up 28% of all supply chain movements [20], and depending on different regional features, it can account for 13% to 37% of the total cost of the supply chain [16]. These figures show that poorly managed LMD operations can have a detrimental impact on logistics service providers. End consumers can enjoy "the convenience, simplicity, information, and time efficiency of online shopping" through successful LMD operations. These elements are critical to the success of an e-commerce service provider [14]. In order to address the environmental and social issues that countries throughout the world confront, sustainable supply chains are becoming more and more important. A crucial part of the supply chain is last-mile delivery, which entails moving goods from a warehouse or distribution center to the ultimate location, usually a customer's doorstep [33]. Academic interest in last mile logistics has grown dramatically in tandem with the rapid expansion of omni-channel shopping, urbanization, shifting consumer behavior, and greater emphasis on sustainability [44].

Demand for effective and convenient last-mile delivery solutions has increased due to the growth of e-commerce, prompting research into innovative and promising technology like drones [58]. Last-mile delivery has grown in importance within the global supply chain in recent years. In order to improve the overall efficiency of the supply chain, there has been a growing global interest in creating last-mile delivery robots and vehicles [23]. Figure 3 shows a chart of innovations to be made in Last Mile Delivery. The cost-effective delivery of goods to every client is one of the major issues facing last-mile delivery in the midst of the explosive expansion of online retail. Meeting client expectations—such as timely delivery, package security, and customer service—determines the quality of the service. The last-mile delivery phase of the package shipping process is one factor that influences delivery timeliness [54].

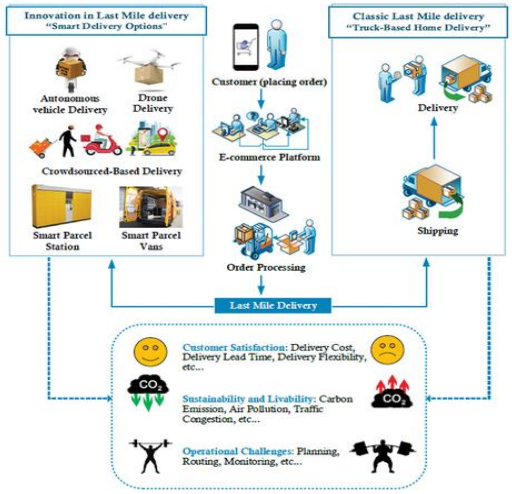

Figure 3: Mile-Delivery Image. Extracted from [39]

Problem statement

41% of supply chain expenses are related to last-mile delivery, and transportation-related emissions are a major cause of both air pollution and climate change [35]. Designing last-mile delivery systems that minimize environmental effects while also optimizing costs is a challenge. For contemporary businesses dedicated to fulfilling environmental goals and practicing corporate social responsibility (CSR), this balance is crucial.

Objectives

This research aims to:

1. Explore current challenges and opportunities in last-mile delivery optimization.

2. Analyze the trade-offs between cost efficiency and environmental sustainability.

3. Propose optimization strategies that balance these dual objectives.

Research Questions

1. How can last-mile delivery systems be optimized to reduce both costs and environmental impacts?
2. What technological and operational innovations are most effective in balancing these goals?
3. How do consumer behaviors influence the design of sustainable last-mile delivery systems?

Figure 4: Last-mile delivery steps. Extracted from www.trackobit.com

2. LITERATURE REVIEW

In order to identify knowledge gaps and suggest a framework for future research direction regarding sustainability in the field, [21] conducted a systematic literature review (SLR) and structured insight into last mile delivery. The results revealed that during the previous 15 years (2005-2020), there has been a notable increase in the number of published articles about last mile delivery. [39] conducted a thorough review and analysis of the most recent developments in last-mile delivery solutions from both industry and academic viewpoints. They did this by using a content analysis literature review to examine more than 80 pertinent publications, identify the essential characteristics of the most recent last-mile delivery innovation, and highlight its varying levels of maturity as well as the associated theoretical and practical difficulties.

[43] looked into the advantages and disadvantages of various last-mile delivery systems, weighing the advantages and disadvantages of logistics companies' present operations and assessing how last-mile technologies may improve logistics and lower delivery costs. The study took a viewpoint that was mostly concerned with Finnish supply chain companies. The research's conclusions contained useful suggestions, analysis, and best practices for organizations, legislators, and logistics firms looking to maximize Logisoft's Last mile Delivery technology. Figure 4 shows some involved steps in the Last Mile Delivery.

According to a review by [46], DHL eCommerce in Vietnam used last-mile delivery as part of its supply chain strategy to offer local online retailers competitive logistical services. The findings indicated that the current DHL e-Commerce's LMD operation model and service offerings provide delivery tracking, high occurrence cash remittance for sellers, and dense service points network as their competitive offerings.

In order to present a more cohesive picture of last mile logistics research, [44] conducted a systematic evaluation and classification of the literature. 155 peer-reviewed journal articles about last-mile logistics are included in the review. The results showed that the literature covers a wide range of topics and features that fall under five categories: supply chain structures, performance measurement, operational optimization, new trends and technologies, and policy. The findings suggested directions for further research, which laid the groundwork for the field's continued growth.

According to [17], last mile logistics in particular are evolving into something far more than a transportation optimization exercise and a necessity for consumer convenience. Research investigating the feasibility of last-mile delivery options for sustainable supply chains was conducted by [42] in 2023. The research examined case studies of sustainable last-mile delivery solutions, last-mile delivery issues, and sustainable last-mile delivery solutions. According to the findings, cutting-edge last-mile delivery technologies like drones, cargo bikes, and electric cars have the potential to increase social fairness while lowering environmental impact and increasing last-mile delivery efficiency. Additionally, partnerships between different stakeholders, including governments, logistics companies, and consumers, can contribute to the development of sustainable last-mile delivery solutions.

In order to group homogeneous DMUs, [54] performed a cluster analysis that splits the station into two

groups: the Leader and Majority clusters. For every cluster, an efficiency study using DEA was provided. 136 out of 466 stations are reasonably efficient for the Majority cluster stations, while 94 out of 133 stations are relatively efficient for the Leader cluster stations, according to the results. To identify the features of a reasonably efficient station, classification modeling was done using a decision tree approach.

The first factor that determines whether a station joins the Leader or Majority cluster is the total daily delivery. The variable number and quantity of goods delivered on time make up the second criterion. In order to fill this knowledge vacuum, [47] conducted a thorough evaluation and analysis of 55 interdisciplinary studies on drone applications in last-mile delivery, concentrating on important factors including consumer accessibility, possible cost savings, and environmental sustainability. The results revealed important gaps in the literature, such as the inability to clarify how items delivered by drone will improve consumer accessibility and the frequent omission of crucial presumptions like weather, flight time, and battery life.

Cost Efficiency in Last-Mile Delivery

Last-mile delivery cost effectiveness is mostly determined by variables including delivery density, vehicle capacity, warehouse location, and route optimization. In logistics, optimization techniques such as the Vehicle Routing Problem (VRP) and the Traveling Salesman Problem (TSP) have been widely used to reduce operating expenses [37]. Designing more efficient routes is becoming easier thanks to technological developments in artificial intelligence (AI), machine learning, and real-time data analytics. This is cutting down on delivery times and fuel usage [1]. However, because quick delivery necessitate more trips and cars, cutting costs frequently results in higher carbon emissions. Because of this trade-off, cost-focused solutions must be reevaluated to take environmental factors into account. A thorough examination of Amazon's Last Mile Routing dataset by [53] reveals the complex dynamics and trends that influence delivery route efficiency. Using sophisticated clustering techniques, the researchers were able to successfully divide delivery routes into discrete groups, each of which had distinctive traits that affected operational effectiveness. The study also highlighted the importance of environmental factors in route optimization, pointing to possible changes in delivery methods toward more environmentally friendly options. Our findings, which highlight the potential for greater efficiency, adaptability, and sustainability, provide an integrated, data-driven framework to improve Amazon's shipping operations by incorporating recent academic research.

Environmental Sustainability in Last-Mile Delivery

Reducing the carbon footprint of global supply chains is becoming more and more dependent on sustainability in logistics, especially last-mile delivery. The International Energy Agency (IEA) estimates that 24% of worldwide CO2 emissions are caused by transportation, with urban delivery contributing significantly to these emissions [24]. Delivery drones, bike couriers, and electric vehicles (EVs) are some of the methods being used to lessen this environmental impact. Additionally, it has been demonstrated that green delivery networks that use consolidated shipments and eco-friendly packaging can lessen the adverse effects of urban freight distribution [3].
Even if these breakthroughs show promise, they come with a considerable cost, and companies, particularly in highly competitive sectors, frequently put cost reductions ahead of environmental objectives. [43] claims that last-mile distribution of business-to-consumer (B2C) e-commerce has altered logistics in recent years due to new environmental and economic issues. Furthermore, the high levels of greenhouse gas (GHG) emissions linked to freight transportation and sustainability have not been taken into account.

[43] addressed the following research issues in order to close this gap: What are the primary strategies for advancing sustainability in last-mile distribution? How do the economic, environmental, and social axes relate to the advantages and opportunities brought about by the sustainability of B2C e-commerce deliveries? How do the advantages and opportunities of the various last-mile distribution sustainability approaches (Logistics, Consumer, Logistics/Consumer) relate to each other? The need for last-mile (LM) delivery services is rising due to factors such shifting consumer behavior, technology advancements, and the constantly growing population in urban areas.

A number of issues pertaining to the sustainability of cities are brought on by this increasing demand, which also increases business mobility in city centers. These issues include air and noise pollution, emissions, accident hazards, parking issues, and traffic congestion [8]. [29] regard postal system operations to be fiscally demanding and environmentally impactful, representing some of the most complex issues of sustainable development. However, for both economic and environmental reasons, its deployment is anticipated soon. Urban settings' sustainability is greatly influenced by last-mile delivery, the last and frequently most difficult phase of the logistics process [13].

According to [5], urban logistics is getting more complicated and expensive. This is due to a number of factors, including the expansion of e-commerce, rising customer expectations, the need to improve delivery efficiency at reduced prices, and advancements in the sustainability and livability of cities and urban areas. [41] noted in 2021 that the expansion of e-commerce has led to a rise in urban freight transportation, resulting in adverse externalities such as pollution, noise, emissions, traffic, and habitat loss. There is a noticeable attempt to improve the sustainability of urban last-mile (LM) deliveries, mostly in terms of the environment.

According to [4], the use of new digital technologies, heightened sustainability standards, and shifting consumer behavior have all caused disruptions to traditional food supply chains, creating difficulties for last-mile logistics and food product distribution. Sustainable LM delivery techniques including parcel locker, drone, cargo bike, and micro-hub delivery are replacing traditional house delivery in order to address these problems. Furthermore, because of the chances they present to boost productivity, cut expenses, and lessen environmental damage, the integrated application of these sustainable LM delivery techniques has become essential.

In order to address the increasing needs of e-commerce and urbanization while promoting a sustainable environment, [13] looked into last-mile delivery optimization solutions. The study looked at the main issues that last-mile logistics players confront, such as traffic, pollution, and customer expectations, by conducting a thorough examination of the literature, case studies, and industry trends. From vehicle selection models and route planning algorithms to alternative delivery techniques and new technology, creative approaches to last-mile delivery operations optimization were investigated. A blueprint for creating a sustainable last-mile delivery ecosystem that strikes a compromise between cost effectiveness and environmental stewardship was presented in the study by combining insights from government, business, and academic projects.

Technological Solutions for Last-Mile Delivery Optimization

Technological developments in transportation and logistics provide workable answers for attaining sustainability and cost effectiveness. Among these solutions are: In order to optimize fuel consumption and shorten delivery times, AI-driven routing algorithms can modify delivery routes in real-time depending on traffic patterns, weather predictions, and delivery demand [50]. According to [10], the use of autonomous delivery robots and electric vehicles (EVs) lowers labor costs, fuel consumption, and greenhouse gas emissions.

For lightweight, short-distance deliveries, drones provide a sustainable alternative, particularly in crowded metropolitan settings. Strategically placed across cities, micro-fulfillment facilities cut down on the distance that items must travel, which lowers expenses and emissions [35]. Advances in technology have led to the implementation of various different logistical solutions as creative substitutes for package delivery. This involves, among other things, drone delivery, robot delivery, smart parcel stations, and crowdsourcing [39]. According to [57], there is potential for integrating autonomous delivery technologies into last-mile logistics operations.

Last-mile logistics issues in metropolitan areas can be addressed with the use of autonomous delivery systems. Traffic, air pollution, and accident rates all rise as a result of urbanization's increased need for mobility and transportation. Furthermore, logistics firms must respond to rising customer expectations about delivery speed and service due to megatrends like e-commerce. In terms of service, electrified autonomous delivery systems can assist address the driver shortage and perhaps run around the clock.

The last mile delivery (LMD) process is one of the most complicated logistics processes, according to [32]. They cited a number of uncertainties, such as weather and road conditions, traffic hours and route selection, auto accidents, and delivery vehicle anomalies, as well as the need to prevent package damage and delivery errors while corresponding with the parcel's recipient. The challenges of successfully delivering packages to clients' doorsteps are caused by the aforementioned issues. Consequently, companies must look for technological solutions that will boost the effectiveness of last-mile deliveries. In order to improve distribution without raising prices, the study suggested a last-mile solution that combines disruptive technologies.

According to [12], last-mile delivery operations optimization is a critical component for maintaining customer happiness and operational efficiency in the modern retail and e-commerce scenario. By combining automated smart locker systems, capillary distribution networks, crowdshipping, last-mile delivery, and supply chain management, [6] tackled logistics and transportation issues with the goals of increasing productivity, cutting expenses, and raising customer satisfaction. The logistics industry has demonstrated the efficacy of multi-criteria models by implementing them to maximize automated smart locker deployment, capillary distribution design, crowd shipping, and last-mile delivery tactics. Last-mile deliveries play a significant role in the local economy, the standard of living in cities, and the appeal of urban neighborhoods in metropolitan areas. However, the freight transportation industry bears the primary responsibility for adverse effects, including traffic jams, carbon dioxide emissions, and noise and air pollution. Private businesses, municipal planners, and policymakers have created programs to support organizational and technical breakthroughs in urban logistics and implement new regulations in an effort to increase efficiency and lessen negative effects [40].

Consumer Behavior and Last-Mile Delivery

Last-mile delivery system design is heavily influenced by customer preferences. Costs and carbon emissions have increased due to the sharp increase in demand for same-day and next-day delivery services [30].Nonetheless, some customers are growing more ecologically aware, and many are prepared to choose slower delivery options if doing so helps to lessen their negative effects on the environment. This change makes it possible for businesses to differentiate themselves in the market by providing green delivery options [18]. By using delivery

options that attempt to reduce costs through automation or cooperation, many online businesses try to optimize last-mile delivery costs. To do this, it is essential to persuade customers to use economical last-mile delivery options. However, there is no data on how customers feel about various delivery methods, and it is currently unclear what factors contribute to these attitudes [7]. E-commerce has changed consumer behavior, especially last-mile deliveries, in the retail industry's changing landscape. Research on last-mile deliveries usually ignores consumer behavior, even though customers usually have the last say when it comes to delivery requirements [11]. As more and more customers shop online, specifications like timely delivery and cost-effective shipping are crucial. Finding tactics that provide a profitable and quick last-mile delivery service that meets customer preferences and expectations is a challenge for retail and logistics organizations. Since last-mile delivery must meet customer preferences and provide the greatest possible customer experience, it presents both an opportunity and a challenge for logistics firms and e-commerce businesses [19].

Route Optimization

One of the best strategies for lowering last-mile delivery expenses and limiting environmental impact is dynamic route optimization. Businesses can cut down on trip distances and the number of trucks required for delivery by incorporating real-time data, such as traffic patterns, vehicle capacity, and client preferences [50]. This cuts expenses and fuel consumption.

[31] asserts that the use of contemporary technology to improve logistics distribution routes has become a crucial issue due to the expanding issues facing the logistics sector, particularly in fulfilling the growing demand for distribution accuracy and efficiency. [55] presented a data-driven approach to increase the effectiveness of last-mile deliveries for supply chain and e-commerce companies. The method creates economical delivery routes while improving customer satisfaction by utilizing demand pattern analysis, data integration, and configurable limits. Its adaptability to market dynamics and specific timeframes makes it a versatile solution for various supply chain scenarios, empowering businesses to optimize operations, reduce costs, and elevate customer service.

Electric Vehicles and Sustainable Fleet Management

Due to cheaper fuel and maintenance costs, using electric vehicles (EVs) for last-mile deliveries can help cut carbon emissions and save money over time. However, many businesses find it difficult to afford the initial expense of EVs. Subsidies or collaborations with governmental organizations can lessen this financial obstacle. To further improve sustainability, delivery fleets must be optimized in terms of size and capacity in order to minimize the overall number of trips needed [45].

Rising oil prices and rising carbon emissions are the two main issues facing the world's main transportation systems. Because they don't consume oil and don't emit greenhouse gases, electric cars (EVs) are becoming more and more popular [2]. [2] suggested that governments invest in developing a strong infrastructure for charging EVs and provide tax credits or subsidies to encourage consumers to buy EVs. Governments and industry players should work together to address these issues and encourage the use of EVs, which may help lower air pollution and carbon emissions. One potential remedy for lessening the environmental effect of the transportation industry is electric mobility [52].

Consolidation and Micro-Hub Strategies

Delivery consolidation can significantly increase sustainability and economic effectiveness, especially in crowded urban regions. Businesses can save money on labor and gasoline by combining delivery to adjacent sites and cutting down on the number of journeys. Micro-fulfillment facilities close to final consumers allow for shorter travel distances and faster, more effective deliveries [36]. Micro-hubs are thought to be a viable way to boost the consolidation of deliveries within cities; in the case of the City of Lagos, they are a potential way to improve logistical efficiency in and around the city center's planned zero-emission zone. A number of factors should be taken into account while planning the layout of micro-hubs in an urban environment, including their location, the kind of vehicles that will be used to operate them, and the business strategy that will be used to run them [32]. The quick growth of e-commerce has changed how businesses operate and how consumers shop. Although it may decrease consumer travel, it has also led to a rise in delivery vehicles' vehicle kilometers traveled (VKT), which has raised greenhouse gas (GHG) emissions, particularly in last-mile deliveries [27].

Delivery Drones and Robots

An emerging last-mile delivery solution is the use of drones and autonomous delivery robots. By eliminating the need for conventional delivery trucks, especially for short-distance deliveries, these technologies help to cut emissions and traffic jams. Particularly, drones provide a very environmentally friendly way to transport small, light products in crowded cities [22]. However, widespread use is still hampered by technology limits and regulatory issues. Drones and Unmanned Aerial Vehicles (UAVs) have developed into sophisticated tools with a variety of uses in the Logistics and Supply Chain (LSC) industry [25]. The use of autonomous delivery robots (ADRs) in a variety of delivery applications has increased dramatically in recent years, largely due to the need for contactless deliveries caused by the pandemic, increased difficulties with traditional delivery, and legislative and technological advancements [51]. Companies involved in logistics and

transportation should generate and provide their stakeholders with sustainable value. They may be able to take the necessary steps to remove the negative externalities (such as emissions and air pollutants) of their operations with the aid of cutting-edge robotic technology and environmental thinking [26]. Robotics, drones, and autonomous cars are anticipated to be crucial in addressing the increasing difficulties of last-mile delivery as the logistics and distribution sector undergoes a technological revolution [49].

Trade-Offs Between Cost Efficiency and Environmental Sustainability

A number of trade-offs must be made in order to balance sustainability objectives with cost effectiveness. For instance, even though electric cars reduce pollution, their initial costs are expensive. In a similar vein, providing same-day delivery raises fuel usage and road congestion while improving customer happiness. Businesses must weigh the short-term cost pressures against the long-term advantages of sustainability expenditures, such as lower regulatory costs and enhanced brand image. According to GEO-6's natural science, if societies continue on their current growth patterns, a wide range of undesirable outcomes for humanity—including potentially serious health effects—become more plausible [15]. Two significant issues facing humanity are halting climate change and accomplishing the Sustainable Development Goals (SDGs) of the UN. Although they can help fulfill these two goals, natural climate solutions (NCSs) may also result in trade-offs that are incongruous [34]. The urgent need to drastically cut global CO2 emissions is highlighted by the worsening climate change catastrophe. Simultaneously, a significant rise in the need for infrastructure systems worldwide is anticipated [38]. The majority of businesses' operations are impacted by the challenges they face in meeting the demands of the market today, therefore identifying and resolving these issues is crucial. Consumers today demand affordable, customized, environmentally friendly products delivered right to their door. Customers' rights, the need for sustainable products, and reducing the negative environmental effects of unsustainable production methods are the main objectives of the majority of government regulations in this field [56].

3. METHODOLOGY

The study used a descriptive design and collected and analyzed quantitative data. Key players in last-mile delivery, including logistics firms, online merchants, and delivery service providers, were given surveys via Google Forms to collect primary data. Current procedures, cost structures, environmental issues, and optimization techniques were the main topics of discussion. Data on current last-mile delivery strategies, optimization techniques, and environmental sustainability projects were gathered through a literature review. Additionally, the review pointed out gaps in the existing literature that this study attempts to fill. The research involved urban areas, with a case study in Lagos, Nigeria, where delivery services are growing but face infrastructure and environmental challenges. A purposive sampling technique was employed to select participants with extensive experience in last-mile delivery and logistics. The sample included 20 Logistics and Supply Chain Managers, 10 Delivery Drivers and Couriers, 10 E-commerce Business Owners, 30 Consumers, 5 Transportation and Logistics Service Providers, 5 Sustainability Experts, 8 Urban Planners and City Officials and 7 Technology Providers The analysis with statistical methods, such as table and charts, was used to analyzed the participants opinions. All participants involved in the surveys were informed about the purpose of the research and provided consent before participation. The confidentiality of all respondents and company data was maintained. The collected data were securely stored and anonymized where necessary to protect company and participant privacy. Access to detailed cost and emissions data limited in some cases, especially from private logistics companies, while the focus on Lagos provides relevant insights for urban areas in Nigeria, the findings might not be directly applicable to rural areas or other countries with different infrastructure and regulatory frameworks.

4. RESULTS AND ANALYSIS

Demographic Information

Table 1: Participants of the study

S/N	Participants	Roles	Frequency
1	Logistics and Supply Chain Managers	Professionals who oversee the overall supply chain process, with direct involvement in last-mile delivery operations	20
2	Delivery Drivers and Couriers	Individuals actively engaged in the last-mile delivery process, offering firsthand insights into operational challenges and opportunities for optimization	10
3	E-commerce Business Owners	Representatives from businesses that rely on last-mile delivery to ensure their products reach consumers, such as online retailers, marketplaces, and local sellers	10
4	Consumers	End users who experience the final stage of delivery and can provide feedback on delivery efficiency, timing, and environmental	30

		concerns	
5	Transportation and Logistics Service Providers	Companies that provide transportation services for last-mile delivery, including third-party logistics (3PL) providers, courier services, and ride-hailing companies.	5
6	Sustainability Experts	Environmental specialists and consultants who can assess the environmental impact of delivery operations and propose solutions for sustainable practices.	5
7	Urban Planners and City Officials	Individuals involved in urban transportation planning, traffic management, and sustainability initiatives, whose decisions can affect delivery efficiency and environmental impact.	8
8	Technology Providers	Developers and providers of technology solutions (e.g., route optimization software, GPS tracking) that are used to improve last-mile delivery performance.	7
	Total		95

Table 1 shows the participants involved in the study with thier roles and frequency. It reveals that 20 of Logistics and Supply Chain Managers, 10 of Delivery Drivers and Couriers, 10 of E-commerce Business Owners, 30 of Consumers, 5 of Transportation and Logistics Service Providers, 5 of Sustainability Experts, 8 of Urban Planners and City Officials, and 7 of Technology Providers totaling 95 respondents participated in the study.

5. TESTING OF RESEARCH QUESTIONS

RQ1: How can last-mile delivery systems be optimized to reduce both costs and environmental impacts?

Figure 5: Chart showing How last-mile delivery systems can be optimized to reduce both costs and environmental impacts

Last-mile delivery systems can be optimized to lower costs and environmental impacts through the use of AI and machine learning algorithms, dynamic routing, parcel grouping, smart hubs, electric delivery vans and bikes, drones and autonomous vehicles, sustainable packaging, reverse logistics for recycling, crowdsourced delivery platforms, gig economy models, time-slot selection, incentivizing green choices, urban consolidation centers, drone delivery, big data analytics, predictive analytics, click-and-collect, smart lockers, shared delivery platforms, and third-party logistics providers according to Figure 5.

RQ2: What technological and operational innovations are most effective in balancing these goals?

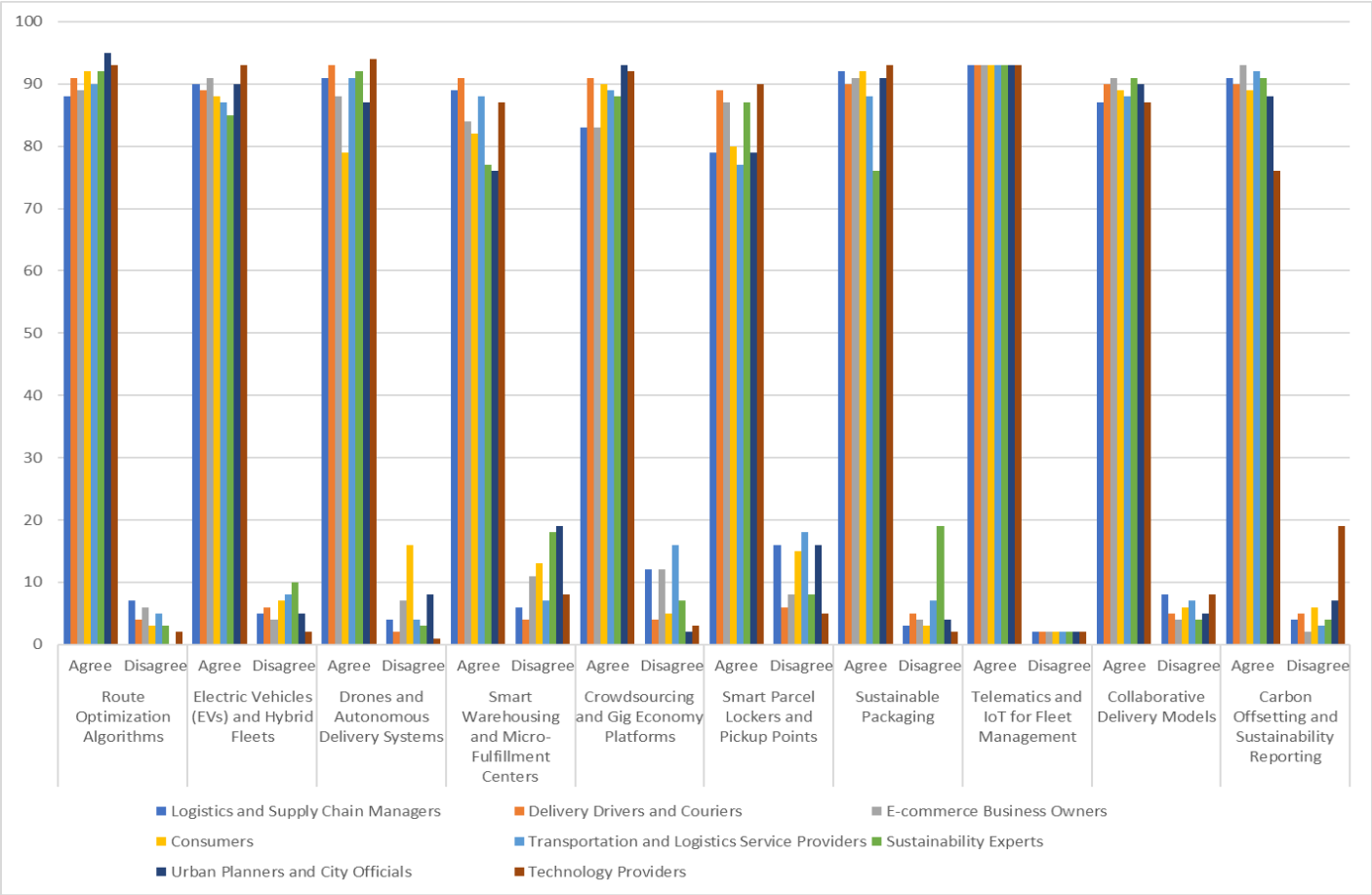

Figure 6: The chart that shows technological and operational innovations that are most effective in balancing the goals, among the technological and operational innovations

Route optimization algorithms, electric vehicles (EVs) and hybrid fleets, drones and autonomous delivery systems, smart warehousing and micro-fulfillment centers, crowdsourcing and gig economy platforms, smart parcel lockers and pickup points, sustainable packaging, telematics and iot for fleet management, collaborative delivery models, carbon offsetting and sustainability reporting, and more are some of the technological and operational innovations that are most successful at balancing the goals, as illustrated in Figure 6.

RQ3: How do consumer behaviors influence the design of sustainable last-mile delivery systems?

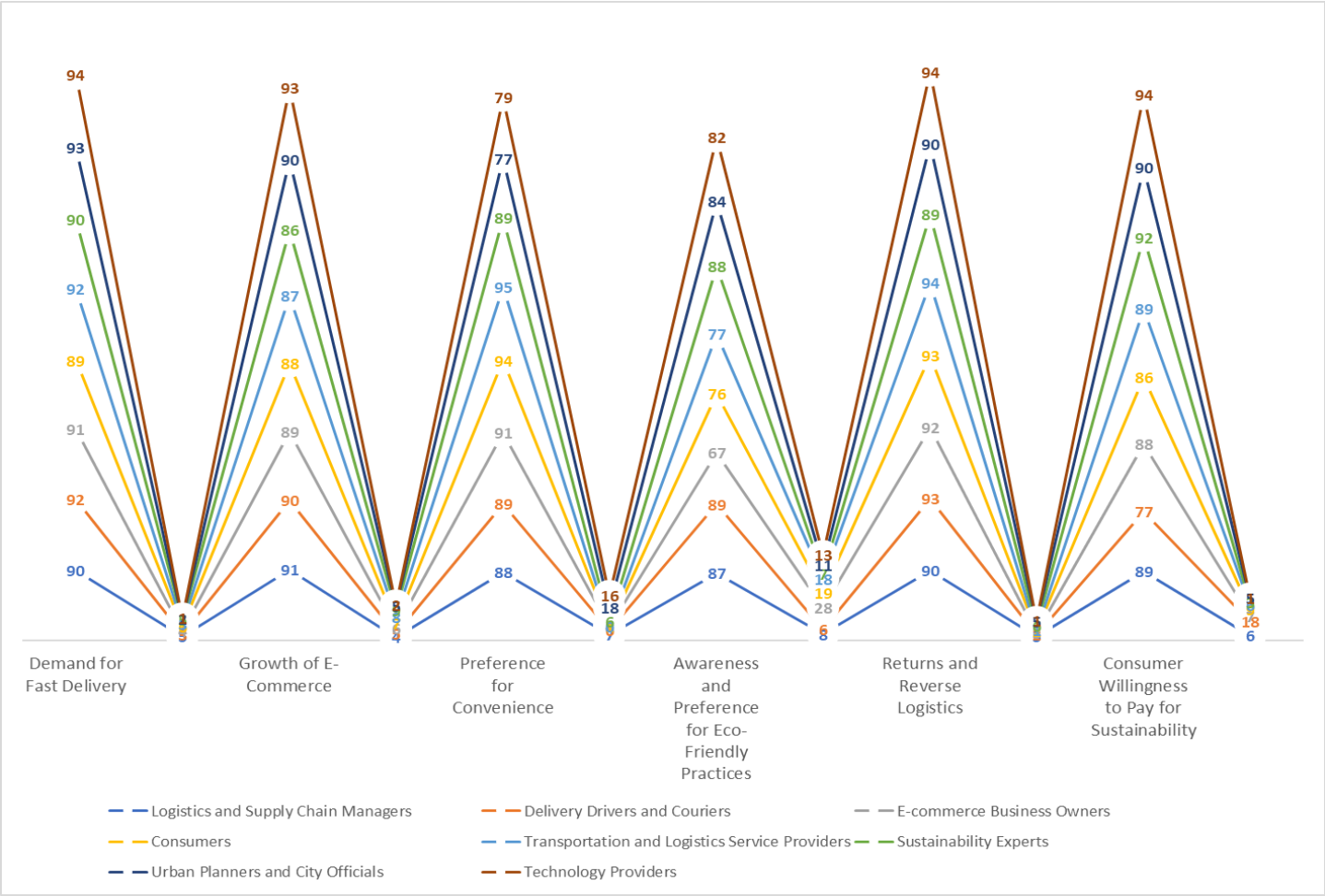

Figure 7: Showing how consumer behaviors influence the design of sustainable last-mile delivery systems

The design of sustainable last-mile delivery systems can be influenced by consumer behavior, as shown in Figure 7. It indicates that customer demands for quick delivery, the expansion of e-commerce, convenience preferences, awareness and preference for environmentally friendly practices, returns and reverse logistics, and consumer willingness to pay for sustainability can all have an impact on the design of sustainable last-mile delivery systems.

6. DISCUSSION

By using AI and machine learning algorithms, dynamic routing, parcel grouping, smart hubs, electric delivery vans and bikes, drones and autonomous vehicles, sustainable packaging, reverse logistics for recycling, crowdsourced delivery platforms, gig economy models, time-slot selection, incentivizing green choices, urban consolidation centers, drone delivery, big data analytics, predictive analytics, click-and-collect, smart lockers, shared delivery platforms, and third-party logistics providers, it is revealed that last-mile delivery systems can be optimized to minimize costs and environmental impacts. This is in support of [25] who said that drones and Unmanned Aerial Vehicles (UAVs) have evolved into advanced instruments with diverse applications within the Logistics and Supply Chain (LSC) sector. Also [35] said that micro-fulfillment centers located near end customers enable quicker, more efficient deliveries with shorter travel distances.

In a similar vein, it demonstrates which technological and operational innovations are most successful in striking a balance between the objectives. These innovations include drones and autonomous delivery systems, electric vehicles (EVs) and hybrid fleets, route optimization algorithms, carbon offsetting and sustainability reporting, smart warehousing and micro-fulfillment centers, crowdsourcing and gig economy platforms, smart parcel lockers and pickup points, sustainable packaging, telematics and iot for fleet management, and collaborative delivery models. The study of [50] corroborated that by integrating real-time data such as traffic patterns, vehicle capacity, and customer preferences, companies can minimize travel distances and reduce the number of vehicles needed for deliveries.

According to the same pattern, the study shows how customer behavior might affect how sustainable last-mile delivery networks are designed. It indicates that consumer demands for quick delivery, the expansion of e-commerce, convenience preferences, awareness and preference for environmentally friendly practices, returns and reverse logistics, and consumer willingness to pay for sustainability can all have an impact on the design of sustainable last-mile delivery systems. According to [28], since more and more people shop online, specifications like on-time delivery and cost-effective delivery are crucial.

The findings contribute to the larger subject of green logistics by providing practical advice for logistics firms trying to cut expenses while upholding environmental objectives. A thorough grasp of the trade-offs and synergies between cost and sustainability in last-mile delivery is provided by the research.

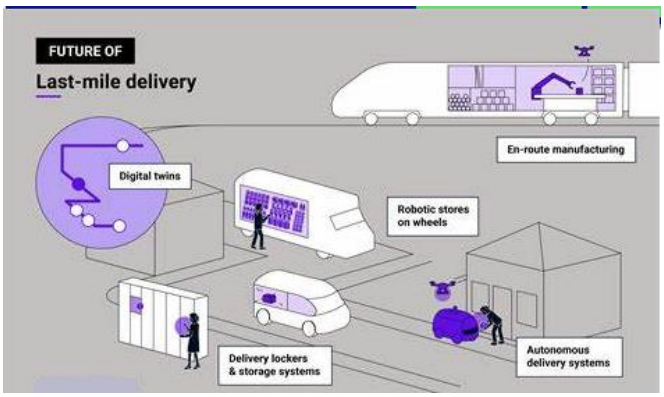

Figure 8: Future of Last-Mile Delivery

7. CONCLUSION

Optimization of last-mile delivery necessitates a multifaceted strategy that takes environmental sustainability and financial effectiveness into account. Potential answers are provided by technological advancements such as drones, electric cars, dynamic routing, and micro-fulfillment centers. The true difficulty, though, is striking a balance between these goals so as to satisfy customer needs while minimizing environmental effects. Businesses must approach their logistics operations holistically, taking into account both short-term cost reductions and long-term sustainability benefits (see figure 8).

8. RECOMMENDATIONS

The following recommendations guide this study:

1. Implement Smart Routing and Delivery Consolidation: Utilize advanced route optimization algorithms and AI-driven tools to minimize travel distances, reduce fuel consumption, and lower emissions. Consolidating deliveries to fewer trips can also decrease operational costs while boosting environmental sustainability.
2. Adopt Eco-Friendly Delivery Methods: Invest in green transportation methods such as electric vehicles (EVs), bicycles, or even walking couriers for urban deliveries. Partner with logistics companies that prioritize sustainability, contributing to both cost savings in fuel and reduced carbon footprints.
3. Leverage Real-Time Data and IoT for Efficiency: Integrate Internet of Things (IoT) sensors and real-time data analytics to monitor traffic patterns, vehicle performance, and delivery conditions. This data can help dynamically optimize delivery routes and times, reducing delays and energy usage.
4. Use Sustainable Packaging Solutions: Encourage the use of biodegradable, recyclable, or reusable packaging materials. This not only reduces environmental waste but can also decrease packaging costs in the long term by encouraging circular supply chains.
5. Promote Crowdshipping and Micro-Hubs: Consider employing crowdshipping models or localized micro-hubs to decentralize deliveries. Engaging local couriers or freelance drivers to handle last-mile deliveries can cut costs associated with large fleets and contribute to community sustainability.
6. Incentivize Off-Peak Deliveries: Implement dynamic pricing models that incentivize off-peak deliveries to avoid traffic congestion and optimize fuel usage. By reducing peak-hour deliveries, businesses can further cut costs and emissions.
7. Measure and Report Environmental Impact: Establish a framework for continuously measuring and reporting the environmental impact of last-mile delivery operations. Transparent reporting on emissions, fuel consumption, and sustainability initiatives can help companies stay accountable and attract environmentally conscious customers.
8. Adopt Drone and Autonomous Vehicle Deliveries: Explore the use of drones and autonomous delivery vehicles in appropriate areas. These innovations can cut down on labor and fuel costs while providing zero-emission delivery options, especially for shorter, last-mile trips.

REFERENCES

1. Agatz, N. A. H., Campbell, A. M., Fleischmann, M., & Savelsbergh, M. W. P. (2018). Time slot management in attended home delivery. Transportation Science, 52(1), 1-23.
2. Alanazi, Fayez. (2023). Electric Vehicles: Benefits, Challenges, and Potential Solutions for Widespread

Adaptation. Applied Sciences. 13. 6016. 10.3390/app13106016.

3. Allen, J., Browne, M., Woodburn, A., & Leonardi, J. (2017). Freight transport and logistics in urban areas: How to improve environmental sustainability. Research in Transportation Business & Management, 24, 1-8.
4. Ani Melkonyan, Tim Gruchmann, Fabian Lohmar, Vasanth Kamath, Stefan Spinler, (2020). Sustainability assessment of last-mile logistics and distribution strategies: The case of local food networks, International Journal of Production Economics,Volume 228, https://doi.org/10.1016/j.ijpe.2020.107746.
5. Antonio Comi, & Lidiia Savchenko, (2021). Last-mile delivering: Analysis of environment-friendly transport, Sustainable Cities and Society, Volume 74(1), https://doi.org/10.1016/j.scs.2021.103213.
6. Bartosz Sawik (2024). Optimizing Last-Mile Delivery: A Multi-Criteria Approach with Automated Smart Lockers, Capillary Distribution and Crowdshipping. Logistics, 8(2), 52; https://doi.org/10.3390/logistics8020052
7. Benjamin Dominique Klink, Samuel Schweizer &Thomas Rudolph, (2024). Identifying and testing drivers of consumers' attitude towards last-mile delivery modes. Electronic Commerce Research, https://doi.org/10.1007/s10660-024-09834-5
8. Bilgili, F., Yılmaz, Ş.F., Zaralı, F. et al. (2024). Evaluation of integrated sustainable last-mile delivery methods in an intuitionistic fuzzy environment. Environ Dev Sustain (2024). https://doi.org/10.1007/s10668-024-05461-0
9. Boysen, Nils; Fedtke, Stefan & Schwerdfeger, Stefan. (2021). Last-mile delivery concepts: a survey from an operational research perspective. OR Spectrum. 43. 1-58. 10.1007/s00291-020-00607-8.
10. Campbell, J. F., Clarke, L. W., Kleywegt, A. J., & Savelsbergh, M. W. P. (2017). The vehicle routing problem. Transportation Science, 52(1), 123-150.
11. Cauwelier, K, H; Rai, Buldeo; Puttemans, K; Macharis, K & Mommens, C (2024). From cart to door: Unravelling consumer behaviour through attitudinal sustainability profiles, Transportation Research Part D: Transport and Environment, 130(1), 104168, https://doi.org/10.1016/j.trd.2024.104168
12. Chandramouli, Arun. (2023). Optimizing Last-Mile Delivery Operations: Leveraging Predictive Analytics, Technology Integration, and Sustainable Practices. Journal of Mathematical & Computer Applications. 2. 1-7. 10.47363/JMCA/2023(2)145.
13. Chandratreya, Abhijit & Patil, Sanjaykumar & Joshi, Nitin & Londhe, Sandeep & Anbhule, Hemant. (2024). LAST-MILE DELIVERY OPTIMIZATION FOR SUSTAINABLE ENVIRONMENT. Community practitioner: the journal of the Community Practitioners' & Health Visitors' Association. 21. 1184-1205. 10.5281/zenodo.12743186.
14. Chen, C & Demir, E. (2022). Drones and Delivery Robots: Models and Applications to Last Mile Delivery. In: Salhi, S., Boylan, J. (eds) The Palgrave Handbook of Operations Research . Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-96935-6_27
15. Ekins, P & Zenghelis, D. (2021). The costs and benefits of environmental sustainability. Sustain Sci 16, 949–965. https://doi.org/10.1007/s11625-021-00910-5
16. Emrah Demir, Aris Syntetos, Tom van Woensel, (2022). Last mile logistics: Research trends and needs, *IMA Journal of Management Mathematics*, Volume 33, Issue 4, October 2022, Pages 549–561, https://doi.org/10.1093/imaman/dpac006
17. Emrah, Aris & Tom, (2022) investigated recent technological advancements and pending needs related to business and social innovations, emphasizing green logistics and city logistics concepts.
18. Esper, T. L., Jensen, T. D., & Turnipseed, F. L. (2003). Consumer acceptability of sustainable transportation solutions in the last mile of e-commerce. Journal of Supply Chain Management, 39(1), 58-71.
19. Filiopoulou, Evangelia; Bardaki, Cleopatra; Boukouvalas, Dimitrios; Nikolaidou, Mara & Kourouthanassis, Panos. (2022). Last-Mile Delivery Options: Exploring Customer Preferences and Challenges. 1-6. 10.1109/SMAP56125.2022.9942122.
20. Goodchild, A., & Toy, J. (2018). Delivery by drone: An evaluation of unmanned aerial vehicle technology in reducing CO2 emissions in the delivery service industry. Transportation Research Part D: Transport and Environment, 61, 58-67.
21. Ha, Nghiep; Akbari, Mohammadreza & Au, Bill. (2022). Last mile delivery in logistics and supply chain management: a bibliometric analysis and future directions. Benchmarking An International Journal. Ahead-of-print. 10.1108/BIJ-07-2021-0409.
22. Hoffmann, T., & Prause, G. (2018). On the Regulatory Framework for Last-Mile Delivery Robots. Machines, 6(33), 1-16. https://doi.org/10.3390/machines6030033
23. Huang, Yuanyuan & Feng, Xuan (2021). Time and Cost Efficiency of Autonomous Vehicles in the Last-Mile Delivery: A UK Case. International Business Research; 14(3), 26-40, doi:10.5539/ibr.v14n3p26
24. International Energy Agency (IEA). (2021). Transport: Improving the sustainability of urban freight deliveries. Retrieved from https://www.iea.org
25. Jahani, H., Khosravi, Y., Kargar, B., Ong, K. L., & Arisian, S. (2024). Exploring the role of drones and UAVs in logistics and supply chain management: a novel text-based literature review. International Journal of Production Research, 1–25. https://doi.org/10.1080/00207543.2024.2373425
26. Joerss, M., Neuhaus, F., & Schröder, J. (2016). How customer demands are reshaping last-mile delivery. Travel, Transport & Logistics October 2016, Mckinsey & Company.

27. Kahalimoghadam, Masoud; Thompson, Russell & Rajabifard, Abbas. (2024). Determining the number and location of micro-consolidation centres as a solution to growing e-commerce demand. Journal of Transport Geography. 117. 103875. 10.1016/j.jtrangeo.2024.103875.
28. Kumar, I., & Chidambara. (2024). A systematic literature review and bibliometric analysis of last-mile E-commerce delivery in urban areas. Urban, Planning and Transport Research, 12(1). https://doi.org/10.1080/21650020.2024.2357577
29. Lazarević, Dragan & Dobrodolac, Momcilo. (2020). SUSTAINABILITY TRENDS IN THE POSTAL SYSTEMS OF LAST-MILE DELIVERY. Perner's Contacts. 15. 10.46585/pc.2020.1.1547.
30. Lim, S., Lee, J., & Kim, J. (2021). Environmental impacts of e-commerce delivery services in urban areas. Sustainable Cities and Society, 71, 102993.
31. Liu, Qianfei. (2024). Logistics Distribution Route Optimization in Artificial Intelligence and Internet of Things Environment. Decision Making: Applications in Management and Engineering. 7. 221-239. 10.31181/dmame7220241072.
32. Luís B. Elvas, Ulpan Tokkozhina, Ana Lúcia Martins, João C. Ferreira, (2023). Implementation of disruptive technologies for the last mile delivery efficiency achievement, Transportation Research Procedia, Volume 72, 32-39, https://doi.org/10.1016/j.trpro.2023.11.319.
33. MANIATIS, PARASCHOS. (2023). Exploring the Viability of Last-Mile Delivery Solutions for Sustainable Supply Chains. 10.20944/preprints202306.0982.v1.
34. Mariani, Gaël; Moullec, Fabien; Atwood, Trisha; Clarkson, Beverley; Conant, Richard; Cullen-Unsworth, Leanne; Griscom, Bronson; Gutt, Julian; Howard, Jennifer; Krause-Jensen, Dorte; Leavitt, Sara; Lee, Shing; Livesley, Stephen; Macreadie, Peter; St-John, Michael; Zganjar, Chris; Cheung, William; Duarte, Carlos; Shin, Yunne-Jai & Mouillot, David. (2024). Co-benefits of and trade-offs between natural climate solutions and Sustainable Development Goals. Frontiers in Ecology and the Environment. 10.1002/fee.2807.
35. McKinsey & Company. (2022). The future of last-mile delivery: Delivery methods and technologies to meet evolving customer demands. Retrieved from https://www.mckinsey.com
36. Mckinsey&Company. (2019). A new look at autonomous-vehicle infrastructure. Retrieved from http://ibr.ccsenet.org. International Business Research, Vol. 14, No. 3; 2021
37. Michiel de Bok, Sofia Giasoumi, Lori Tavasszy, Sebastiaan Thoen, Ali Nadi, Jos Streng, (2024). A simulation study of the impacts of micro-hub scenarios for city logistics in Rotterdam, Research in Transportation Business & Management, 56(1), 101186, https://doi.org/10.1016/j.rtbm.2024.101186.
38. Min Liu, Da-Gang Lu & Michael Havbro Faber, (2024). On CO2 efficiency and trade-offs between sustainability, safety, economy and resilience in infrastructure developments, Sustainable Cities and Society, 113(1), 105647, https://doi.org/10.1016/j.scs.2024.105647.
39. Mohammad, W. A., Nazih Diab, Y., Elomri, A., & Triki, C. (2023). Innovative solutions in last mile delivery: concepts, practices, challenges, and future directions. Supply Chain Forum: An International Journal, 24(2), 151–169. https://doi.org/10.1080/16258312.2023.2173488
40. Morganti, E., Dablanc, L. (2014). Recent Innovation in Last Mile Deliveries. In: Non-technological Innovations for Sustainable Transport. SpringerBriefs in Applied Sciences and Technology. Springer, Cham. https://doi.org/10.1007/978-3-319-09791-6_3
41. Mucowska, M. (2021). Trends of Environmentally Sustainable Solutions of Urban Last-Mile Deliveries on the E-Commerce Market—A Literature Review. Sustainability, 13, 5894. https://doi.org/ 10.3390/su13115894
42. Nguyen Hoa Khanh (2024). Optimizing the Last-mile Segment in the Supply Chain – The Last-mile system applied on Logisoft. Thesis for a Master(UAS) - degree Digital Business and Management Degree Programme Vaasa. 1-67
43. Nogueira, G.P.M., Silva, S.V., Hasenclever, L. et al. (2024). Sustainability in B2C e-commerce: a literature review and future research opportunities in last-mile deliveries. Environ Dev Sustain (2024). https://doi.org/10.1007/s10668-024-04471-2
44. Olsson, John; Hellström, Daniel & Pålsson, Henrik. (2019). Framework of Last Mile Logistics Research: A Systematic Review of the Literature. Sustainability. 11. 7131. 10.3390/su11247131.
45. Pal, Subharun. (2023). Optimizing the Last Mile: Advanced Predictive Analytics for Delivery Time Estimation in Supply Chain Logistics. 9. 55 - 61. 10.2015/IJIRMF/202311010.
46. Pham, Hiep Cong; Nguyen, Dat; Doan, Chau; Thai, Quyen & Nguyen, Ngoc, (2019). Last Mile Delivery As A Competitive Logistics Service – A Case Study. 9th International Conference on Operations and Supply Chain Management, Vietnam, 2019
47. Ranieri, L., Digiesi, S., Silvestri, B., & Roccotelli, M. (2018). A Review of Last Mile Logistics Innovations in an Externalities Cost Reduction Vision. Sustainability, 10(782), 1-18. https://doi.org/10.3390/su10030782
48. Ray, Papri; Duraipandian, R; Varun, G & Harsh, Hari Om (2020). Exploration of the challenges in the last mile delivery in supply chain. https://www.researchgate.net/publication/349303976_Exploration_of_the_challenges_in_the_last_mile_delivery_in_supply_chain

49. Said, M., Aeschliman, S. & Stathopoulos, A (2023). Robots at your doorstep: acceptance of near-future technologies for automated parcel delivery. Sci Rep 13, 18556 (2023). https://doi.org/10.1038/s41598-023-45371-1
50. Savelsbergh, M., & Van Woensel, T. (2016). City logistics: Challenges and opportunities. Transportation Science, 50(2), 579-590.
51. Sharan Srinivas, Surya Ramachandiran & Suchithra Rajendran, (2022). Autonomous robot-driven deliveries: A review of recent developments and future directions, Transportation Research Part E: Logistics and Transportation Review, 165(1), 02834, https://doi.org/10.1016/j.tre.2022.102834.
52. Simone Franzò & Alessio Nasca, (2021). The environmental impact of electric vehicles: A novel life cycle-based evaluation framework and its applications to multi-country scenarios, Journal of Cleaner Production, 315(1), 128005, https://doi.org/10.1016/j.jclepro.2021.128005.
53. Singh, Ankur. (2023). Understanding Last-Mile Delivery: An Analysis of the Amazon Last Mile Routing Dataset. 10.13140/RG.2.2.14352.99841.
54. Surjandari, Isti; Rindrasari, Rahajeng & Dhini Arian(2023). Evaluation of Efficiency in Logistics Company: An Analysis of Last-Mile Delivery. EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 10, Issue 02, pp649-657
55. Vaka, Dilip Kumar (2024). Route Optimization in Supply Chain Management. 386-389. 10.51219/JAIMLD/dilip-kumar-vaka/100.
56. Valentas Gružauskas, Saulius Baskutis & Valentinas Navickas, (2018). Minimizing the trade-off between sustainability and cost effective performance by using autonomous vehicles, Journal of Cleaner Production, 184(1), 709-717, https://doi.org/10.1016/j.jclepro.2018.02.302.
57. Valeska Engesser, Evy Rombaut, Lieselot Vanhaverbeke & Philippe Lebeau (2023). Autonomous Delivery Solutions for Last-Mile Logistics Operations: A Literature Review and Research Agenda. Sustainability 2023, 15(3), 2774; https://doi.org/10.3390/su15032774
58. Vipul Garg, Suman Niranjan, Victor Prybutok, Terrance Pohlen, David Gligor, (2023). Drones in last-mile delivery: A systematic review on Efficiency, Accessibility, and Sustainability,Transportation Research Part D: Transport and Environment, Volume 123, https://doi.org/10.1016/j.trd.2023.103831.