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Characterising Sustainability of Urban Last-Mile Delivery Logistics: An Ethiopian Case

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Abstract

The surge in e-commerce is fuelled by globalisation, population growth, and urbanisation. E-commerce significantly depends on last-mile delivery. Its notable aspects are enhanced efficiency and heightened challenges related to cost, environmental impact, and urban congestion. Due to the fragmented nature of previous research in the area of urban last-mile delivery, this study aims to comprehensively explore the sustainability of last-mile delivery logistics, recognising its multidisciplinary nature. A descriptive and explanatory research design with a mixed research approach was used. A survey was conducted with diverse stakeholders resulting in a total of 135 usable responses out of 215 to examine interconnections among nine intertwined factors identified from the literature within the last-mile delivery ecosystem using the DEMATEL technique. While electric vehicles offer a potential solution, their adoption is hampered by infrastructure, battery, and cost limitations. The study identified six factors as effects and three as causes within the delivery ecosystem. Home delivery emerged as a top priority, requiring significant efforts to ensure sustainability. Collaboration was determined to be the most influential factor among the causes. This research establishes a cause-and-effect relationship among nine factors having significant implications for the last-mile delivery logistics sustainability from an Ethiopian context. The findings serve as a stepping stone for further investigation in this industry. The findings will guide city logistics leaders and government officials on where to focus to improve the sustainability of last-mile delivery logistics.

Keywords: Urban Logistics, Last-Mile Delivery, Sustainability, Addis Ababa, DEMATEL

Introduction

At present, e-commerce has experienced significant growth, fuelled by the ease of online shopping, e-payments, and flexible delivery options. Online shopping allows people in a city (both at home and in the office) and out of the city to place order for products with a simple click from where they are without leaving home or office. The completion of placing an electronic order with just a final click sets a vast network of activities in motion in the value chain where the delivery of the goods occurs over the last mile.

The growth in population, rapid urbanisation, the increase in e-commerce sales, and the customers' expectations for shorter delivery times (Boggio-Marzet et al., 2021; Juan et al., 2023; Chen & Chankov, 2017; Guo et al., 2019; Silva et al., 2023) force companies and other stakeholders to give due attention to Last-Mile Logistics (LML) aspect of supply chain. The rising cost of living, fuelled by inflation, the rising cost of living has led people to become busier and seek ways to reduce travel, especially in the post-pandemic era. This has increased the demand for direct deliveries to residences, contributing to a surge in cargo vehicle circulation in urban centres (Silva et al., 2023). Last-mile delivery is understood as the most expensive, ineffective, inefficient, challenging, and pollutant (Juan et al., 2023; Silva et al., 2023; Visser et al., 2014; Chen & Chankov, 2017; Fatehi & Wagner, 2022; Guo et al., 2019; Gonzalez et al., 2023) accounting for 13 – 75% of all supply chain expenses.

This new reality of major cities has increased fuel consumption, emissions, congestion, delivery costs and road-related traffic incidents (Ignat & Chankov, 2020; Gonzalez et al., 2023) impacting society's quality of life and safety be it direct or indirect. Research in this area is fragmented with disparate conclusions and last-mile delivery faces unique challenges in developing countries due to infrastructure, economic, and social factors.

Ethiopia is the second most populous nation in Africa with huge potential for last-mile delivery business. Addis Ababa ("new flower" in local language) is the capital of Ethiopia with a projected residents of 5,704,000 in 2024. The government of Ethiopia has been working towards the realisation of Digital Ethiopia by 2025 initiative for ensuring prosperity and creation of jobs for the youth. In Addis Ababa, city logistics infrastructure is limited or unparalleled with the rate of population growth and urbanisation. Congestion is becoming more prevalent in the city. People are increasingly busy due to the rising cost of living and are seeking for easy, convenient, reliable, and efficient last-mile delivery services to simplify their lives.

Some of the routes in the city are not allowed for motor cycles operated by last-mile delivery service providers. Businesses are not concentrated. Most of the vehicles used at the moment are fuel-based. There is a policy inclination from the government towards enforcing the use of electric vehicles aspiring to make the city sustainable as its name. Although more than 20 last-mile delivery providers have emerged in the city, the status of urban last-mile delivery is uncharted from the peculiar context of Addis Ababa City.

While there has been growing research on last-mile delivery logistics in developed countries, there is a notable absence of comprehensive studies assessing the sustainability of last-mile delivery in developing countries. Existing research often focuses on specific aspects of sustainability (e.g., environmental impact, economic efficiency) but lacks a comprehensive approach that considers all three dimensions of sustainability: economic, environmental, and social.

Considering last-mile delivery logistics as a multidisciplinary issue, this study aims to explore sustainability of urban last-mile delivery logistics. The study conducted urban last-mile delivery logistics stakeholder and process mapping in order to identify weakest link with regard to sustainability, efficiency, and inclusivity.

This study aims to address the following research questions:

- How is last-mile delivery logistics practiced in Addis Ababa city?
- What are the weaknesses of the current last-mile delivery logistics practices?
- What does the cause-and-effect relationship among the approaches to last-mile delivery logistics look like?

The study employs a pragmatic or interpretivist approach, often utilising a qualitative-dominant mixed approach. The pragmatic paradigm has been adopted because DEMATEL is a problem-solving methodology that focuses on understanding complex relationships. Since DEMATEL relies on expert opinions and subjective assessments to establish cause-and-effect relationships between last-mile delivery logistics approaches, an interpretivist perspective is found to be relevant.

This paper is structured in five sections. Section two reviews existing literature on last-mile delivery logistics and relevant sustainability concepts. Section three outlines the research methodology used. Section four presents the analysis and key findings. Finally, section five summarises the conclusions and discusses managerial implications derived from the research.

Literature Review

Last Mile Delivery

Last-mile delivery logistics is becoming increasingly important in urban areas due to several trends: the anticipated rise expected in the global urban population (UN, 2018; Silva et al., 2023) is driving demand for last-mile delivery services; new technologies, such as e-commerce platforms and mobile apps, have changed consumer behaviour and increased demand for convenient delivery options (Rust & Lemon, 2001); the growth of online shopping has sparked a significant rise in demand for last-mile delivery (Lashgari & Shahab, 2022); and increasing awareness of the environmental impact of urban freight transportation has created a demand for more sustainable delivery solutions (ALICE, 2015).

Factors such as growth in population, urbanisation, desire for speed, increasing e-commerce adoption, the sharing economy, climate change (Savelsbergh & Van Woensel, 2016), globalisation, increasing of the transport distance and historical contexts of cities are affecting city logistics (Bosona, 2020). Fleet increment not matched by expansion in infrastructure and insufficient unloading/loading spaces are the major obstacles from a developing country's context (Arvianto et al., 2021).

Meanwhile growing urbanisation, traffic congestion, and environmental challenges are common to both economies (Silva et al., 2023).

Last-mile delivery logistics as the final stage of the broader supply chain, plays a critical role in urban transportation. The last-mile delivery logistics business is defined as: “the transport of goods from a transportation hub to the customer” (Wang et al., 2016), and such business includes business-to-customer and business-to-business deliveries (Morganti et al., 2014). However, it also presents significant sustainability challenges due to its environment impact, energy consumption, and traffic congestion.

To this end, related literature review was carried out to identify criteria used for evaluating the sustainability performance of last-mile delivery logistics (Wang et al., 2023) and some of the most analysed initiatives, concepts, and technologies for last-mile delivery. Studies focusing on delivery approaches identify alternatives such as green vehicles (Tadić et al., 2014; Nocerino et al., 2016; Lebeau et al., 2018; Kumar & Bharj, 2020; Krstić et al., 2021; Zuniga-Garcia et al., 2022), parcel lockers (Iwan et al., 2016; Vakulenko et al., 2018; van Duin et al., 2020; Leyerer et al., 2020; Krstić et al., 2021), convenience store pickup or collection and delivery points (Yuen et al.; 2018; Nakayama & Yan, 2019; Gielens et al., 2021), autonomous vehicles (Karak & Abdelghany, 2019; Figliozzi, 2020; Krstić et al., 2021), and crowdsourcing (Wang et al., 2016; Castillo et al., 2017; Huang & Ardiansyah, 2019; Krstić et al., 2021).

Undoubtedly, the COVID-19 pandemic accelerated the growth of e-commerce, significantly boosting the demand for home delivery services. While this surge enhanced convenience, it also led to increased CO_2 emissions. Simultaneously, delivery operations experienced greater efficiency gains due to economies of scale (Villa & Monzon, 2021; Milewski & Milewska, 2021).

According to Bjørgen et al. (2021) home delivery provides more benefits from an environmental aspect compared to brick-and-mortar approach. This occurs due to fewer trips being involved leading to reduced vehicle usage. This is the case when orders are consolidated. Home delivery is the consumers’ preferred choice than ‘click and pick’ and ‘brick-and-mortar’ system (Gatta et al., 2021; de Oliveira et al., 2017). Following a different approach, Lim et al. (2018) concluded that anticipatory supply models like home delivery are favoured by consumers who do not want to get involved in physical movement (high physical convenience); pull-centric models like brick-and-mortar stores are favoured by consumers who have the time to fetch the goods from certain places and such consumers prioritise order lead time, visibility of order, and product returnability performance. Still other consumers prefer hybrid models like locker system prioritising physical over time convenience.

Unavailability at home is one of the significant challenges associated with home delivery. Delivering and storing in a locker system until the consumer collects the goods is regarded as a solution to the home delivery issue (Silva et al., 2023; Savelsbergh and Van Woensel, 2016). Their location, safety, and hours of operation (accessibility) play an important role when using locker systems. Reception boxes (Boysen et al., 2021), delivery using the trunks of private cars (Silva et al., 2023), delivering to the consumer’s workplace to minimise unsuccessful home deliveries (Allen et al., 2018), and mobile depots (Allen et al., 2018; He & Haasis, 2019) are considered emerging concepts.

According to Milewski and Milewska (2021), utilising a parcel locker system can substantially minimise fuel consumption per parcel compared to the home delivery option, as the number of parcels delivered increases. This leads to reduced trips, savings in fuel, time, and external costs (Alves et al., 2019). They argued that parcel lockers result in higher returns and cost savings from the customer’s point of view.

Lazarevic et al. (2020) recommended a 24/7 delivery option in contrast to the common daytime delivery. They concluded that such a shift could lower fuel consumption, and consequently decrease CO_2 emissions. According to Mousavi et al. (2020), off-peak delivery alternatives such as deliveries during evenings and overnights allow swift delivery, absence of noise complaints, and reduced GHG emissions. de Oliveira and de Oliveira (2016) found that residents and administrators viewed off-peak delivery as efficient though not for carriers and retailers. According to Kijewska et al. (2018), night deliveries are viewed as an alternative solution with high implementation possibilities and lower environmental impacts. However, practically implementing such a solution may be complex (De Marco et al., 2018).

Studies that examined delivery alternatives reported that consumers accept slower deliveries when the method is less polluting. Some consumers give priority to traceability over delivery time, delays or emissions (Caspersen & Navrud, 2021). Demographic factors such as income, age, and the items being bought influence which attribute to prioritise for other consumers (Dias et al., 2021). In contrast, information, traceability, adjustable delivery schedule, and reduced cost were among the key criteria for other consumers even within the same country (de Oliveira et al., 2017). Factors like product's selling price, range, and cost of service tend to be more critical when customers choose the channel than lead time or time window and travel time in Shanghai (Gatta et al., 2021).

Sustainability of Last Mile Delivery Logistics

The definition of last-mile logistics is increasingly tied to sustainability. This focus extends beyond operational efficiency and consistency to encompass economic, social, and environmental aspects. As such, the discussion should delve deeper into strategies that promote sustainability in last-mile delivery (Woidasky et al., 2016).

Last-Mile Logistics (LML) sustainability is measured in terms of meeting the current needs of customers and businesses while ensuring social and economic well-being for future generations and protecting the environment as well (Juan et al., 2023). Sustainability of LML activities includes minimising negative impacts on the environment due to transportation, storage, and delivery. It aims at fostering economic growth while ensuring access to goods and services that are sustainable for everyone in a society (Lyons & McDonald, 2023). Sustainability of LML is often viewed from economic, social and environmental aspects (Liu, 2014; Gonzalez et al., 2023). Delivery attributes such as speed, cost, and delivery options influence the economic aspect of LML sustainability (Ignat & Chankov, 2020). For instance, home delivery, collection-and-delivery points, and reception boxes have different cost and speed implications. Air pollution, greenhouse gas emissions, noise pollution, and traffic congestion are among the environmental effects of LML following freight mobility using road transport (Ignat & Chankov, 2020). The use of plastic and non-returnable packaging also impacts environmental sustainability. Several scholars argue that implementing energy-efficient transportation modes or cleaner vehicles, using alternative fuels, employing eco-driving practices, and promoting sustainable customer behaviour are among the measures to reduce polluting emissions (Boggio-Marzet et al., 2021; Manerba, Mansini, & Zanotti, 2018; Muñoz-Villamizar et al., 2019; Juan et al., 2023).

According to Wiu-Roing and Alvarez (2020), the environmental impact is the aspect most commonly considered followed by the social and economic impacts. Olsson et al. (2019), on the other hand, provided disparate conclusion stating that the economic dimension of sustainability receives the most attention followed by environmental and social dimensions. Comparing the various channels in terms of their impacts on consumers' opinions, Shahmohammadi et al. (2020) found that online shopping complemented by physical stores lowers the GHG emissions more than traditional shopping. They also assumed using pure digital shopping platforms could considerably decrease GHG footprints when electric cargo bikes are used, and facilities are located closer to the target customers.

The social aspect of LML involves considering impacts on employees' working conditions and the spillover effects on the population in terms of noise pollution and traffic congestion (Ignat & Chankov, 2020). To mitigate these impacts, attention must be paid to factors like employee schedules, salaries, insurance, training, and the potential loss of time and living standards for population (Ignat & Chankov, 2020; Kim et al., 2021).

The stakeholders' perspective is crucial in achieving the sustainability of last-mile logistics (Gonzalez, Garrido, and Vassallo, 2023). This occurs because stakeholders do not always agree on the best ways to implement sustainability measures (Juan et al., 2023). Logistics companies may use innovative technologies to optimise delivery such as alternative fuel vehicles, implement efficient routing and scheduling, and promote sustainable packaging and labelling as strategies to achieve sustainability in LML (Lyons & McDonald, 2023). Sustainability of last-mile delivery can also be fostered through collaboration among private operators and public authorities or by encouraging customers to adopt more sustainable consumption behaviours (Juan et al., 2023). It is crucial to understand that sustainable LML is a multidimensional concept (Silva et al., 2023) that reduces the environmental impact and at the same time promotes social and economic well-being (Juan et al., 2023).

Cardanas et al. (2017) found that urban areas generate more external costs than rural areas. On the other hand, the external cost per parcel is higher for rural areas due to low customer geographic density. Hidayatno et al. (2019) developed a model that depicted factors generating external costs. A significant share of all waste generated by food delivery services emanates from the use of excessive and disposable packaging materials (Zhang et al., 2022). Escursell et al. (2021) suggested adopting reusable packaging materials as more environmentally friendly options. Taniguchi et al. (2024) also complemented this argument by suggesting 3D printing to reduce packaging-related waste.

One way to achieve sustainability in last-mile delivery logistics is through the adoption of alternative vehicles, a concept that has gained significant attention in recent literature. Alternative fuel vehicles like electric vehicles, cargo bikes, drones, or autonomous vehicles are introduced into the transportation system with the potential to offer significant benefits (Silva et al., 2023; Patella et al., 2021; de Oliveira et al., 2017) such as lower energy consumption, GHG emissions leading to lower environmental impacts and reduced operational costs (Silva et al., 2023; Tsakalidis et al., 2020; Siragusa et al., 2022; Brotcorne et al., 2019). However, they are not free from drawbacks. Some of the challenges include operational barriers like the limited driving range, long recharging issues for batteries, and high investment costs (Anosike et al., 2023), as well as innovation, infrastructure and financial complexity of replacing existing fuel vehicles and high acquisition costs (Bates et al., 2018; Bosona, 2020).

The battery-related issue is subject to debate as Martins-Turner et al. (2020) and Iwan et al. (2021) argue that the battery capacity of electric vehicles is suitable for last-mile delivery operations. Settey et al., (2021) also showed that electric vehicles' driving range could be enhanced if recharged during loading/unloading. However, this could seem less feasible for parcel deliveries where the volume is smaller.

Cargo bikes are believed to help decrease congestion, noise, and air pollution (Nürnberg, 2019). However, they need adequate road infrastructure dedicated to them, supportive governing policies, community approval, adaptation to the city landscape and last-mile delivery tasks. Speed and capacity limitations along with the need for new road infrastructure, are identified as the shortcomings of cargo bikes (Bosona, 2020). Amold et al. (2018) indicated that cargo bikes bring in an increase in operational costs while decreasing external costs, which is the opposite of the case with locker systems. Silva et al. (2023) suggested, based on a literature review, the integration of both modalities as a helpful option. However, the findings reported by Zhang et al. (2018) are inconsistent with the previous findings as they found the use of cargo bikes decreases both operational and environmental costs.

There is some literature reporting drones, autonomous vehicles and modular vehicles as emerging vehicular technologies (Bosona, 2020; Patella et al., 2021; Oliveira et al., 2017). Patella et al. (2021) identified autonomous vehicles as the most promising and challenging solution for last-mile delivery logistics. In addition, Savelsbergh and Van Woensel (2016) questioned the benefits of such technologies, how to effectively use and how to integrate such technologies with traditional delivery systems remains unexplored. The use of such technologies still depends on city context in terms of having applicable policies, investment and community acceptance level.

Research Methods

The study employed both descriptive and explanatory designs. A descriptive design was employed to describe the study participants' responses to the sustainability evaluation criteria. An explanatory design was employed to establish the cause-and-effect relationship among the various approaches towards last-mile delivery logistics. The study approach is mixed-method, as the study employed both qualitative and quantitative data. Expert opinion obtained through interview and survey data collected using questionnaire were used in the study.

The study population is deliberately targeted at those who have a logistical background, including academicians (PhD holders and masters students), those who are in the logistics operations, and those directly working on last-mile delivery activities. In total, 215 questionnaires were distributed, of which 135 usable questionnaires were returned and employed in the analysis. Both a drop-and-collect approach and online platforms were employed.

The study adopted the decision-making trial and evaluation laboratory (DEMATEL) method. The DEMATEL method was initially developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva between 1972 and 1976 to study and resolve the complicated and intertwined problem group (Tzeng et al., 2007; Wu, 2008; Shieh et al., 2010; Ogrodnik, 2018; Kashyap et al., 2022). The DEMATEL method could improve understanding of the specific problematique, the cluster of intertwined problems, and contribute to the identification of workable solutions through a hierarchical structure (Chen-Y et al., 2017; Tsai & Chou, 2009; Tzeng et al., 2007; Ogrodnik, 2018; Kashyap et al., 2022). DEMATEL was chosen over the Analytical Hierarchy Process (AHP), Total Interpretive Structural Modelling (TISM), Interpretive Structural Modelling (ISM), and any other Multiple Criteria Decision-Making (MCDM) approach because it categorises difficulties into groups based on causes (i.e., higher priority factors that overall have a greater effect) and effects (i.e., lower priority factors that are overall influenced by others) and also shows the gravity of those impacts (Kashyap et al., 2022; Vaz-Patto et al., 2024).

Unlike the traditional techniques such as analytic hierarchy process with the assumption that elements are independent, this method, one of the structural modelling techniques, can identify the interdependence among the elements of a system through a causal diagram (Kim Yonghun, 2006; Tzeng et al., 2007; Wu & Lee, 2007; Ogrodnik, 2018; Kashyap et al., 2022). The causal diagram employs digraphs rather than directionless graphs to portray contextual relationships and the strengths of influence among the elements (Wu, 2008; Kashyap et al., 2022). The steps in the DEMATEL method are summarised as follows (Tzeng et al., 2007; Wu, 2008; Shieh et al., 2010; Ogrodnik, 2018; Kashyap et al., 2022):

Step 1: Compute the average matrix. Each respondent was asked to evaluate the direct influence between any two factors by an integer score ranging from 0, 1, 2, 3, and 4, representing "no influence", "very low influence", "low influence", "high influence", and "very high influence", respectively. The notation of x_{ij} indicates the degree to which the respondent believes factor i affects factor j. For i = j, the diagonal elements are set to zero. An n x n non-negative matrix can be established for each respondent as $X^k = [x^k_{ij}]$, where k is the number of respondents with $1 \leq k \leq H$, and n is the number of factors. Thus, $X^1, X^2, X^3, \ldots, X^H$ are the matrices from H respondents. To incorporate all opinions from H respondents, the average matrix A = [aij] can be constructed as follows:

$$aij=1/H\sum_{k=1}^{H} X_{ij}^{k} \qquad (1)$$

Step 2: Calculate the normalised initial direct-relation matrix. Normalise initial direct-relation matrix D by D = A x S, where

$$S = \frac{1}{max_{1\leq i\leq n} \sum_{j=1}^{n} a_{ij}}. \qquad (2)$$

Each element in matrix D fails between zero and one.

Step 3: Calculate the total relation matrix. The total relation matrix T is $T = D(I - D)^{-1}$, where I is the identity matrix. Define r and c be n x 1 and 1 x n vectors representing the sum of rows and sum of columns of the total relation matrix T, respectively. Suppose r_i be the sum of ith row in matrix T, then r_i summarises both direct and indirect effects given by factor i to the other factors. If c_j denotes the sum of jth column in matrix T, then c_j shows both direct and indirect effects by factor j from the other factors. When j = i, the sum $(r_i + c_j)$ shows the total effects given and received by factor i. That is, $(r_i + c_j)$ indicates the degree of importance that factor i plays in the entire system. On the contrary, the difference $(r_i - c_j)$ depicts the net effect that factor i contributes to the system. Specifically, if $(r_i - c_j)$ is positive, factor i is a net cause, while factor i is a net receiver or result if $(r_i - c_j)$ is negative (Lee et al., 2008; Liou et al., 2007).

Step 4: Set up a threshold value to obtain the digraph. Since matrix T provides information on how one factor affects another, it is necessary for a decision maker to set up a threshold value to filter out some negligible effects (Table 2). In doing so, only the effects greater than the threshold value will be chosen and shown in the digraph. In this study, the threshold value is set by computing the average of the elements in matrix T. The digraph can be acquired by mapping the dataset of (r + c, r - c).

Results and Analysis

Table 1: Demographic Data

Respondents by Gender	Frequency	Percentage
Male	83 (61.48%)	61.48%
Female	52	38.52%
Work experience		

Respondents by Gender	Frequency	Percentage
Five years or below	65	48.15%
Six to ten years	35	25.92%
Above ten years	35	25.92%
Have online shopping experience		
Yes	100	74%
No	35	26%

In terms of position, the respondents are from diverse areas of logistics such as Warehouse Coordinator, Import Specialist or officer, Customer Officer, Bank Officer, Admin Assistant, Sales and Promoter, Commercial Manager, Accountant, Site Manager, Category Officer, Marketing Manager, Business Owner, Commercial Account Manager, Academia, Senior Officer, Operator, Senior Pharmaceuticals Procurement & Forecasting Officer, Commodities Officer, Coordinator, Technical Manager, Fleet Operation Administrator, Senior Supply Chain Officer, Procurement and SC Coordinator, Regional Program Coordinator, Route Planner, International Marketing SEO Manager, Program Manager, Director, Logistics Data analyst, Operations Director and Customer.

Table 2: Last Mile Delivery Logistics Sustainability Evaluation Criteria

Criteria Group	Criteria	Ranking
Technical	Efficiency	2nd
	Reliability	3rd
	Flexibility	5th
	Ease of implementation	8th
	Traceability and information security	1st
Economic	Cost of implementation & control	7th
	Delivery cost reduction	6th
	Congestion reduction	10th
	Increasing availability of public space	12th
Social	Consistency with urban planning	9th
	Voice of customer	4th
	Ease of mobility	11th
	Enhancing Stakeholders' cooperation	14th
Environmental	Air pollution reduction	15th
	Energy consumption reduction	13th

2024 Survey result based on Wang et al., 2023.

The experts were asked to rank the fifteen LML sustainability assessment criteria. Accordingly, traceability and information security, efficiency, reliability, voice of the customers, and flexibility were ranked from first to fifth.

The last-mile delivery process typically begins when a shipper, either a seller or a consumer, initiates a delivery request. The delivery operator then collects items and consolidates them at a hub before dispatch. Deliveries can be made using motorcycles, vans, or other vehicles, depending on the shipment volume and destination. Deliveries range from residential to office locations and can include various items, excluding restricted goods. While fuel-based vehicles remain the dominant mode of transport, electric vehicles are less common due to perceived limitations in capacity, charging infrastructure, and susceptibility to damage.

The operator respondents mentioned a lack of adequate road infrastructure, insufficient supportive policy frameworks, limited parking spaces, inadequate loading/ unloading areas, significant distances between business areas and residential zones, and the unavailability of tailored cargo e-bikes. These factors often necessitate longer travel distances, resulting in increased fuel consumption and higher spare part costs.

The informal nature of the last-mile delivery logistics sector exacerbates these challenges. For instance, traffic violations committed by a few motorbike drivers can lead to blanket restrictions on all motorbike deliveries for extended periods. Common traffic violations include disregarding traffic lights, driving on the wrong side of the road, and other illegal activities.

After collecting the experts' opinion, the average direct-relation matrix is prepared as shown in Table 3 (see Annex 1).

Step 2 is to calculate the normalised initial direct-relation matrix (D), depicted below is obtained the formula:

$$D = A\text{x} \frac{1}{max_{1\leq i\leq 9} \sum_{j=1}^{9} a_{ij}}$$

The average Direct-Relation Matrix (D) is normalised and listed in Table 4 (See Annex 2).

In Step 3, we calculate the total relation matrix (T) by the following formula:

$T = D(I - D)^{-1}$ = D is the normalised direct relation matrix (Given in Table 4).

Table 4: The Normalised Initial Direct-Relation Matrix (D)

0	0.1138	0.1292	0.1099	0.1138	0.1458	0.1215	0.1087	0.1305
0.1189	0	0.1113	0.0998	0.0793	0.1189	0.1023	0.0895	0.096
0.1240	0.1138	0	0.1075	0.1138	0.1292	0.1189	0.1074	0.1266
0.1138	0.1036	0.1049	0	0.1228	0.1087	0.1113	0.1087	0.0882
0.1177	0.1049	0.1113	0.1177	0	0.0998	0.1036	0.1240	0.1113
0.1497	0.1368	0.1368	0.1061	0.1036	0	0.1164	0.0934	0.1189
0.1279	0.0946	0.1215	0.0946	0.0959	0.1125	0	0.0959	0.1266
0.1113	0.0857	0.1138	0.1253	0.1317	0.1074	0.1087	0	0.1074
0.1356	0.1036	0.1356	0.1099	0.1432	0.1253	0.1329	0.1138	0

Table 5: The Difference (I – D) Matrix, I is an Identity Matrix and D is the Normalised Direct Relation Matrix (See Annex 3).

Table 6: The Inverse of the Difference Matrix, Table 5 Obtained Using the Formula, $(I – D)^{-1}$

2.2469	1.1904	1.3233	1.1974	1.2391	1.3187	1.2613	1.1642	1.2601
1.1693	1.9280	1.1308	1.0272	1.0431	1.1223	1.0759	0.9912	1.0636
1.3192	1.1571	2.1721	1.1623	1.2047	1.2695	1.2243	1.1311	1.2222
1.2142	1.0645	1.1731	1.9807	1.1239	1.1605	1.1286	1.0500	1.1026
1.2518	1.0954	1.21187	1.11678	2.0469	1.18666	1.1547	1.0922	1.1528
1.3625	1.1961	1.3149	1.1811	1.2167	2.1778	1.2435	1.1391	1.2374
1.2429	1.0721	1.2036	1.0817	1.1181	1.1806	2.0448	1.0538	1.1498
1.2487	1.0817	1.2157	1.1247	1.1655	1.1942	1.1606	1.9838	1.1516
1.3954	1.2074	1.3567	1.2237	1.2898	1.3304	1.2975	1.1943	2.1719

The total relation matrix is the product of the two matrices, the normalised direct relation matrix and the inverse of the difference matrix obtained using the following formula: $T = D(I – D)^{-1}$

Table 7: The Total Relation Matrix (T) (See Annex 4).

Table 8: The Sum of Influences Given and Received Among These Nine Factors or Dimensions

Factors	Ri	Cj	Ri + Cj	Ri - Cj	Ranking	Identify
Preference for home delivery	11.2013	11.45089	22.65217	-0.24961	1	Effect
Preference for reception boxes	9.551424	9.99271	19.54413	-0.44128	9	Effect
Preference for Pick up or CDP	10.8626	11.10207	21.96462	-0.23952	4	Effect
Utilising cleaner vehicles	9.99885	10.09558	20.09377	-0.0974	8	Effect
Adopting Eco-driving practices	10.30916	10.44782	20.75698	-0.13866	5	Effect
Changing consumer consumption behaviour	11.06908	10.94068	22.00976	0.1284	2	Cause
Improving employee working conditions	10.1473	10.59118	20.73848	-0.44388	6	Effect
Using alternative fuel vehicles	10.32661	9.799689	20.1263	0.526921	7	Cause
Fostering collaboration	11.46705	10.51202	21.97907	0.95503	3	Cause

We can produce the total relation matrix's causal-and-effect values based on the total relation matrix. The sum of all "i"th row items in the total relation matrix are denoted as Ri, while the Sum of all "j"th row elements is denoted as Cj. Ri + Cj and Ri – Cj values are produced, where Ri + Cj denotes the relationship between last-mile delivery logistics sustainability approaches, and Ri – Cj denotes a cause-and-effect relationship. The positive value of Ri – Cj indicates the cause, whereas a negative value shows an effect. The sum of the influence given and received on each of the approaches is shown in Table 6, where six of them were found to be effects, and three of them were found to be causes.

Table 8 represents the final ranking obtained after applying DEMATEL. The methodology also helped determine which approaches are causes and which are effects. The author used DEMATEL approach to classify the delivery approaches into cause-and-effect groups.

The Fig. 1 depicts the cause-and-effect relationship among the nine approaches considered in this study based on the Ri -Cj values. Expert advice has been used to assess how the nine approaches affect one another. Information has been gathered from five experts, including two logistics academic and professional experts, and three practitioner experts who have worked in the logistics sector for at least five years in manager-level roles with professional credentials. The survey was carried out using both a drop-and-collect method and online tools (Fig. 2).

In this study, it has been observed that Ri + Cj has the highest value for approach 1, which is a 'preference for home delivery'. Hence, this approach has been given the highest priority and requires work to achieve sustainability in last-mile delivery logistics. Also, in the cause category, approach 9, i.e., 'fostering collaboration for achieving sustainability in last-mile delivery logistics', has the highest priority.

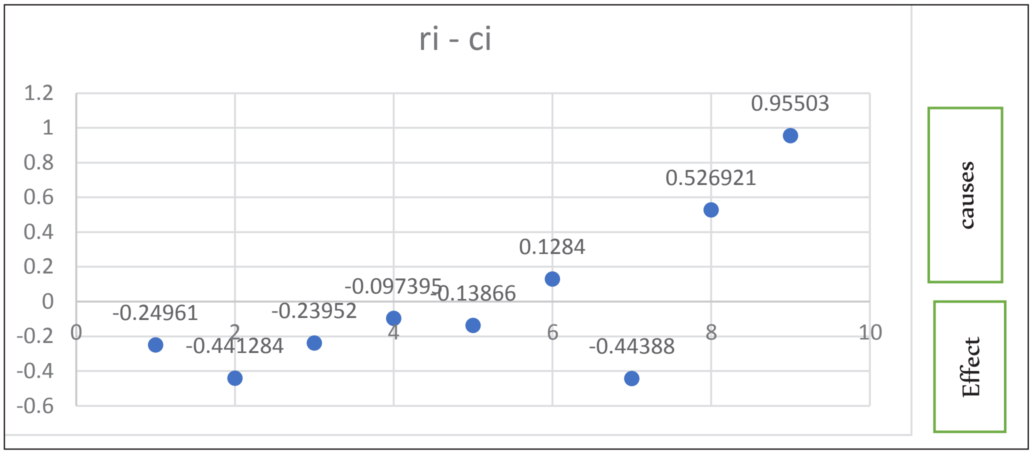

Fig. 1: Factors Identified as Cause and Effect

The result also shows 3 approaches in the cause group and 6 in the effect group. The observations from this study can be very helpful in developing the framework for achieving sustainability in last-mile delivery logistics in major cities.

Step 4: Set up a threshold value to obtain the digraph.

Table 9: The Threshold value

	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**
A1	1.2469	**1.1904**	**1.3233**	**1.1974**	**1.2391**	**1.3187**	**1.2613**	1.1642	**1.26**
A2	1.1693	0.928	1.1308	1.0272	1.0431	1.1223	1.0759	0.9912	1.0636
A3	**1.3193**	1.1572	**1.1721**	1.1623	**1.2047**	**1.2695**	**1.2243**	1.1311	**1.2222**
A4	**1.2142**	1.0645	**1.1731**	0.9807	1.1239	1.1605	1.1286	1.05	1.1026
A5	**1.2518**	1.0954	**1.2119**	1.1168	1.0469	**1.1866**	1.1547	1.0923	1.1528
A6	**1.3625**	**1.1961**	**1.3149**	**1.1811**	**1.2167**	**1.1778**	**1.2435**	1.1391	**1.2374**
A7	**1.2429**	1.0721	**1.2036**	1.0817	1.1181	**1.1806**	1.0448	1.0538	1.1498
A8	**1.2487**	1.0817	**1.2157**	1.1247	1.1655	**1.1942**	1.1606	0.9838	1.1516
A9	**1.3954**	**1.2074**	**1.3567**	**1.2237**	**1.2898**	**1.3304**	**1.2975**	**1.1943**	1.1719
Threshold (alpha) value		1.17201							

Table 10: An Inner Relation Matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9
A1	1.2469	**1.1904**	1.3233	1.1974	1.2391	1.3187	1.2613		1.26
A2									
A3	1.3193		1.1721		1.2047	1.2695	1.2243		1.2222
A4	1.2142		1.1731						
A5	1.2518		1.2119			1.1866			
A6	1.3625	1.1961	1.3149	1.1811	1.2167	1.1778	1.2435		1.2374
A7	1.2429		1.2036			1.1806			
A8	1.2487		1.2157			1.1942			
A9	1.3954	1.2074	1.3567	1.2237	1.2898	1.3304	1.2975	1.1943	
Threshold (alpha) value		1.17201							

Following the formation of the total relation matrix, an inner relation matrix is also formed as shown in Table 10. An inner relation matrix is formed by eliminating all the values from the total relation matrix that are less than the threshold value. Basically the inner relation matrix signifies the rate of correlation among different approaches. Only factor A9 has the influence on all the other factors as shown in Table 10. Preference for reception boxes (A2) has no effect on the other approaches.

The cause-and-effect relationship diagraph is shown in figure below.

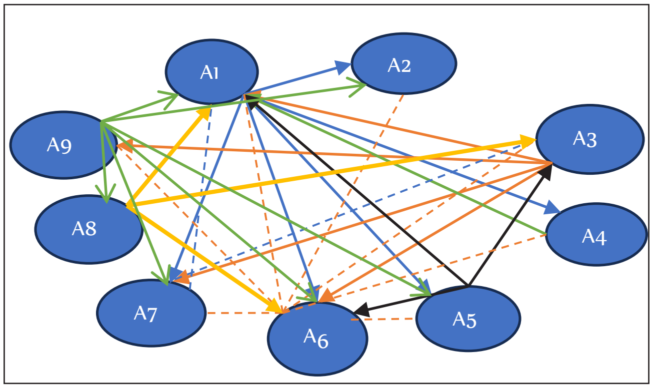

Fig. 2: The Relationship Diagraph

Managerial Implications, Conclusions and Limitations

The intensifying market competition is forcing companies to prioritise efficiency, often at the expense of environmental sustainability. Last-mile delivery, a critical component of the supply chain, is particularly inefficient and polluting. This has led to a myriad of economic, social, and environmental challenges, including climate change, resource scarcity, and health hazards. To maintain competitiveness, businesses have prioritised economic growth over environmental protection, exacerbating these issues.

However, there is still an opportunity to reverse this trend. Ensuring the sustainability of urban last-mile delivery logistics is paramount as the global population becomes increasingly urbanised. By adopting eco-friendly practices and utilising low-emission vehicles, we can protect the environment and preserve scarce resources.

This research focused on identifying key strategies to achieve sustainability in last-mile delivery. The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method was employed to assess the relative importance of various approaches. The findings aim to guide stakeholders in developing collaborative solutions, including shippers, retailers, consumers, local authorities, logistics service providers, and governments. City administrators hold a crucial role in fostering sustainability by investing in infrastructure, implementing supportive policies, and promoting environmentally friendly behaviour among citizens.

The researcher offers the following valuable contributions and recommendations to the urban last-mile delivery logistics sector:

This study proposes shaping urban last-mile delivery approaches from economic, social, and environmental perspectives. To address the sector's challenges holistically, it is crucial to prioritise different approaches and their interconnections. A collaborative platform for key stakeholders is essential to align interests and identify shared priorities.

Overcoming the challenges of the sector requires strong leadership from city administrations. Developing comprehensive policies, regulations, and standards in consultation with industry stakeholders can enhance efficiency, motivation, and shared responsibility for improving urban living standards. The research findings underscore the importance of a balanced approach to sustainability in last-mile delivery logistics, particularly for developing economies. Practical and managerial implications from this study can guide stakeholders in making informed decisions. To achieve sustainable urban last-mile delivery, fostering collaboration among shippers, retailers, consumers, local authorities, logistics service providers, and the government is imperative. By prioritising sustainability and implementing effective strategies, the sector can contribute to a greener and more resilient urban environment.

The study's findings and recommendations are based on data collected from a single metropolitan city in a developing country, which might be considered as a limitation. Future studies considering data from multiple countries will help in filling such a limitation.

Annex

Annex 1

Table 3: The Average Matrix A Can Be Constructed Based on Eq. (1)

0	2.5429	2.8857	2.4571	2.5429	3.2571	2.7143	2.4286	2.9143
2.6571	0	2.4857	2.2286	1.7714	2.6571	2.2857	2.0000	2.1429
2.7714	2.5249	0	2.400	2.5429	2.8857	2.6571	2.400	2.8289
2.5429	2.3143	2.3429	0	2.7429	2.4289	2.4857	2.4286	1.9714
2.6286	2.3429	2.4857	2.6286	0	2.2286	2.3143	2.7714	2.4857
3.3429	3.0571	2.0571	2.3714	2.3143	0	2.600	2.0857	2.6571
2.8571	2.1143	2.7143	2.1143	2.1429	2.5143	0	2.1429	2.8286
2.4857	1.9143	2.5429	2.800	2.9429	2.4000	2.4286	0	2.4000
3.0286	2.3143	3.0286	2.4571	3.200	2.8000	2.9714	2.5429	0

Annex 2

Table 4: The Normalised Initial Direct-Relation Matrix (D)

0	0.1138	0.1292	0.1099	0.1138	0.1458	0.1215	0.1087	0.1305
0.1189	0	0.1113	0.0998	0.0793	0.1189	0.1023	0.0895	0.096
0.1240	0.1138	0	0.1075	0.1138	0.1292	0.1189	0.1074	0.096
0.1138	0.10.36	0.1049	0	0.1228	0.1087	0.1113	0.1087	0.0882
0.1177	0.1049	0.1113	0.1177	0	0.0998	0.1036	0.1240	0.1113
0.1497	0.1368	0.1368	0.1061	0.1036	0	0.1164	0.0934	0.1189
0.1279	0.0946	0.1215	0.0946	0.0959	0.1125	0	0.959	0.1266
0.1113	0.0857	0.1138	0.1253	0.1317	0.1074	0.1087	0	0.1074
0.1356	0.1036	0.1356	0.1099	0.1432	0.1253	0.1329	0.1138	0

Annex 3

Table 5: The Difference (I – D) Matrix

1	-0.1138	-0.1292	-0.1099	-0.1138	-0.1458	-0.1215	-0.1087	-0.1305
-0.1189	1	-0.1113	-0.0998	-0.0793	-0.1189	-0.1023	-0.0895	-0.096
-0.124	-0.1138	1	-0.1075	-0.1138	-0.1292	-0.1189	-0.1074	-0.1266
-0.1138	-0.1036	-0.1049	1	-0.1228	-0.1087	-0.1113	-0.1087	-0.0882
-0.1177	-0.1049	-0.1113	-0.1177	1	-0.0998	-0.1036	-0.124	-0.1113
-0.1497	-0.1368	-0.1368	-0.1061	-0.1036	1	-0.1164	-0.0934	-0.1189
-0.1279	-0.0946	-0.1215	-0.0946	-0.0959	-0.1125	1	-0.0959	-0.1266
-0.1113	-0.0857	-0.1138	-0.1253	-0.1317	-0.1074	-0.1087	1	-0.1074
-0.1356	-0.1036	-0.1356	-0.1099	-0.1432	-0.1253	-0.1329	-0.1138	1

Annex 4

Table 7: The Total Relation Matrix (T)

1.2469	1.1904	1.3233	1.1974	1.2391	1.3187	1.2613	1.1642	1.2600
1.1693	0.9280	1.1308	1.0272	1.0431	1.1223	1.0759	0.9912	1.0636
1.3193	1.1572	1.1721	1.1623	1.2047	1.2695	1.2243	1.1311	1.2222
1.2142	1.0645	1.1731	0.9807	1.1239	1.1605	1.1286	1.0500	1.1026
1.2518	1.0954	1.2119	1.1168	1.0469	1.1866	1.1547	1.0923	1.1528
1.3625	1.1961	1.3149	1.1811	1.2167	1.1778	1.2435	1.1391	1.2374
1.2429	1.0721	1.2036	1.0817	1.1181	1.1806	1.0448	1.0538	1.1498
1.2487	1.0817	1.2157	1.1247	1.1655	1.1942	1.1606	0.9838	1.1516
1.3954	1.2074	1.3567	1.2237	1.2898	1.3304	1.2975	1.1943	1.1719

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