TOWARDS SUSTAINABLE LAST-MILE LOGISTICS: ANALYZING ENVIRONMENTAL CHALLENGES AND SOLUTIONS IN POST-COVID E-COMMERCE ERA

Thesis Submitted
In partial fulfillment of the Requirements for the Degree of

MASTERS OF TECHNOLOGY

in

Industrial Engineering and Management

by

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(2K22/IEM/10)

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June, 2024

ACKNOWLEDGEMENTS

Foremost, I immensely thank Almighty for the wisdom, blessings and inspiration throughout this research work.

I embrace the opportunity to express my deep sense of gratitude to my supervisor **Dr. Mohd. Shuaib**, Assistant Professor, Department of Mechanical Engineering, Delhi Technological University, Delhi, for his constant guidance, valuable suggestions and encouragement during this research. His encouragement, support, intellectual stimulation, perceptive guidance, immensely valuable ideas, and suggestions from the initial to the final level enabled me to develop an understanding of the subject. His scholarly suggestions, constant help and affectionate behavior have been a source of inspiration for me. I am extremely grateful to him for his continuous guidance.

I am cordially thankful to the **Prof. Prateek Sharma**, Hon'ble Vice-Chancellor, Delhi Technological University, Delhi for providing this world class platform to conduct this research work. My acknowledgement will never be complete without the special mention of **Prof. S.K. Garg**, Professor, Delhi Technological University and **Prof. B.B. Arora**, HOD Department of Mechanical Engineering, Delhi Technological University, Delhi.

I am thankful to Central library, Delhi Technological University for providing me the access to world class research literature that helped me in this research work.

I am highly thankful to **Mr. Gaurav Mishra**, Research Scholar, Department of Mechanical Engineering, Delhi Technological University, Delhi and **Mr. Roshan Kumar**, Technical Assistant, Industrial Engineering Lab, Department of Mechanical Engineering, Delhi Technological University, Delhi for assisting in this research work.

I am thankful to all the authors and publishers whose research work has helped me in this research project.

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CANDIDATE’S DECLARATION

I, **Sheetal Sharma,** hereby certify that the work which is being presented in The thesis entitled **“Towards Sustainable Last-Mile Logistics: Analyzing Environmental Challenges and Solutions in Post-Covid E-Commerce Era”** in partial fulfillment of the requirements for the award of the Degree of Master of Technology, submitted in the Department of Mechanical Engineering, Delhi Technological University is an authentic record of my own work carried out during the period from 2022 to 2024 under supervision of **Dr. Mohd. Shuaib**, Assistant Professor, Department of Mechanical Engineering, Delhi Technological University, Delhi.

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other Institute.

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CERTIFICATE BY THE SUPERVISOR

Certified that **Sheetal Sharma (**2K22/IEM/10) has carried out the research work presented in this thesis entitled **"Towards Sustainable Last-Mile Logistics: Analyzing Environmental Challenges and Solutions in Post-Covid E-Commerce Era"** for the award of **Master of Technology** from Department of Mechanical Engineering, Delhi Technological University, Delhi, under my supervision. The thesis embodies results of original work, and studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

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Towards Sustainable Last-Mile Logistics: Analysing Environmental Challenges and Solutions in Post-COVID E-commerce Era

Sheetal Sharma

ABSTRACT

There has been a considerable shift from conventional market to e-commerce in recent years. This rise in e-commerce has significantly increased the demand for efficient delivery solutions, thereby increasing concerns about its environmental impact. As such it is critical to analyse the sustainability concerns in last mile logistics. Out of the complete delivery process, the most critical is the last mile that connects the distribution centre to the end consumers. Due to exponential growth in e-commerce, there has been a considerable growth in logistics sector putting a question mark on sustainability of logistics. Since last mile is the most critical portion of logistics due to the costs and complexity associated, it becomes necessary to investigate the factors affecting its sustainability. A thorough literature review is utilized to give an overview of the research performed on the topic last mile delivery. COVID-19 has been a main reason for the exponential surge in e-commerce and logistics. Hence, the literature is categorized in two categories pre-covid and post-covid literature and insights are developed. The literature on last mile delivery and sustainability is studied and findings and discussions are summarized. By reviewing the existing research literature this study finds the factors associated with last mile logistics and its sustainability. Moreover, this study identifies the most critical stability issues within last mile distribution. Fuzzy Analytic Hierarchy Process (AHP), a multi criteria decision making (MCDM) method is applied to rank the identified factors. Fuzzy AHP is a rational strategy that eliminates the challenge associated with comparing two factors. It aids decision-makers in choosing the most crucial factor by prioritizing and ranking methods. In this study this methodology has been used to rank the factors affecting sustainability in last mile logistics. It helps stakeholders to understand the issues faced in achieving sustainability in last mile operations. The ranks of factors affecting sustainability in last mile operations along with their respective priority weight are presented in this study.

Keywords: Last mile delivery, Sustainability, Fuzzy AHP, MCDM

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LIST OF ABBREVIATIONS

Abbreviation	Full Form
LML	Last Mile Logistics
LMD	Last Mile Delivery
AHP	Analytic Hierarchy Process
MCDM	Multi Criteria Decision Making
DC	Distribution Centre
3PL	Third-party logistics
FC	Fulfillment Centre
OF	Operational factors
CSF	Customer Service factors
EF	Economic Factors
ESF	Environmental and Social factors

CHAPTER 1

INTRODUCTION

1.1 Introduction

Over the past few years, last mile delivery has become an area of keen interest for researchers. Urbanization and population growth are the primary drivers for this rapid growth in last mile logistics according to Ketchen et al (2014). Although the term "last mile logistics" is having many definitions in the literature, all accept that it pertains to the last portion of the supply chain that connects the final distribution centre to the end consumer’s preferred location Lim et al (2017), Gevaers (2009) and Harrington et al (2016). Study by Gevaers et al (2014) has shown that last mile is the most inefficient and expense full portion of supply chain. Study by Gevaers et al (2011) has shown that the last mile delivery in a supply chain can cost up to 75% of the total cost of transportation. Moreover, it is the major contributor to environmental pollution. Delivery of goods from distribution centres to end consumer might contribute as much as 28% of the overall transportation expenses as discussed by Goodman (2005). In addition, a significant portion of the traffic load and pollution emissions that e-commerce logistics impose on a city are caused by first and last-mile delivery according to Rodrigue et al (2016). Sustainability is becoming more significant in the contemporary world. It can be defined as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” as defined by United Nations, (1987). In addition, the definition of sustainable development states that it is a "process of transformation in which the utilization of resources, the allocation of investments, the trajectory of technological advancement, and institutional reform are aligned with both current and future requirements" as given in United Nations, (1987).

The rise of e-commerce has changed consumer behaviour leading to increased online shopping. As such a corresponding demand for efficient delivery solutions has increased. As a result, last-mile logistics, short yet crucial final leg of the supply chain has become a critical factor in the success of e-commerce according to Chopra and Meindl (2013). The recent COVID-19 outbreak and subsequent constraints have intensified the shift in consumer and corporate behaviour, hence further promoting the use of e-commerce as discussed by Kim (2020). Studies have shown that last mile delivery is having a significant effect on customer satisfaction. Efficient and on time deliveries give a boost to brand value and help in building a loyal customer base thereby generating repeated business. On the other hand, a delayed, damaged or a missed delivery erode customer trust and satisfaction thereby causing losses to the business as explained by Kim et al (2012).

As far as the costs involved in last mile delivery are concerned, studies show that approximately 13 – 75 % of total supply chain expenditure is incurred by last mile delivery, reason being a number of factors as discussed by Gevaers (2009). Efficiency of last mile delivery operation depends on a number of factors such as costumer density and time of delivery according to Boyer et al (2009), traffic congestion according to Muñuzuri et al (2012), segmentation of deliveries according to Leung et al (2017), and size of package according to Xing et al (2011). Some of the challenges posed by last mile logistics include emission of greenhouse gas as discussed by Patricia et al (2015) and Edwards et al, (2010), noise and air pollution as discussed by Digiesi et al (2017) and Ajiohani & Thompson (2017), as well as traffic congestion as discussed by Allen et al (2017). Emissions by last mile logistics operation are predicted to be increased by 30% by 2030 as per world economic forum. Therefore, all these challenges faced in last mile operations are having a significant effect on the sustainability of last mile logistics. Hence, to improve the last mile's sustainability on the social, environmental, and economic fronts, a thorough investigation is needed. In this study, a thorough literature review is used to identify the factors affecting sustainability in last mile logistics. Then the identified factors are categorized into four main groups namely Operational factors (OF), Customer Service factors (CSF), Economic Factors (EF), and Environmental and Social factors (ESF) on the basis of similarity and relevance. After this categorization, from each factor group sub factors are shortlisted that form the basis of our analysis and ranking. The multi criteria decision making (MCDM) technique used in this ranking and analysis is fuzzy analytic hierarchy process (AHP).

1.2 Research Gap and Contribution

1.2.1 Research Gap

a) There has been a lot of interest in sustainable solutions in last mile logistics due to growing e-commerce in recent years. However, there is a scarcity of literature when it comes to last mile delivery along with its sustainability concerns.

b) There are a lot of factors affecting sustainability. Although there is a number of research articles on last mile logistics, the literature on sustainability factors in last mile delivery is still in development. The literature enlisting all of these relevant factors is still scarce.

1.2.1 Research Objective

a) The literature survey performed in this study helps in summarising the existing research literature on last mile delivery and its sustainability. This study enlists all the relevant factors that affect sustainability in last mile logistics.
b) This study contributes to the enrichment of existing scientific literature by identifying the key factors that affect sustainability in last mile logistics.
c) The key factors affecting sustainability in last mile delivery are categorised in four major groups namely Operational factors (OF), Customer Service factors (CSF), Economic Factors (EF), and Environmental and Social factors (ESF).
d) The identified factors are ranked by utilizing multi-criteria decision making (MCDM) technique namely fuzzy analytic hierarchy process (AHP). The ranking helped in identifying the most critical factors affecting sustainability in last mile operations.

CHAPTER 2

LITERATURE SURVEY

2.1 Literature survey

The term last mile logistics covers a broad range of topics including challenges and solutions in supply chain including humanitarian and commercial supply chain along with role of emerging technologies and sustainability concerns in last mile logistics. Several terms like last mile delivery, last mile logistics, last mile distribution and last mile network are used for describing the final stretch of supply chain that connects distribution centres to end consumers as discussed by Olsson et al (2019) and Lim et al (2017). All these terms are often used interchangeably as no substantial differentiation among these has been made. The interest in last mile delivery and urban logistics is increasing from past few years. However, most of the authors have taken individual challenges in last mile delivery such as opinion of customers on new delivery methods as shown by Iwan et al (2016), using optimization models for last mile challenges as used by Florio et al (2018) and research on logistics organizations as discussed by Wang et al (2016).

Literature on last mile delivery covers a wide range of topics like challenges and innovations in commercial and humanitarian supply chains, impact of emerging technologies and sustainability concerns in last mile networks. A review of the literature conducted by Liu and Hassini (2023) from 2010 to 2021 reveals a focus on three main clusters namely humanitarian relief, commercial logistics, and emerging technologies, each with its own research gaps and trends.

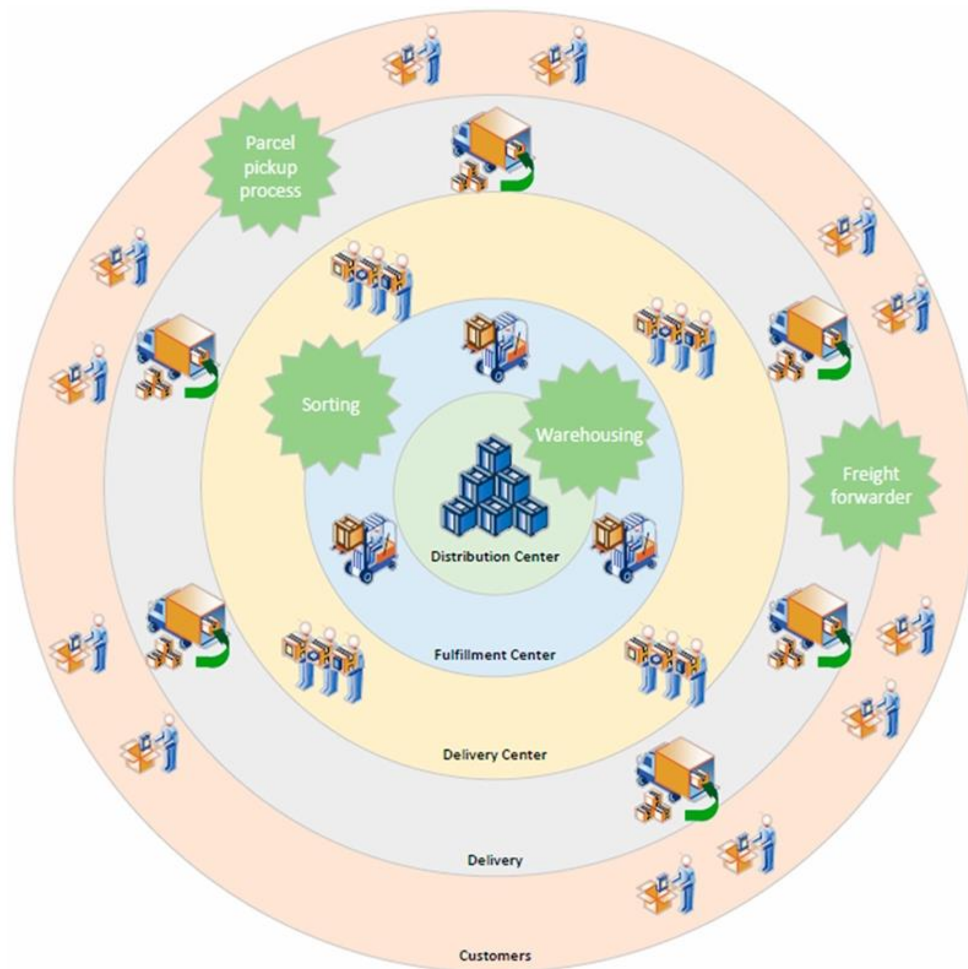

Fig.2.1. A typical modern e-commerce last mile network by Liu & Hassini (2023)

Fig.2.1 shows a typical supply chain network in e-commerce, which includes several players. Potential stakeholders in this context may consist of distribution centres (DCs) along with fulfilment centres (FCs), the third-party logistics providers (3PLs) who manage the delivery centres and FCs and end consumers as explained by Liu & Hassini (2023).

Fig. 2.2 gives an overview of position of last mile delivery in supply chain. All the operations and processes performed in the transportation of package from delivery centre to the end consumers come under last-mile delivery.

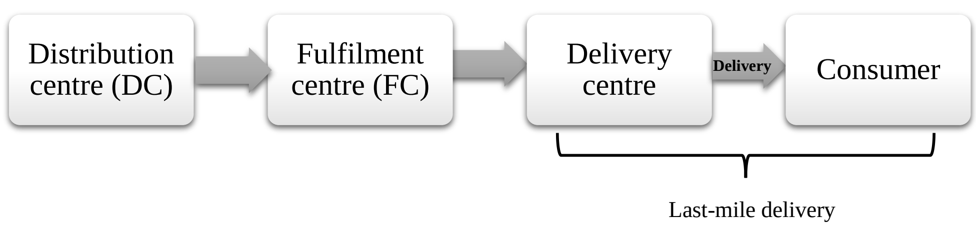

Fig.2.2. Position of last mile delivery in supply chain.

Table 2.1 gives a brief summary of research literature on last mile logistics. It gives a brief overview of few research papers along with their findings and discussion. It can be concluded from the table that last mile is the most expensive portion of supply chain. Urban last-mile logistics operations create economic, environmental, and social challenges that need to be addressed. Moreover, there is a need for research on collaboration. Orsic et al, (2022) has suggested the use machine learning to forecast demand and optimize routes to improve sustainability in last-mile delivery.

Table 2.1. Findings and discussion from literature on last mile delivery

Title	Findings	Discussion	REFERENCE
“Framework of Last Mile Logistics Research: A Systematic Review of the Literature”	Last-mile is the most expensive and inefficient portion of supply chain.	Highlights the need for research on operational and tactical aspects. Calls for more focus on sustainability concerns.	Olsson et al, (2019)
“Sustainable Urban Last-Mile Logistics: A Systematic Literature Review”	Urban last-mile logistics create economic, environmental, and social challenges.	Sustainable practices in last-mile delivery like including alternative fuels and electric vehicles is discussed.	Silva et al, (2023)
“Last mile delivery in logistics and supply chain management: a bibliometric analysis and future directions”	Research on last-mile logistics focuses on strategic, tactical and operational aspects.	Need for future research on collaboration, big data analytics, and last-mile service design is identified.	Ha et al, (2023)
“Last mile logistics: Research trends and needs”	Routing optimization is a key area of research in last-mile logistics.	Use of interval robust optimization for planning under uncertainty is suggested.	Demir et al, (2022)
“Sustainable Operations of Last Mile Logistics Based on Machine Learning Processes”	Machine learning can improve sustainability in last-mile delivery through real-time route planning.	Use of machine learning to forecast demand and optimize routes is suggested.	Orsic et al, (2022)

(continued on page 9)

Table 2.1 (continued)

Title	Findings	Discussion	REFERENCE
“Last-Mile Delivery Options: Exploring Customer Preferences and Challenges”	Greek consumers generally prefer home over other last-mile delivery options like in-store pick-up points and lockers.	Importance of Consumer preferences in last mile delivery options is highlighted and challenges like trust issues with drone delivery is discussed.	Filiopoulou et al., (2022)
“Multi-objective Optimization for Green Delivery Routing Problems with Flexible Time Windows”	Importance of security and reliability in last mile delivery is highlighted	Emphasizes the significance of security in last mile distribution, advocates for the development of standardized test cases, and underscores the potential impact on decision-making in humanitarian logistics.	Gülmez et al, (2024)
“Freight last mile delivery: a literature review”	Last mile delivery face challenges in efficiency, sustainability and technology adoption.	Role of last mile delivery is highlighted; challenges are identified and future research directions are suggested to enhance sustainability.	Liu & Hassini, (2024).

2.2 Bibliometric Analysis

Bibliometric analysis is popular method utilized to review and analyse scientific literature as discussed by Merigó and Yang (2017). In this study we have utilized bibliometrix R-package created by Aria and Cuccurullo (2017).

This study utilizes SCOPUS database as the search database to ensure the quality of reviewed literature. To ensure that only relevant literature is reviewed we have used keywords “last mile logistics”, “last mile delivery”, “last mile distribution”, “last mile network”. The first search with input “last mile logistics OR last mile delivery OR last mile distribution OR last mile network” gave about 2200 results. To narrow down the search and keep the relevant literature we added the keyword “sustainability” to the search. The modified search input “last mile logistics AND sustainability” OR “last mile delivery AND sustainability” OR “last mile distribution AND sustainability” OR “last mile network AND sustainability” lead to 284 results. The search period was set from 2010 to 2023. Out of 284 works 146 are open access. This set of 146 research works is used for the bibliometric analysis. COVID-19 pandemic has been a major reason for breakthrough and transformation in the field of logistics and e-commerce. As such we have divided the literature in two major clusters- pre covid and post covid literature.

Table 2.2 shows an overview of literature work on last mile logistics during pre-covid and post-covid timeframe. It can be concluded from this table that there has been a considerable growth in scientific literature pertaining to sustainable last mile delivery. The obvious reason being consumers opting for e-shopping instead of conventional shopping.

Table 2.2. Information of pre-covid and post-covid literature

Description	Pre-COVID	Post-COVID
Information about data		
Timespan	2010:2020	2020:2023
Sources (Journals, Books, etc)	18	52
Documents	38	108
Annual Growth Rate %	32.75	23.47
Document Average Age	5.47	2.26
Average citations per doc	41.87	16.51
Document contents		
Keywords Plus (ID)	207	583
Author's Keywords (DE)	148	394
AUTHORS		
Authors	119	356
Authors of single-authored docs	5	7
Authors collaboration		
Single-authored docs	5	7
Co-Authors per Doc	3.89	3.71
International co-authorships %	23.68	23.15
Document types		
article	25	86
conference paper	11	1
review	2	11

Fig. 2.3 depicts a brief summary of literature on last mile logistics and sustainability. From 2010 to 2023 there is approximately 30.55% of annual growth and international co-authorship of 20.93% in scientific literature related to sustainable last mile delivery.

Fig.2.3. Overview of literature on last mile logistics.

Fig. 2.4 depicts a chart on annual scientific production of literature on last mile logistics. It can be concluded that there has been an uptrend in literature on last mile from 2017 and after covid 19 pandemic there has been significant research in last mile.

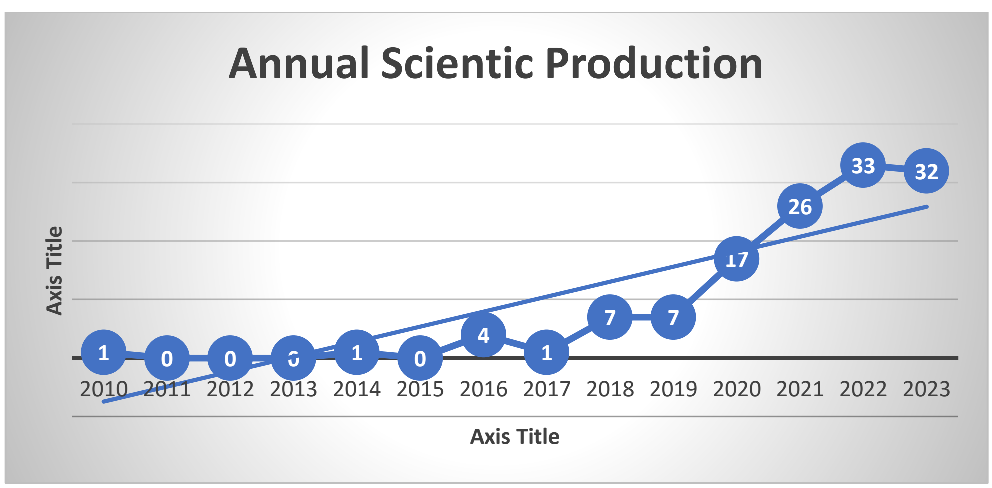

Fig.2.4. Number of papers published in Scopus relevant to last mile logistics and sustainability

Fig. 2.5 shows the co-occurrence network, generated using VOS viewer, of main keywords namely, sustainability, e-commerce, last mile delivery, last mile logistics, etc.

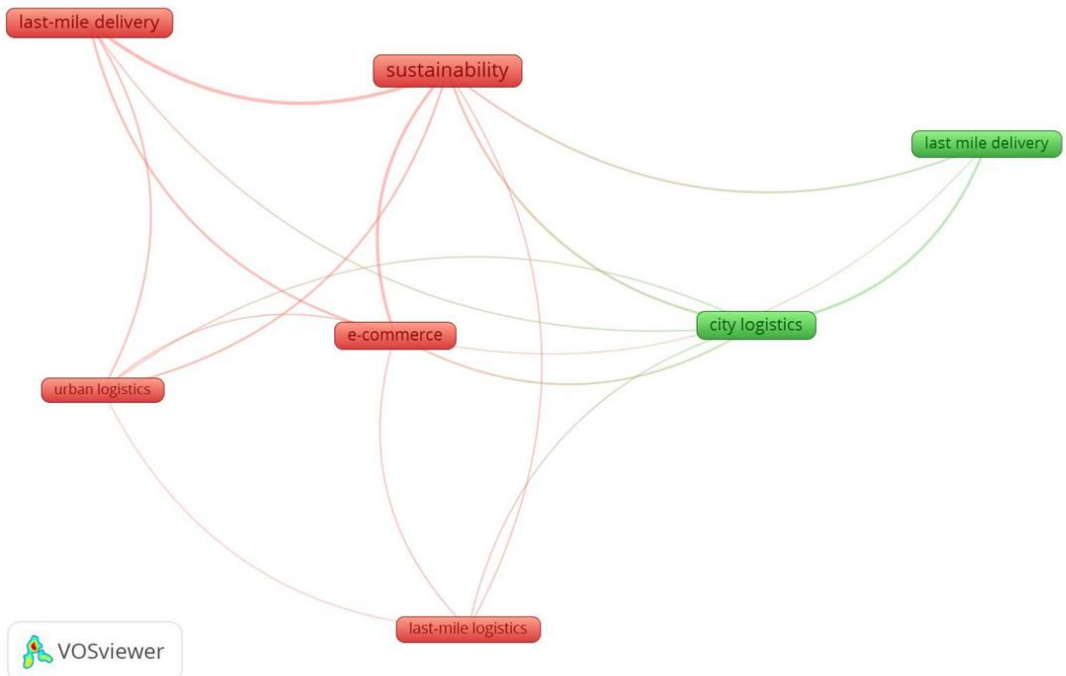

Fig.2.5. Co-occurrence network of keywords.

In three-field plots shown in Fig. 2.6, interconnection between top 10 keywords, countries and abstracts is shows. The main words being sustainability, delivery, last mile delivery, etc.

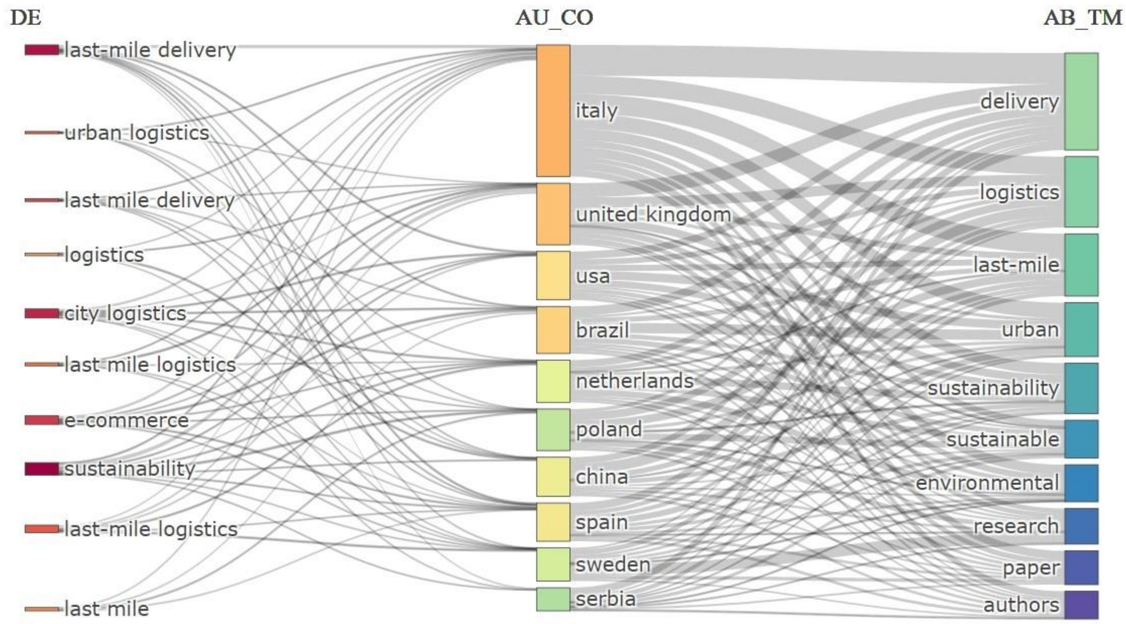

Fig.2.6. Three-field plot of keywords, countries and abstracts.

In Fig. 2.7, word map of most frequent keywords identified by bibliometric analysis is shown. Top five words with frequent occurrence are sustainability, logistics, last mile delivery, e-commerce and last mile logistics.

Fig.2.7. Word map of most frequent words.

Fig. 2.8 shows the frequency of words over time and it can be concluded that sustainability in last mile delivery is having most appearance in research papers since 2019.

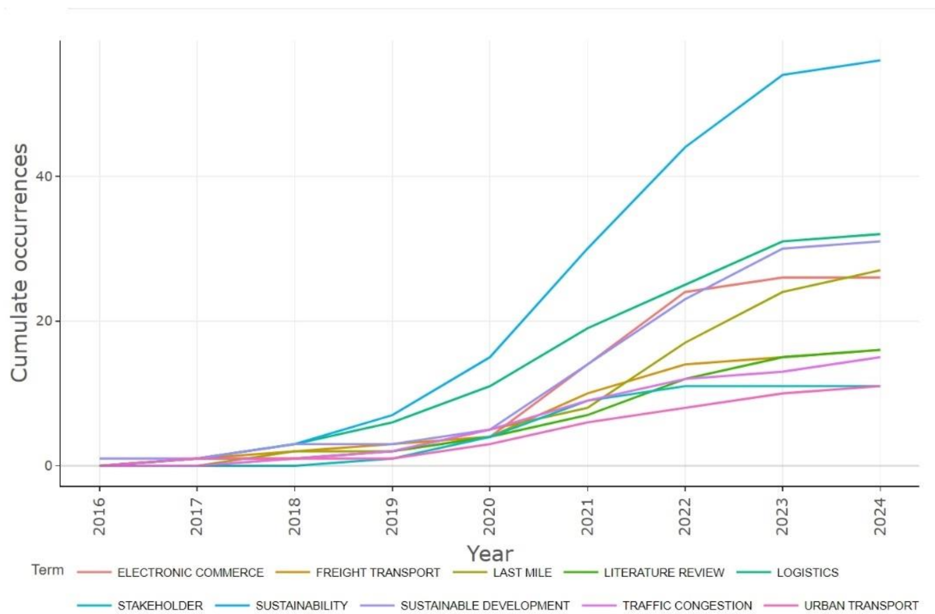

Fig.2.8. keyword frequency over time.

2.3 Identification of factor affecting sustainability

Based on literature review, key factors that affect sustainability like route optimization, use of electric vehicles, green packaging, bicycle delivery, use of renewable energy, Informal transport networks, traffic congestion, zero-emission vehicles, Eco-driving, alternate fuel adoption, Sustainable packaging, environmental education, route planning, use of IoT and Data analytics are identified. On the basis of literature review conducted a total of 51 factors that affect sustainability in last mile delivery are identified. Table 2.3 summarizes give the list of all these factors and their respective sources.

Table 2.3. Factors affecting sustainability in last mile delivery.

S. No.	Paper Title	Factors	Reference
1.	"Using the FAHP, ISM, and MICMAC Approaches to Study the Sustainability Influencing Factors of the Last Mile Delivery of Rural E-Commerce Logistics"	i. Payment convenience ii. Ease of determining the designated time for collection iii. Ease of returning goods iv. Promptness of customer care response v. Promptness of processing goods return vi. Promptness of goods delivery vii. Punctuality of goods arrival viii. Integrity of goods ix. Accuracy of goods arrival x. Accuracy of logistics information xi. Employee service attitude xii. Employees actively remind customers to open the inspection xiii. Advance reservation of goods pickup xiv. Delivery costs xv. Rationality of the value-added services	Jiang et al., (2019)
2.	"Evaluating the Selection Factors for Vietnamese Last-Mile Delivery Service Providers using Best Worst Method"	i. Shipping cost ii. Lead time iii. Customer service iv. Insurance policy v. Delivery reliability	D'agostini et al., (2023)
3.	"A study on the influential factors of the last mile delivery projects during Covid-19 era"	i. Customers' expectations ii. Health iii. Delivery density iv. Cost of last mile delivery v. Types of goods vi. Achieving routing efficiency vii. Infrastructure viii. Issues from customers' side ix. Unpredictability in transit x. Meeting fulfilment timeline	Suguna et al., (2021)

(continued on page no. 17)

Table 2.3 (continued)

S. No.	Paper Title	Factors	Reference
4.	"A hybrid approach integrating Affinity Diagram, AHP and fuzzy TOPSIS for sustainable city logistics planning"	i. Logistical efficiency ii. Mobility iii. Accessibility iv. Service quality v. Loading factor vi. Customer coverage vii. Freeing of public space viii. Energy conservation ix. Trip effectiveness x. Revenues xi. Volume of freight handled xii. Accidents xiii. Costs xiv. Congestion xv. Air pollution xvi. Noise	Awasthi and Chauhan, (2011)
5.	"Sustainable Last-Mile Delivery Solution Evaluation in the Context of a Developing Country: A Novel OPA–Fuzzy MARCOS Approach"	i. Green vehicles ii. Parcel lockers iii. Convenience store pickup iv. Autonomous vehicles v. Crowdsourcing delivery	Wang et al., (2023)

On the basis of similarity these 51 identified factors are categorized into four main groups

1. **Operational factors (OF).**
2. **Customer Service factors (CSF).**
3. **Economic Factors (EF).**
4. **Environmental and Social factors (ESF).**

Operational factors group is having those factors that affect the operational aspects of last mile delivery. Factors like lead time, goods integrity at delivery, effectiveness of trip, infrastructural aspects, logistics efficiency, delivery reliability and ease of returning goods are mapped to operational factors group. In customer service factors group, the factors having direct relation to customer service are placed. Factors like payment convenience, customer service, service quality, customer care effectiveness, etc are mapped to customer service factors group. The factors that linked to economic aspects of sustainability in last mile logistics are placed in economic factors group. Factors such as delivery and shipping costs, revenues generated, cost of last mile operations and other costs are mapped to economic factors group. All the factors that are linked to environmental and social aspects of sustainable last mile delivery are placed in environmental and social factors group. Factors like energy conservation, air pollution, freeing of public space, congestion, noise and accidents are mapped to environmental and social factors group. A complete list of all the factors in each major group is given below.

2.3.1 Operational factors

The factors linked to operational factors group are summarised in the Table 2.4 below along with their respective references.

Table 2.4. Operational factors

S. No.	**Factor**	**References**
1.	Ease of determining the designated time for collection	Jiang et al., (2019)
2.	Ease of returning goods	Jiang et al., (2019)
3.	Promptness of goods delivery	Jiang et al., (2019)
4.	Punctuality of goods arrival	Jiang et al., (2019)
5.	Integrity of goods	Jiang et al., (2019)
6.	Accuracy of goods arrival	Jiang et al., (2019)
7.	Accuracy of logistics information	Jiang et al., (2019)
8.	Lead time	D'agostini et al., (2023)

9.	Delivery reliability	D'agostini et al., (2023)
10.	Achieving routing efficiency	Suguna et al., (2021)
11.	Logistical efficiency	Awasthi and Chauhan, (2011)
12.	Infrastructure	Suguna et al., (2021)
13.	Meeting fulfilment timeline	Suguna et al., (2021)
14.	Loading factor	Awasthi and Chauhan, (2011)
15.	Trip effectiveness	Awasthi and Chauhan, (2011)
16.	Volume of freight handled	Awasthi and Chauhan, (2011)
17.	Parcel lockers	Wang et al., (2023)
18.	Autonomous vehicles	Wang et al., (2023)
19.	Crowdsourcing delivery	Wang et al., (2023)

2.3.2 Customer Service factors

The factors linked to o Customer Service factors group are summarised in the Table 2.5 below along with their respective references.

Table 2.5. Customer Service factors

S. No.	Factor	References
1.	Payment convenience	Jiang et al., (2019)
2.	Promptness of customer care response	Jiang et al., (2019)
3.	Promptness of processing goods return	Jiang et al., (2019)
4.	Employee service attitude	Jiang et al., (2019)
5.	Employees actively remind customers to open the inspection	Jiang et al., (2019)
6.	Customer service	D'agostini et al., (2023)
7.	Issues from customers' side	Suguna et al., (2021)
8.	Customers' expectations	Suguna et al., (2021)
9.	Accessibility	Awasthi and Chauhan, (2011)
10.	Service quality	Awasthi and Chauhan, (2011)
11.	Customer coverage	Awasthi and Chauhan, (2011)
12.	Convenience store pickup	Wang et al., (2023)

2.3.3 Economic Factors

The factors linked to economic factors group are summarised in the Table 2.6 below along with their respective references

Table 2.6. Economic factors

S. No.	Factor	References
1.	Delivery costs	Jiang et al., (2019)
2.	Shipping cost	D'agostini et al., (2023)
3.	Cost of last mile delivery	Suguna et al., (2021)
4.	Rationality of the value-added services	Jiang et al., (2019)
5.	Revenues	Awasthi and Chauhan, (2011)
6.	Costs	v

2.3.4 Environmental and Social factors

The factors linked to Environmental and Social factors group are summarised in the Table 2.7 below along with their respective references

Table 2.7. Environmental and Social factors

S. No.	Factor	References
1.	Energy conservation	Awasthi and Chauhan, (2011)
2.	Congestion	Awasthi and Chauhan, (2011)
3.	Air pollution	Awasthi and Chauhan, (2011)
4.	Noise	Awasthi and Chauhan, (2011)
5.	Green vehicles	Wang et al., (2023)
6.	Health	Suguna et al., (2021)
7.	Mobility	Awasthi and Chauhan, (2011)
8.	Freeing of public space	Awasthi and Chauhan, (2011)
9.	Accidents	Awasthi and Chauhan, (2011)

2.4 Selection of factors for analysis

A total of 51 factors were finally selected. 19 factors were related to operational factors group, 12 to customer service factors group, six to economic factors group and nine to environmental and social factors group. Table 2.4 gives a list of the sub factors which are finally selected for ranking.

The flow chart showing the selection of final factors in major group operational factors (OF) is shown in Fig.2.9. Factor ‘ease of returning goods’ is considered in factor reverse logistics (OF1). Factors ‘ease of determining the designated time for collection’, ‘promptness of goods delivery’, ‘punctuality of goods arrival’, ‘integrity of goods’, ‘accuracy of goods arrival’, ‘logistical efficiency’ and ‘achieving routing efficiency’ are mapped to factor operational efficiency (OF2). Factors ‘volume of freight handled’ and ‘Infrastructure’ are mapped to factor infrastructure (OF3). Factors ‘autonomous vehicles’ and ‘crowdsourcing delivery’ are considered in factor crowdsourcing delivery (OF4).

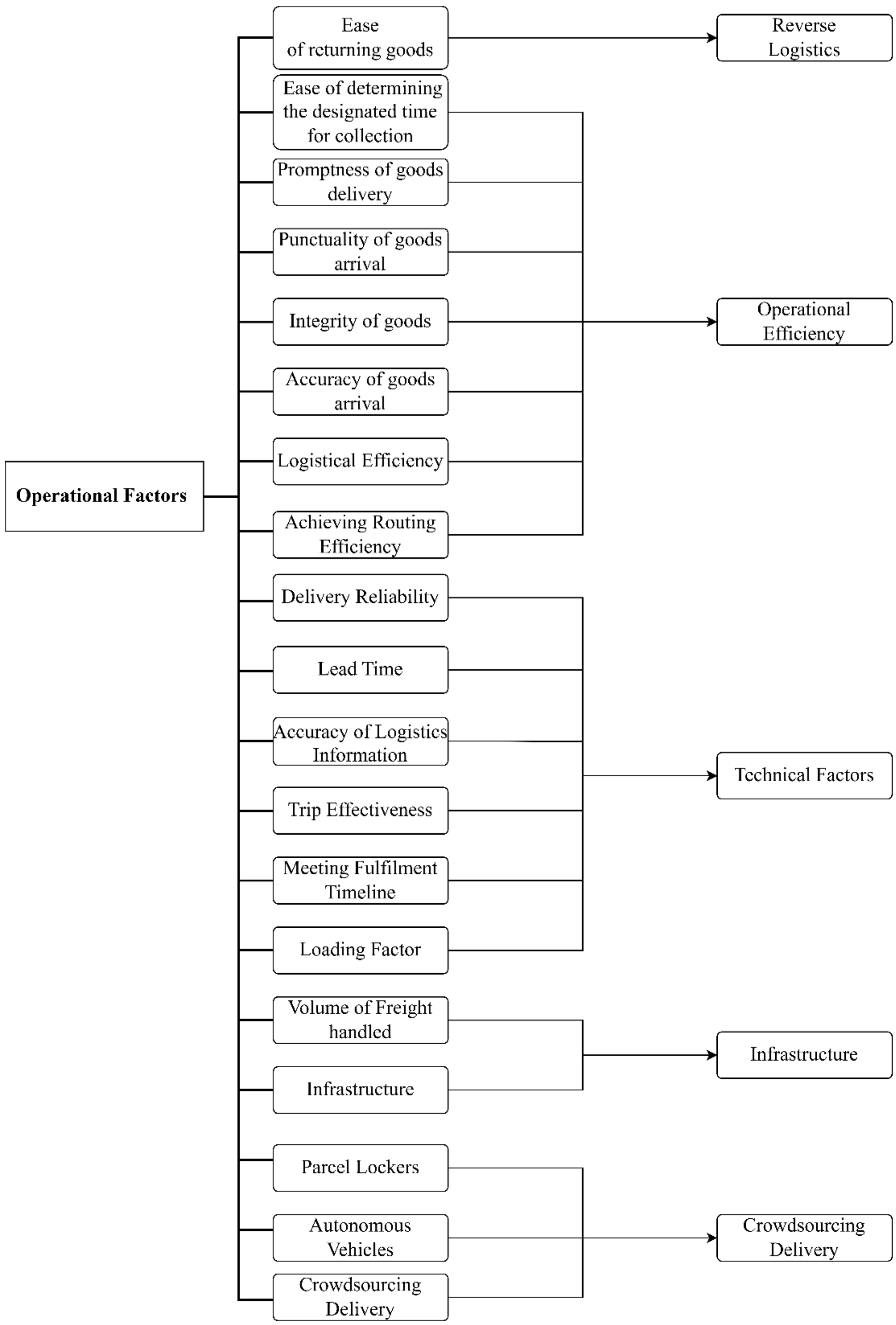

Fig.2.9. Selection of sub factors under Operational factors group.

The flow chart showing the selection of final factors in major group customer service factors (CSF) is shown in Fig.2.10. Factors ‘employees actively remind customers to open the inspection’, ‘promptness of customer care response’, ‘payment convenience’, ‘accessibility’, ‘employee service attitude’ and ‘customer service’ are mapped to factor customer experience (CSF1). ‘Issues from customers’ side’, ‘Promptness of processing goods return’ and ‘Customer coverage’ are considered under factor customer grievance redressal (CSF2). Factors ‘employee service attitude’, ‘customers’ expectations’, ‘service quality’ and ‘convenience store pickup’ are mapped to factor customer satisfaction (CSF3).

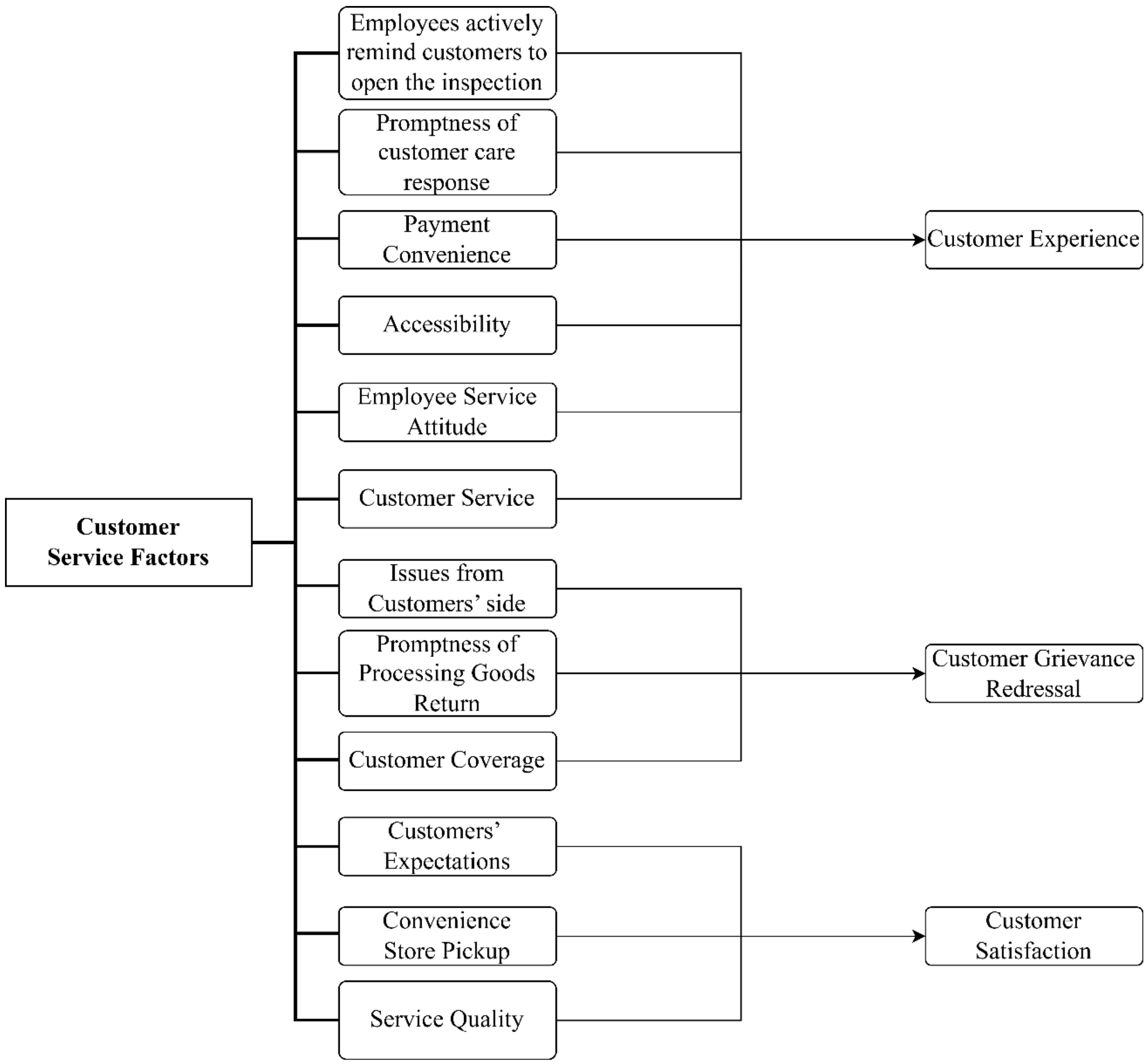

Fig.2.10. Selection of sub factors under Customer Service factors group.

The flow chart showing the selection of final factors in major group economic factors (EF) is shown in Fig.2.11. The factor 'revenues' is directly mapped to factor revenues (EF1). Factors 'delivery costs', 'shipping costs', 'costs' and 'rationality of the value-added services' are mapped to factor delivery costs (EF2). Factor 'cost of last mile delivery' is considered under the factor last mile costs (EF3).

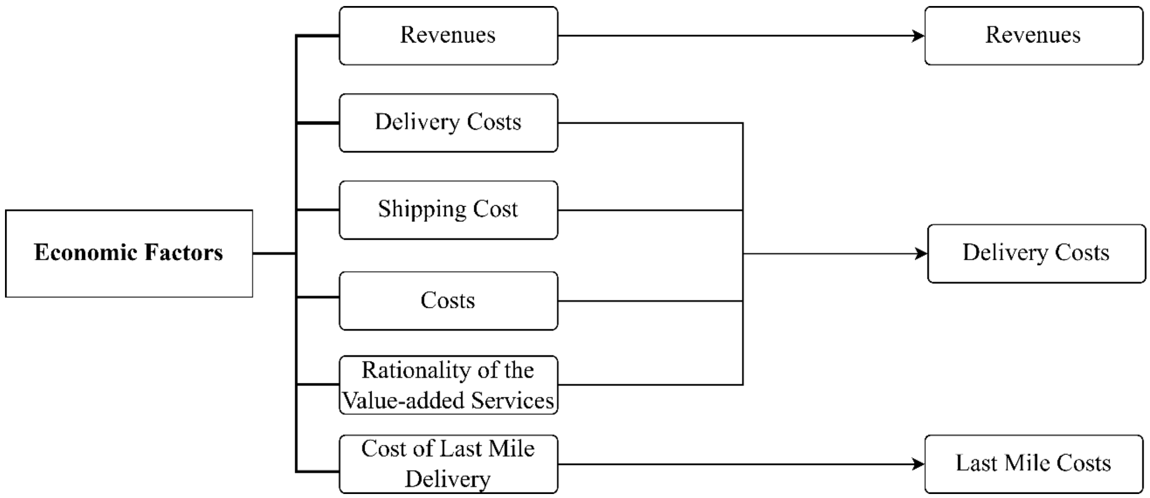

Fig.2.11. Selection of sub factors under Economic factors group.

The flow chart showing the selection of final factors in major group environmental and social factors (EF) is shown in Fig.2.12. factor ‘energy conservation’ is directly mapped to factor energy conservation (ESF1). Factors ‘congestion’, ‘air pollution’ and ‘noise’ are mapped to the factor environmental pollution (ESF2). Factor ‘green vehicles’ is kept as it is and coded as ESF3. Factors ‘health’, ‘mobility’, ‘freeing of public space’ and ‘accidents’ are mapped to the factor social factors (ESF4).

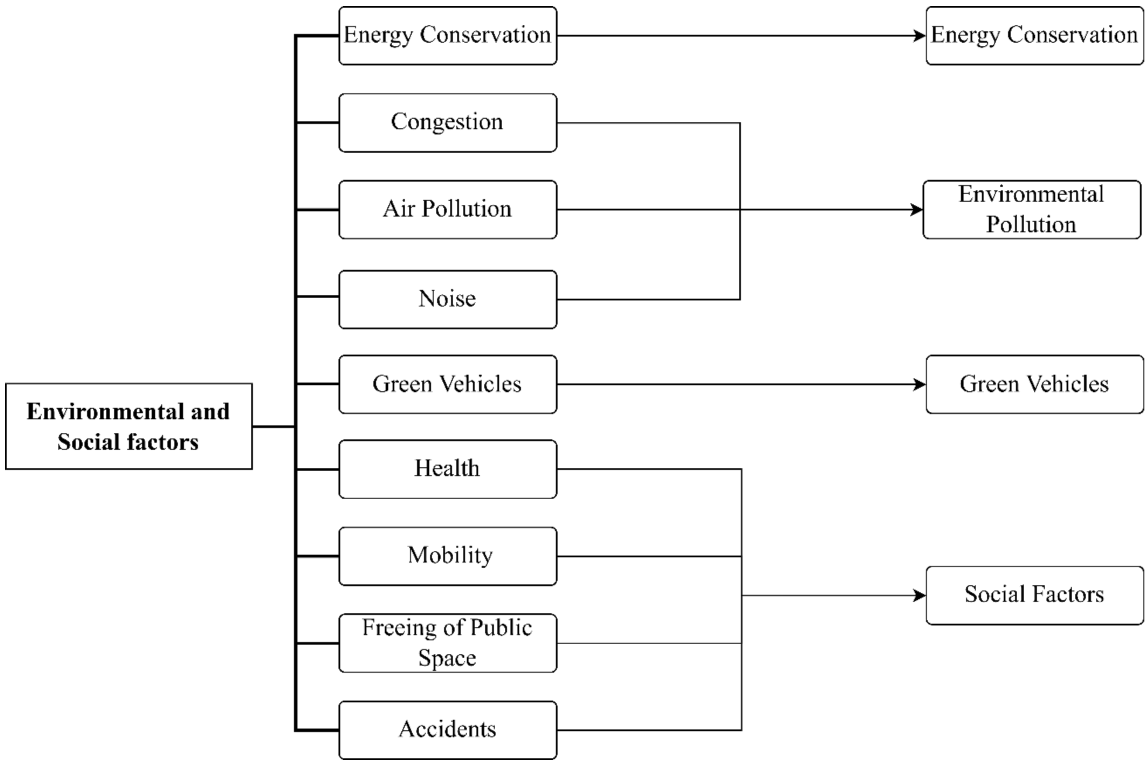

Fig.2.12. Selection of sub factors under Environmental and Social factors group.

The final factors selected for the analysis are summarized in Table 2.8. Each selected factor is given a code name on the basis of major group it belongs to. For example, the selected factor reverse logistics belongs to major group operational factors (OF), it is given the code OF1. Another factor operational efficiency belonging to major group operational factors (OF) is given the code OF2. Similarly, customer experience belonging to customer service factors (CSF) group is code as CSF1. All these codes are mentioned in parenthesis in column three of Table 2.8 preceded by the name of respective selected factor.

Table 2.8. Finally selected sub factors.

Factor group	**Identified factors**	**Selected factors**
Operational factors	i. Ease of determining the designated time for collection ii. Ease of returning goods iii. Promptness of goods delivery iv. Punctuality of goods arrival v. Integrity of goods vi. Accuracy of goods arrival vii. Accuracy of logistics information viii. Lead time ix. Delivery reliability x. Achieving routing efficiency xi. Logistical efficiency xii. Infrastructure xiii. Meeting fulfilment timeline xiv. Loading factor xv. Trip effectiveness xvi. Volume of freight handled xvii. Parcel lockers xviii. Autonomous vehicles xix. Crowdsourcing delivery	i. Reverse logistics (OF1) ii. Operational efficiency (OF2) iii. Technical factors (OF3) iv. Infrastructure (OF4) v. Crowdsourcing delivery (OF5)
Customer Service factors	i. Payment convenience ii. Promptness of customer care response iii. Promptness of processing goods return iv. Employee service attitude v. Employees actively remind customers to open the inspection vi. Customer service vii. Issues from customers' side viii. Customers' expectations ix. Accessibility x. Service quality xi. Customer coverage xii. Convenience store pickup	i. Customer experience (CSF1) ii. Customer grievance redressal (CSF2) iii. Customer satisfaction iv. (CSF3)

(continued on page no. 28)

Table 2.8 (continued)

Factor group	Identified factors	Selected factors
Economic Factors	i. Delivery costs ii. Shipping cost iii. Cost of last mile delivery iv. Rationality of the value-added services v. Revenues vi. Costs	i. Revenues (EF1) ii. Delivery costs (EF2) iii. Last mile costs (EF3)
Environmental and Social factors	i. Energy conservation ii. Congestion iii. Air pollution iv. Noise v. Green vehicles vi. Health vii. Mobility viii. Freeing of public space ix. Accidents	i. Energy conservation (ESF1) ii. Environmental pollution (ESF2) iii. Green vehicles (ESF3) iv. Social factors (ESF4)

2.5 Description of selected factors

A total of 15 factors have been shortlisted for the final analysis using fuzzy AHP technique. Before analysing these factors, it is very critical to explain these factors. A thorough description of these factors is given in Table 2.9.

Table 2.9. Description of factors selected for analysis.

Factor Group	**Factor**	**Description**
Operational factors (OF)	Reverse logistics (OF1)	It encompasses the effect of costs and sustainability concerns in return of goods. As discussed by Jiang et al., (2019), ease of returning goods plays a key role in sustainability. In this study all the factor that are related to return of package and their sustainability concerns are considered in sub-factor reverse logistics (OF1).
	Operational efficiency (OF2)	Sub-factor operational efficiency (OF2) includes all the factors such and logistical performance, punctuality and promptness of delivery, condition of package at the time of delivery and routing efficiency. All these sub-factors are having a direct effect on sustainability concerns in last mile operations. In the study conducted by Awasthi and Chauhan, (2011), logistical efficiency factor was used to represent the performance of logistics operations. The factors identified by Jiang et al., (2019), like promptness of goods delivery, punctuality of goods arrival and integrity of goods are also incorporated in sub factor operational efficiency (OF2) as these factors are having obvious effect on

	sustainability. Suguna et al., (2021) identified factor “achieving routing efficiency” and stated that with an increase in the volume of packages it becomes challenging for the effective execution of last mile delivery, thereby raising sustainability concerns.
Technical factors (OF3)	All the technicalities such as trip effectiveness, sharing of logistical data and information across suppy chain. D'agostini et al., (2023) identified several technical factors that effect last mile delivery operations such as lead time and delivery reliability. Lead time is the time required to deliver the goods after placement of the order as stated by Gevaers et al., (2011). Delivery reliability stand for the ability of the service provider to fulfil the exact demand of consumer in the time frame as discussed by Lim and Wenckebach, (2019). In the study by Awasthi and Chauhan, (2011), trip effectiveness is discussed as reducing the number of overall trips and distance between trips which directly influences sustainability hence kept in technical factors (OF3) group.
Infrastructure (OF4)	The volume of freight handled directly comes under infrastructure. Moreover, distribution centre and vehicles are also included in this. Freight volume factor identified by Awasthi

		and Chauhan, (2011) directly depend upon the capacity of vehicles and the size of distribution centres. Since these are having direct effect on sustainability, therefore they are kept in sub-factor infrastructure (OF4).
	Crowdsourcing delivery (OF5)	Crowdsourcing use local not highly professional delivery persons to deliver the package. Use of crowdsourcing helps in lower the burden on the organization.
Customer service factors (CSF)	Customer experience (CSF1)	Jiang et al., (2019) identified factors such as payment convenience, promptness of customer care response and employee service attitude. In this study all these factors are grouped in sub-factor customer experience (CSF1). D'agostini et al., (2023) discussed customer service as a key factor in sustainability of last mile.
	Customer grievance redressal (CSF2)	Suguna et al., (2021) discussed that Issues from customers’ side and their redressal plays an important role in the performance of last mile operations. Awasthi and Chauhan, (2011) emphasized on proper customer coverage for smooth and fruitful last mile operations.
	Customer satisfaction (CSF3)	Customers’ expectations are a key factor in the last mile delivery as discussed by Suguna et al., (2021). Wang et al., 2023 discussed

		convenience store pickup as an influential factor in sustainability of last mile operations. Moreover, it also contributes to customer satisfaction by providing the customer freedom of collecting the package as per customers' time choice.
Economic factors (EF)	Revenues (EF1)	Awasthi and Chauhan, (2011) has identified this factor revenue. It stands for the revenue generated by the logistics service provider. Since revenues play a key role in overall performance and existence of an organization, hence this factor is considered for the analysis under sub factor group EF1.
	Delivery costs (EF2)	Jiang et al., (2019) has identified delivery costs as an important factor influencing sustainability in last mile logistics. It includes all the costs involved in transportation of product as well as packaging costs.
	Last mile costs (EF3)	Cost of last mile delivery is an influential factor identified by Suguna et al., (2021). Study by Gevaers et al, (2011) has shown that the last mile delivery in a supply chain can cost up to 75% of the total cost of transportation and raise sustainability concerns in last mile logistics. Hence, it is necessary to consider this factor for our analysis.

Environmental and social factors (ESF)	Energy conservation (ESF1)	Awasthi and Chauhan, (2011) identified energy conservation as one of most important factor that affects sustainability in city logistics. This can be done by reducing the consumption of convential fuel such as petrol and diesel. As discuused in literature review, sustainable packaging has been in trend after covid- 19 pandemic. Sustainable packaging uses recycled and eco-friendly material for packaging.
	Environmental pollution (ESF2)	Factors such as congestion, air pollution, noise identified by Awasthi and Chauhan, (2011) pose a serious threat to environment thereby generating sustainability concerns in last mile logistics. As such it becomes important to consider these for the analysis. All the factors that contribute to environmental pollution are put in sub factor group ESF1.
	Green vehicles (ESF3)	Patricia et al, (2015) and Edwards et al, (2010) has considered last mile as major contributor of greenhouse gas and pollutants thereby raising its sustainability concerns. Use of green vehicles is recognized as an effective factor by Wang et al., (2023) for improving sustainability in last mile logistics. Hence, it becomes important to consider green vehicle as a factor for our analysis.

Social factors (ESF4)	Awasthi and Chauhan, (2011) raised the concerns regarding the availability of parking space needed for delivery vehicles. Suguna et al., (2021) discussed the effect of health of the delivery person and corresponding effect on the performance of last mile delivery. Awasthi and Chauhan, (2011) further discussed the issue of accidents and their after effects. All these issues are of societal concern and also affect sustainability, hence, kept under the sub-factor social factors (ESF3).

CHAPTER 3

FORMULATION OF THE PROBLEM AND SOLUTION APPOACH

3.1 Method selection

For ranking of identified factors on the basis of calculated weights, multi criteria decision making (MCDM) techniques are widely used in research works. In this study fuzzy analytic hierarchy process (AHP) is a potent method. In fuzzy AHP fuzzified numbers are used to frame the initial pairwise comparison matrix. Fuzzy AHP has been applied in many real-world problems since its advent. The reliability of Fuzzy AHP is well proven by numerous scientific works. The data collected in this study is in accordance with inputs required for Fuzzy AHP. Hence, in this study fuzzy AHP has been used.

3.2 Fuzzy AHP

The Analytic Hierarchy Process (AHP) is a widely used quantitative method in Multi-Criteria Decision Making (MCDM) technique that is used to determine the ranking and prioritization of factors. It was first developed by Saaty, (1980). The use of

AHP is often limited by specific issues. AHP is unable to manage ambiguity and inaccurate human judgment in an uncertain situation as discussed in Mahtani and Garg, (2018). The outcomes obtained from traditional AHP are significantly influenced by the decisions made by specialists, who use an imbalanced judgment scale. Thus, the fuzzy Analytic Hierarchy Process (AHP) technique is used in this study to address these limitations as done by Kumar and Garg, (2017); Prakash and Barua, (2015). A fuzzy approach is ideal for improving the MCDM method due to its ability to effectively manage uncertainty in collected data as discussed by Zadeh, (1965) and Zimmermann, (2001).

Table 3.1 enlists some of the previous applications of fuzzy AHP in various studies.

Table 3.1. Application of Fuzzy AHP in other studies.

Authors	Application
Prakash and Barua (2015)	Prioritizing barriers to reverse logistics solutions adoption
Kabra and A. Ramesh (2015)	Coordination barriers prioritization in humanitarian supply chain
Kumar and Garg (2017)	Evaluation of indicators in sustainable supply chain in Indian automotive industry
Vishwakarma et al., (2016)	Risk assessment in supply chain in Indian pharmaceutical industry

3.2.1 Fuzzy AHP Algorithm

Fuzzy AHP is the modified form of conventional AHP. It uses fuzzy logic to handle the uncertainties associated with decision making processes. In this study fuzzy

AHP using geometric mean method is utilized to rank the selected factors. A framework depicting the algorithm of fuzzy AHP is shown in Fig. 3.1.

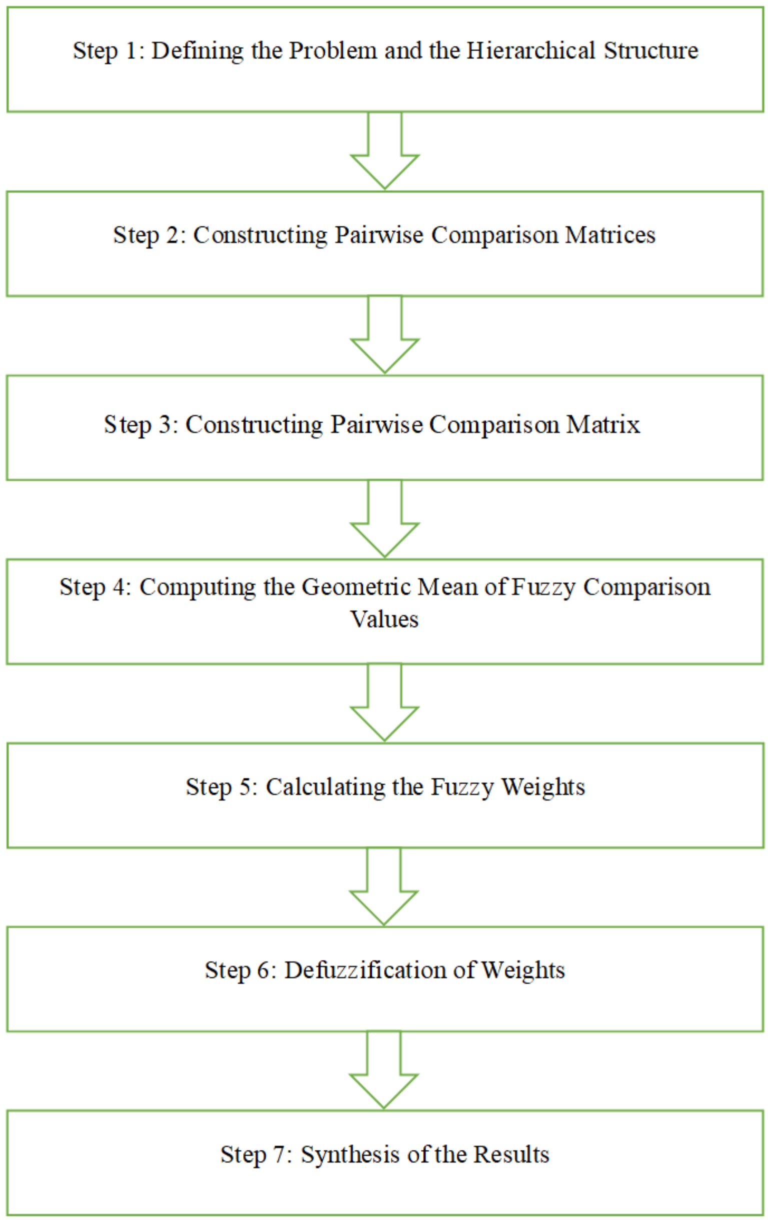

Fig. 3.1. Fuzzy AHP algorithm

All the steps of fuzzy AHP are given in detail below

1. Define the problem and create a hierarchical structure.
2. Construct pairwise comparison matrices. Create square matrices of order *(n x n)* in which each element represents the relative impact of factor *i* in comparison to factor *j*. A scale of 1 to 9 has been used to rank the factors in which 1 stands for low impact and 9 stands for extreme impact. Table 3.2 shows the complete comparison scale used in this study.

Table 3.2. Pairwise comparison scale.

Linguistic variable	**Assigned weight**
Low impact	1
Moderate impact	3
Strong impact	5
Very strong impact	7
Extreme impact	9
Intermediate values between two adjacent judgments	2,4,6,8

3. Convert the pairwise comparison matrix formulated in step 2 into fuzzy pairwise comparison matrix by using fuzzy numbers. Triangular fuzzy number (TFN) is used to formulate pairwise comparison matrix in fuzzy AHP. A TFN is represented as *(l,m,u)* where *l, m* and *n* represent lower, middle and upper value respectively. Fuzzified pairwise comparison scale used in this study is shown in Table 3.3.

Table 3.3. Fuzzified pairwise comparison scale.

Assigned weight	Fuzzified weight
1	(1,1,1)
2	(1,2,3)
3	(2,3,4)
4	(3,4,5)
5	(4,5,6)
6	(5,6,7)
7	(6,7,8
8	(7,8,9)
9	(9,9,9)

4. Calculate the geometric mean of fuzzy comparison values for each factor row wise. For example, if there are three fuzzy comparison numbers (l_1,m_1,u_1), (l_2,m_2,u_2) and (l_3,m_3,u_3) the fuzzy geometric mean represented by (L,M,U) is calculated as

$$L = Geometric\ mean\ of\ (l_1,\ l_2,\ \text{and}\ l_3) = (l_1 \times l_2 \times l_3)^{1/3}$$

$$M = Geometric\ mean\ of\ (m_1 \times m_2 \times m_3) = (m_1 \times m_2 \times m_3)^{1/3}$$

$$U = Geometric\ mean\ of\ (u_1 \times u_2 \times u_3) = (u_1 \times u_2 \times u_3)^{1/3}$$

5. Fuzzy weights are calculated by dividing the fuzzy geometric mean by the reciprocal of geometric mean summation. Geometric mean summation is done by summing the fuzzy geometric means calculated in step 4. Summation two or more TFNs is done by adding the corresponding lower values, corresponding middle values and corresponding upper values. For example, if there are three fuzzy numbers

$$A = (l_1,m_1,u_1),\ B = (l_2,m_2,u_2)\ and\ C = (l_3,m_3,u_3)$$

Then the summation $A+B+C$ is given by

$$A+B+C = (l_1 + l_2 + l_3, m_1 + m_2 + m_3, u_1 + u_2 + u_3)$$

The reciprocal of a TFN is given by taking the reciprocal of lower, middle and upper value and writing them in opposite order. For instance the reciprocal of $A = (l_1,m_1,u_1)$ can be calculated as

$$1/A = (1/ l_1, 1/ l_2, 1/ l_3)$$

Once summation and reciprocal of geometric means are calculated by dividing all TFN values of geometric mean with the corresponding values of reciprocal of geometric mean summation respectively.

6. Defuzzification is the process of converting triangular fuzzy number into a single non fuzzy number. Defuzzification of weights can be done by using centroid method. For example, the centroid of TFN $D =(l,m,u)$ can be calculated by

$$d = \frac{l+m+u}{3}$$

After defuzzification is done we need to normalize the defuzzied weights by dividing each weight with sum of all defuzzied weights.

7. The last step is to synthesize the result based on the final weights calculated in the last step.

3.3 Research Methodology

This study uses Fuzzy AHP method to rank the identified factors that affect sustainability in last mile logistics. In this study 15 final factors are shortlisted on the basis of literature review and bibliometric analysis for the application of proposed method. Framework of the research methodology is shown in Fig. 3.2. The hierarchical structure of factors and groups is shown in Fig. 3.3.

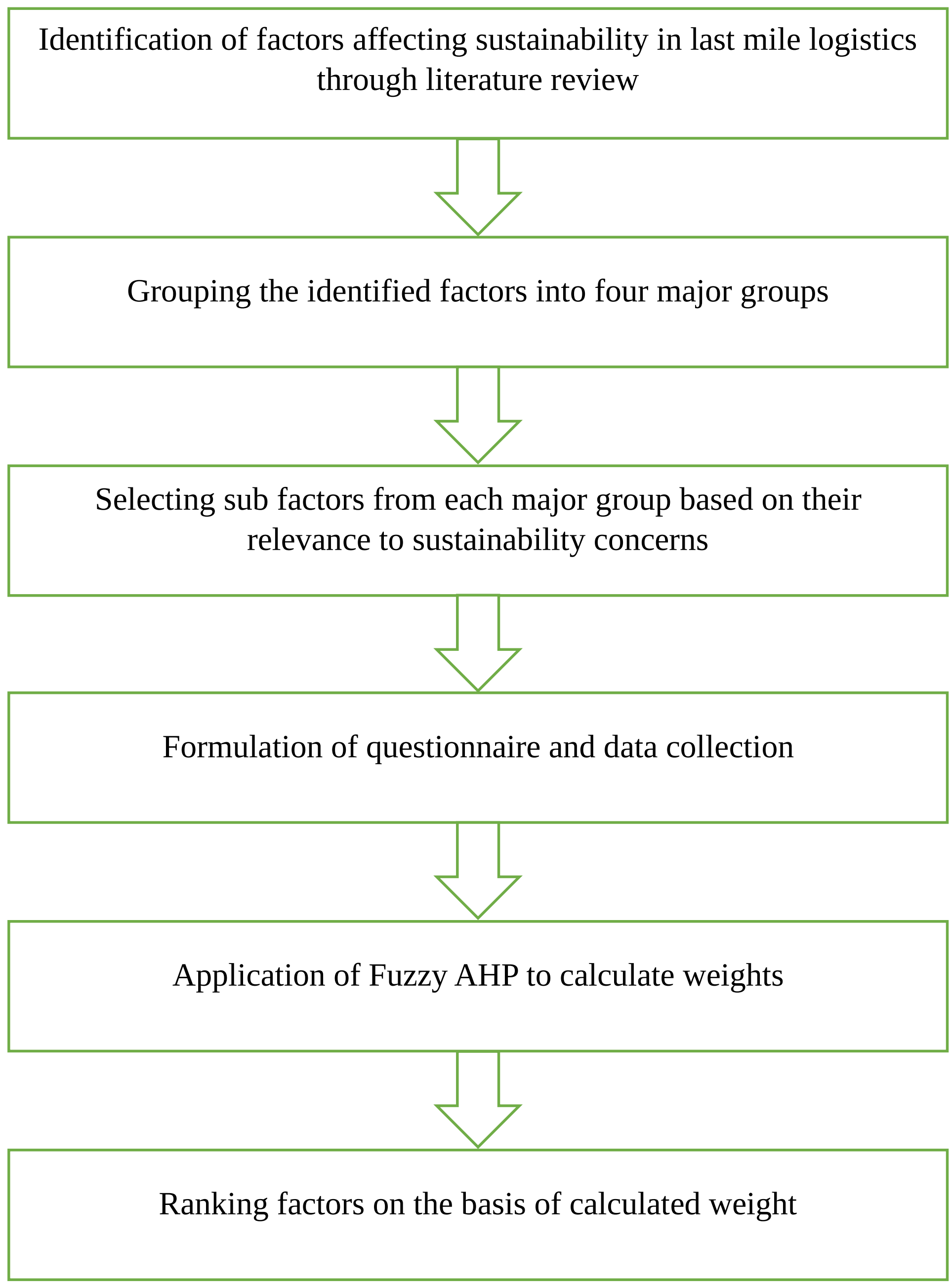

Fig.3.2. Methodology for application of Fuzzy AHP.

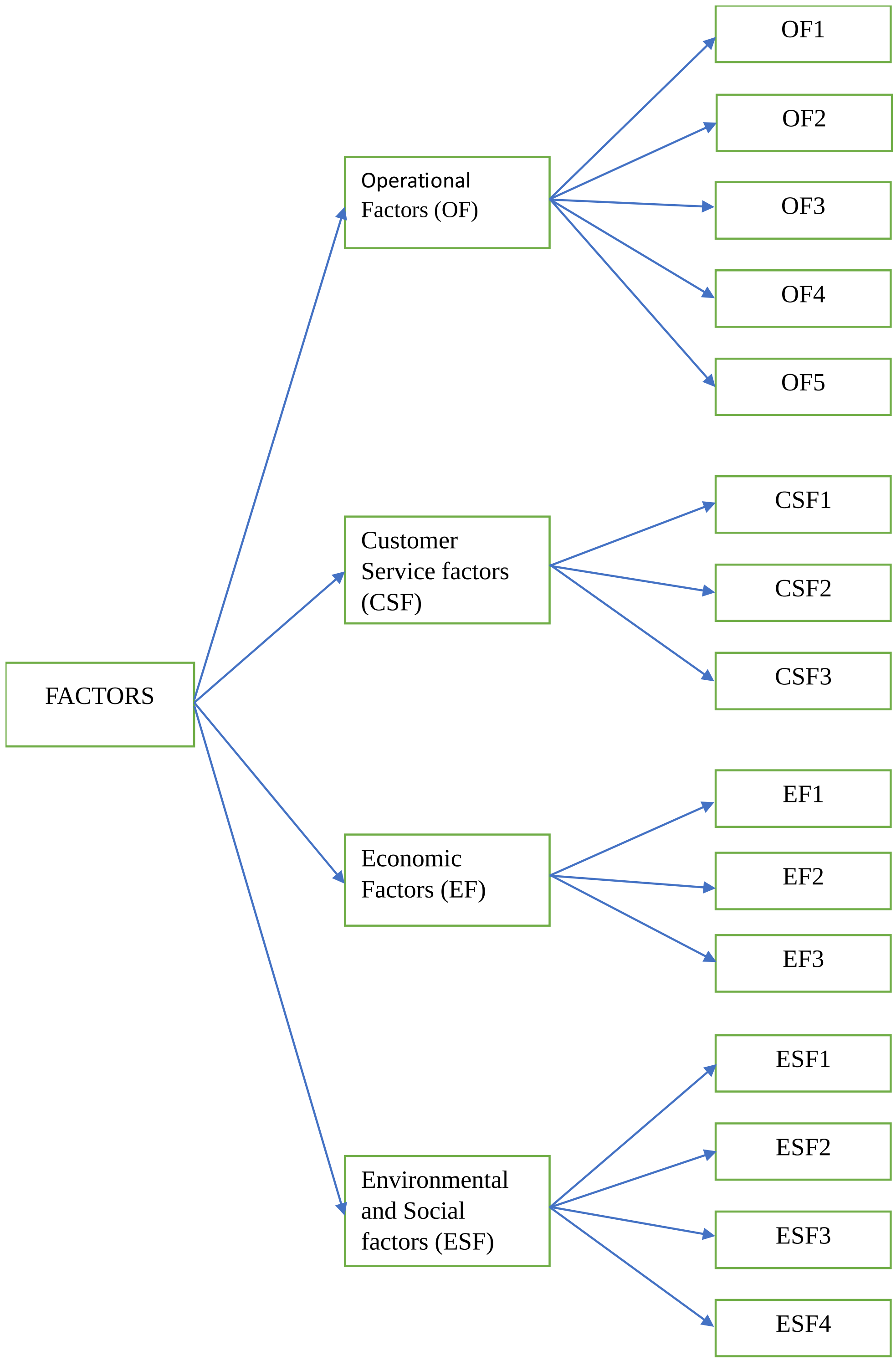

Fig.3.3. Hierarchical structure of factors.

3.4 Application of fuzzy AHP for ranking selected factors

The initial weights assigned in the pairwise comparison matrices were decided by conducting a survey of opinions of 15 domain experts. These were then fuzzified using fuzzy logic to formulate the problem according fuzzy AHP method. All the calculations required for fuzzy AHP method were performed in Microsoft excel. Table 3.4, 3.7, 3.9, 3.11 and 3.13 contains the fuzzified pairwise comparison matrices of major factors, operational factors, customer service factors, economic factors, and environmental and social factors respectively. Table 3.5, 3.8, 3.10, 3.12 and 3.14 show the stated algorithm-based application of fuzzy AHP to major factors, operational factors, customer service factors, economic factors, and environmental and social factors respectively. In Table 3.6 calculated priority weights of major factors has been shown.

Table 3.4 shows the fuzzified pairwise comparison matrix of major factor groups formulated as explained in step 3.

Table 3.4. Fuzzified pairwise comparison matrix of major factors.

	OF	**CSF**	**EF**	**ESF**
OF	(1,1,1)	(9,9,9)	(1,1,1)	(4,5,6)
CSF	(1/9,1/9,1/9)	(1,1,1)	(1/9,1/9,1/9)	(1/6,1/5,1/4)
EF	(1,1,1)	(9,9,9)	(1,1,1)	(4,5,6)
ESF	(1/6,1/5,1/4)	(4,5,6)	(1/6,1/5,1/4)	(1,1,1)

Table 3.5 below shows the application of fuzzy AHP to major factor groups as explained in step 4 to step 7 in fuzzy AHP algorithm.

Table 3.5. Fuzzy AHP application on major factors.

	Fuzzy Geometric mean	Fuzzy weights	DE fuzzified weights	Normalized weights
OF	(2.45,2.59,2.71)	(0.38,0.43,0.47)	0.4269	0.4249
CSF	(0.21,0.22,0.24)	(0.03,0.04,0.04)	0.0370	0.0368
EF	(2.45,2.59,2.71)	(0.38,0.43,0.47)	0.4269	0.4249
ESF	(0.61,0.67,0.78)	(0.09,0.11,0.14)	0.1139	0.1134

Table 3.6 below is having the normalised weights of major factors calculated using fuzzy AHP. Ranks on the basis of normalised weights are also given in Table 3.6.

Table 3.6. Priority Weight of major factors.

	Normalized weights	Rank
OF	0.4249	1
CSF	0.0368	3
EF	0.4249	1
ESF	0.1134	2

Table 3.7 shows the fuzzified pairwise comparison matrix of sub factors in OF group formulated as explained in step 3.

Table 3.7. Fuzzified pairwise comparison matrix of sub factors in OF group.

	OF1	OF2	OF3	OF4	OF5
OF1	(1,1,1)	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(1/9,1/9,1/9)
OF2	(9,9,9)	(1,1,1)	(9,9,9)	(4,5,6)	(2,3,4)
OF3	(9,9,9)	(1/9,1/9,1/9)	(1,1,1)	(1/5,1/4,1/3)	(1/7,1/6,1/5)
OF4	(9,9,9)	(1/6,1/5,1/4)	(3,4,5)	(1,1,1)	(1/3,1/2,1/1)
OF5	(9,9,9)	(1/4,1/3,1/2)	(5,6,7)	(1,2,3)	(1,1,1)

Table 3.5 below shows the application of fuzzy AHP to sub factors in OF group as explained in step 4 to step 7 in fuzzy AHP algorithm.

Table 3.8. Fuzzy AHP application on OF group.

	Fuzzy Geometric mean	**Fuzzy weights**	**DE fuzzified weights**	**Normalized weights**
OF1	(0.17,0.17,0.17)	(0.02,0.02,0.02)	0.0213	0.0207
OF2	(3.65,4.14,4.55)	(0.39,0.51,0.65)	0.5139	0.4995
OF3	(0.49,0.53,0.58)	(0.05,0.06,0.08)	0.0666	0.0647
OF4	(1.08,1.29,1.62)	(0.12,0.16,0.23)	0.1681	0.1634
OF5	(1.62,2.05,2.48)	(0.17,0.25,0.35)	0.2588	0.2516

Table 3.9 shows the fuzzified pairwise comparison matrix of sub factors in CSF group formulated as explained in step 3.

Table 3.9. Fuzzified pairwise comparison matrix of sub factors in CSF group.

	CSF1	**CSF2**	**CSF3**
CSF1	(1,1,1)	(1/9,1/8,1/7)	(1/3,1/2,1/1)
CSF2	(7,8,9)	(1,1,1)	(5,6,7)
CSF3	(1,2,3)	(1/7,1/6,1/5)	(1,1,1)

Table 3.10 below shows the application of fuzzy AHP to sub factors in CSF group as explained in step 4 to step 7 in fuzzy AHP algorithm.

Table 3.10. Fuzzy AHP application on CSF group.

	Fuzzy Geometric mean	Fuzzy weights	DE fuzzified weights	Normalized weights
CSF1	(0.33, 0.40, 0.52)	(0.06, 0.08, 0.13)	0.0910	0.0890
CSF2	(3. 27, 3.63, 3.98)	(0.61, 0.77, 0.96)	0.7818	0.7646
CSF3	(0.52,0. 69,0. 84)	(0.10, 0.15, 0.20)	0.1496	0.1464

Table 3.11 shows the fuzzified pairwise comparison matrix of sub factors in EF group formulated as explained in step 3.

Table 3.11. Fuzzified pairwise comparison matrix of sub factors in EF group.

	EF1	EF2	EF3	EF4
EF1	(1,1,1)	(1/9,1/8,1/7)	(1/5,1/4,1/3)	(3,4,5)
EF2	(7,8,9)	(1,1,1)	(3,4,5)	(9,9,9)
EF3	(3,4,5)	(1/5,1/4,1/3)	(1,1,1)	(7,8,9)

Table 3.12 below shows the application of fuzzy AHP to sub factors in EF group as explained in step 4 to step 7 in fuzzy AHP algorithm.

Table 3.12. Fuzzy AHP application on EF group.

	Fuzzy Geometric mean	Fuzzy weights	DE fuzzified weights	Normalized weights
EF1	(0.28, 0.31, 0.36)	(0.06, 0.07, 0.09)	0.0729	0.0711
EF2	(2.76, 3.17, 3.56)	(0.54, 0.71, 0.92)	0.7212	0.7035
EF3	(0.84,1.00,1.19)	(0.17, 0.22, 0.31)	0.2311	0.2254

Table 3.13 shows the fuzzified pairwise comparison matrix of sub factors in ESF group formulated as explained in step 3.

Table 3.13. Fuzzified pairwise comparison matrix of sub factors in ESF group.

	ESF1	**ESF2**	**ESF3**	**ESF4**
ESF1	(1,1,1)	(1/5,1/4,1/3)	(1,2,3)	(9,9,9)
ESF2	(3,4,5)	(1,1,1)	(5,6,7)	(9,9,9)
ESF3	(1/3,1/2,1/1)	(1/7,1/6,1/5)	(1,1,1)	(9,9,9)
ESF4	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(1,1,1)

Table 3.14 below shows the application of fuzzy AHP to sub factors in ESF group as explained in step 4 to step 7 in fuzzy AHP algorithm.

Table 3.14. Fuzzy AHP application on ESF group.

	Fuzzy Geometric mean	**Fuzzy weights**	**DE fuzzified weights**	**Normalized weights**
ESF1	(1.16, 1.46, 1.73)	(0.16, 0.23, 0.31)	0.2323	0.2268
ESF2	(3.41, 3.83, 4.21)	(0.47, 0.60, 0.76)	0.6072	0.5927
ESF3	(0.81, 0.93, 1.16)	(0.11, 0.15, 0.21)	0.1547	0.1510
ESF4	(0.19, 0.19, 0.19)	(0.03, 0.03, 0.03)	0.0303	0.0296

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

After the successful application of fuzzy AHP method priority weights were calculated for the factor groups as well as individual factors. Global priority weights for the factors are calculated by multiplying the local priority weight of the factor with the priority weight of the corresponding factor group. On the basis of this global weight the factor affecting sustainability in last mile delivery are ranked. Table 4.1 shows the weights and ranks of individual factors as well as the major factor groups. Fig. 4.1 show the bar graph of weights of the four factor groups namely operational factors, customer service factors, economic factors and environmental and social factors. The individual weights of the factors in these factor groups are shown in figures 4.2, 4.3, 4.4 and 4.5.

Table 4.1. Weights and ranks of major factor groups and individual factors.

Main Criteria/Sub Criteria	Code	Local Weights	Global Weights	Rank
1. Operational factors	**OF**	**0.4249**	**-**	**1**
Reverse logistics (OF1)	OF1	0.0207	0.0088	12
Operational efficiency (OF2)	OF2	0.4995	0.2122	2
Technical factors (OF3)	OF3	0.0647	0.0275	9
Infrastructure (OF4)	OF4	0.1634	0.0694	5
Crowdsourcing delivery (OF5)	OF5	0.2516	0.1069	3
2. Customer Service factors	**CSF**	**0.0368**	**-**	**4**
Customer experience	CSF1	0.089	0.0033	15
Customer grievance redressal	CSF2	0.7646	0.0281	8
Customer satisfaction	CSF3	0.1464	0.0054	13
3. Economic Factors	**EF**	**0.4249**	**-**	**2**
Economic revenues (EF1)	EF1	0.0873	0.0371	7
Delivery costs (EF2)	EF2	0.5925	0.2518	1
Last mile costs (EF3)	EF3	0.2461	0.1046	4
4. Environmental and Social factors	**ESF**	**0.1134**	**-**	**3**

Energy conservation (ESF1)	ESF1	0.2268	0.0257	10
Environmental pollution (ESF2)	ESF2	0.5927	0.0672	6
Green vehicles (ESF3)	ESF3	0.151	0.0171	11
Social factors (ESF4)	ESF4	0.0296	0.0034	14

From Fig. 4.1 it can been concluded that on the basis of this analysis major factor group OF and EF are having equal affect on sustainability in last mile delivery.

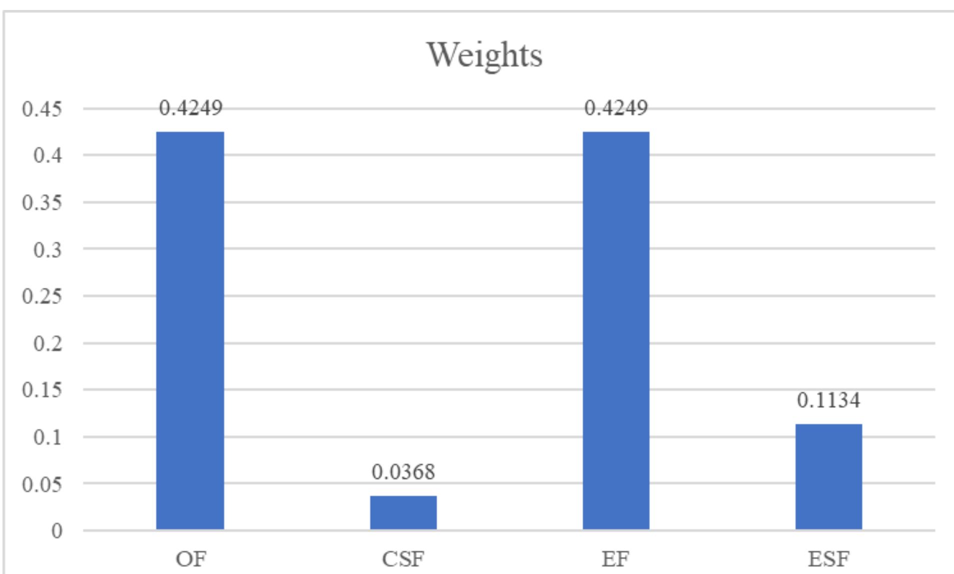

Fig. 4.1. Priority weights of each factor group.

From Fig. 4.2 it can be concluded that technical factors (OF2) are having more affect on sustainability in last mile operations. The second most important factor in operational factors group is use of crowdsourcing delivery (OF5).

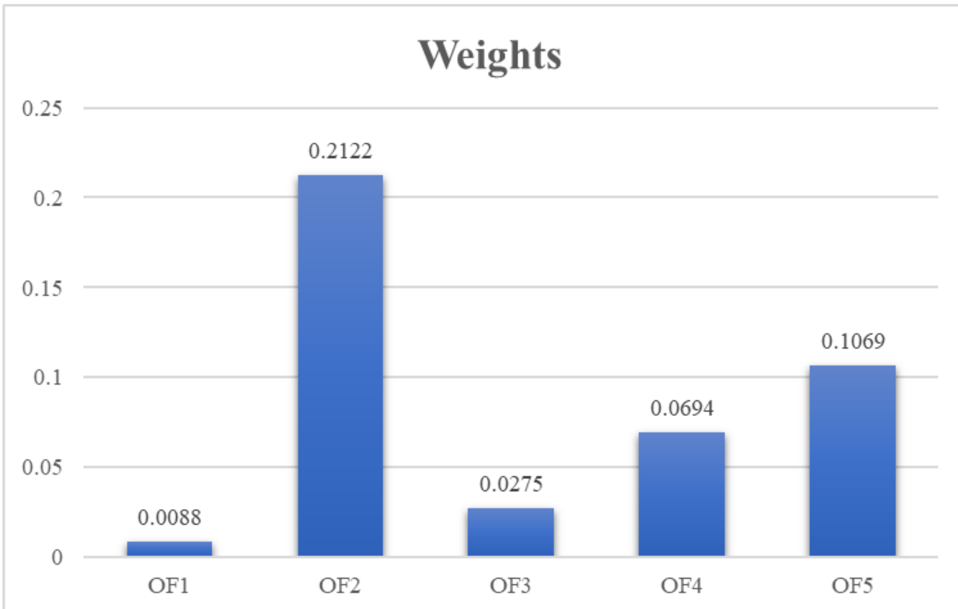

Fig. 4.2. Priority weights of factors in operational factors group.

From Fig. 4.3 it can be concluded that Customer grievance redressal (CSF2) is having more effect on sustainability in last mile operations.

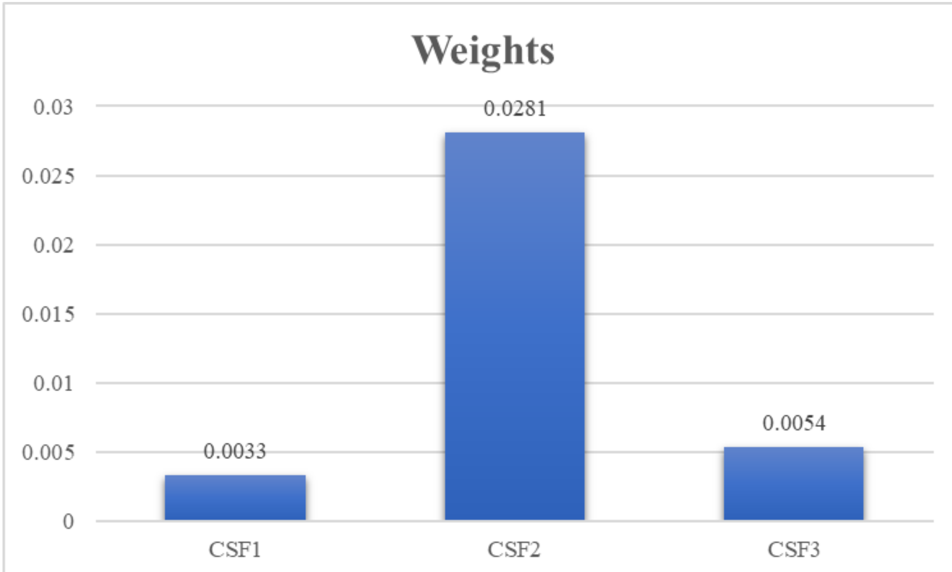

Fig. 4.3. Priority weights of factors in customer service factors group.

From Fig. 4.4 it can be concluded that factor delivery costs (EF2) is having more effect on sustainability in last mile operations followed by last mile costs (EF3).

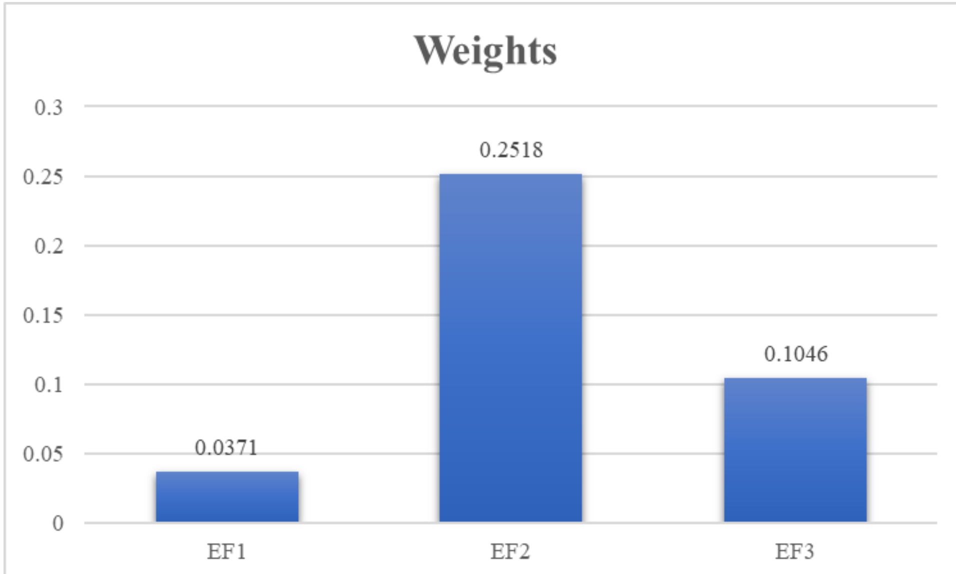

Fig. 4.4. Priority weights of factors in economic factors group.

From Fig. 4.5 it can be concluded that factor environmental pollution (ESF2) is having more effect on sustainability in last mile operations.

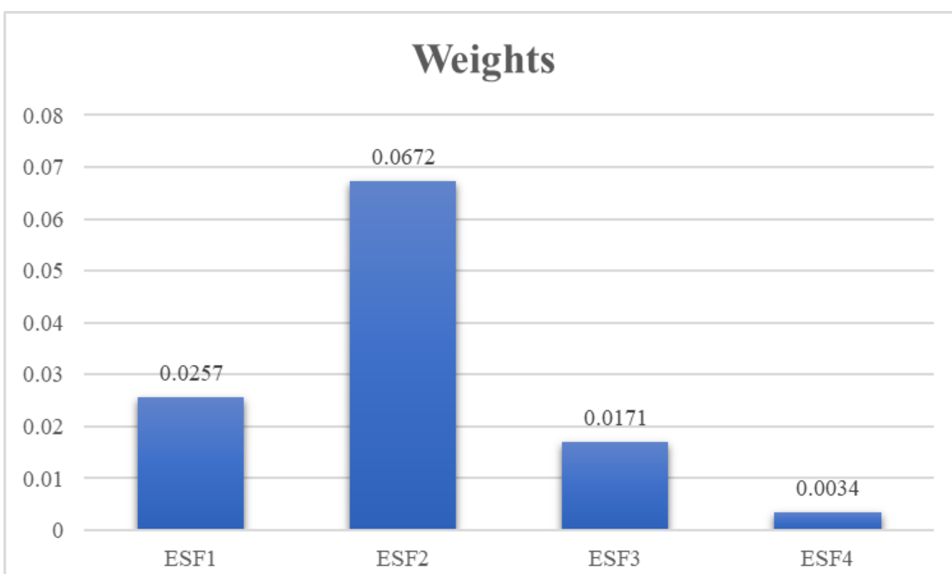

Fig. 4.5. Priority weights of factors in environmental and social factors group.

4.2 Discussion

Based on the thorough literature survey conducted in this study a total of 51 factors affecting sustainability in last mile logistics were identified. These identified factors on the basis of similarity and relevance were mapped to four major groups namely operational factors (OF), customer service factors (CSF), economic factors (EF) and environmental and social factors (ESF). From each factor group the critical factors that encompassed all other minor factors were selected. On these selected factors MCDM technique fuzzy AHP was applied. Based on the weights calculated by fuzzy AHP ranks were given to the major factor groups. On the basis of weights, the order of factor groups is OF = EF > ESF > CSF. From this we can state that the operational and economic factors are the key players that affect sustainability in last mile operations. Similarly, the factors in each factor group were assigned ranks. The top four factors that affect sustainability in last mile logistics are Delivery costs (EF2), Operational efficiency (OF2), Crowdsourcing delivery (OF5), Last mile costs (EF3) and Infrastructure (OF4). By addressing these factors sustainability in last mile operations may be enhanced. Table 4.1 gives a detailed view of the ranks and weights of all the factors and their corresponding groups.

CHAPTER 5

CONCLUSION, FUTURE SCOPE AND SOCIAL IMPACT

5.1 Conclusion

Due to changes in shopping behaviour of consumers, one obvious reason being Covid-19 pandemic, there has been a surge in e-commerce which in turn boosted the logistics industry. As such there has been a substantial growth in infrastructure, delivery vehicles and packaging industry. All these contribute to the rising sustainability concerns. Last mile delivery being the most critical portion of logistics due to the associated costs and complexity call for a thorough investigation.

In this study we utilized a thorough literature survey approach and bibliometric analysis to identify the key factors influencing sustainability in last mile operations. As such a total of 51 factors were identified. These factors were then categorized into four major groups namely operational factors (OF), customer service factors (CSF), economic factors (EF) and environmental and social factors (ESF). In each of these groups the most critical barriers were selected. A total of 15 factors were selected for the final analysis. These factors were assigned initial weights on the basis of their impact on sustainability in last mile delivery by utilizing a survey of domain experts. Fuzzy AHP technique was utilized to perform the analysis. Finally, these factors were ranked on the basis of weights calculated using fuzzy AHP. Based on the analysis and results of this study operational and economic factors were identified as the critical factors for sustainability in last mile operations.

5.2 Limitations

Even after conducting this study with utmost care there is a possibility of shortcomings. Since the literature used for this study was only a subset of the vast scientific literature available on last mile logistics, there are chances that some key factors were skipped. Also, the opinions of the expert cannot be considered as absolute as it represented their personal views. Moreover, there are inaccuracies inherent in the analytical processes.

5.3 Future Scope and Social Impact

Future studies may conduct survey over a larger volume of literature to give a more detailed picture of sustainability concerns in last mile operations. Moreover, improved tool and methods may be employed for conducting the analysis.

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LIST OF PUBLICATIONS

S. No.	Title of Paper	Name of Conference
1.	Sustainable Last-Mile Logistics: A Literature Review.	Presented in ICOTET 2024 and accepted for publishing in the AIP Conference Proceedings (Scopus Index).
2.	Sustainable Last-Mile Logistics: A Critical Analysis of Factors affecting Last-Mile Delivery using Fuzzy AHP.	Accepted for presentation at the conference ISME 2024.

Gmail **Sheetal Sharma <sheetalsharma1147@gmail.com>**

Acceptance : ICOTET 2024

1 message

ICOTET2024 <icotetdgi2024@gmail.com> 27 May 2024 at 13:28
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Greetings from ICOTET 2024**!**

Dear Author (s)

We are pleased to inform you that **Paper ID 2435** entitled **" Sustainable Last-Mile Logistics: A Literature Review "** submitted by you has been accepted by the 2nd International Conference on Optimization Techniques in Engineering and Technology Engineering (ICOTET 2024).

You are advised to register for the conference by **27th of May,** 2024! Payment details for registration can be found at the bottom of this email.

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Abstract: This research develops and evaluates a machine learning-based plant recommendation system using the Random Forest algorithm. The system provides farmers with personalized crop recommendations based on data on soil type, climate conditions, crop varieties and historical yields. Through a rigorous methodology of data collection, pre-processing feature engineering, model development and evaluation, the research demonstrates the effectiveness of machine learning techniques in improving agricultural decision making. Comparative analysis and performance evaluation metrics highlight the superiority of the random forest approach in terms of prediction accuracy and robustness. The discussion will explore impacts on agricultural practices, with a focus on responsible implementation, data quality and stakeholder engagement. Ethical considerations regarding the use of machine learning in agriculture are addressed. Further research is needed to address challenges such as data availability, model interpretability and scalability, with collaboration between researchers, practitioners, policymakers and farmers crucial for widespread adoption and real success. This research helps advance agricultural decisions, improve crop yields, and promote sustainable agricultural practices through the use of machine learning techniques.
Keywords — Artificial Intelligence, Machine Learning, Agriculture, Random Forest

Paper ID- 2435

Sustainable Last-Mile Logistics: A Literature Review

Sheetal SHARMA1, a* Mohd. SHUAIB2, b
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Abstract: Post COVID-19 pandemic there has been a considerable shift from conventional market to e-commerce. This rise in e-commerce has significantly increased the demand for efficient delivery solutions, thereby increasing concerns about its environmental impact. Out of this complete delivery process, the most critical is the last mile that connects the distribution centre to the end consumes. Due to exponential growth in e-commerce, there has been a considerable growth in logistics sector putting a question mark on sustainability of logistics. Since last mile is the most critical portion of logistics due to the costs and complexity associated, it becomes necessary to investigate the factors affecting its sustainability. This study uses bibliometric analysis to find the factors associated with last mile logistics and its sustainability. By reviewing the existing research this study identifies the most critical stability issues within last mile distribution. This paper utilizes literature from Scopus database to perform the bibliometric analysis. COVID-19 has been a main reason for the exponential surge in e-commerce and logistics. Hence, the literature is categorized in two categories pre-covid and post-covid literature and insights are developed. The literature on last mile delivery and sustainability is studied and findings and discussions are summarized.
Keywords: Last-mile delivery, Supply Chain, Bibliometric analysis, Sustainability.

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CANDIDATE'S PROFILE

Sheetal Sharma is an accomplished professional currently pursuing a Master's degree in Industrial Engineering and Management at Delhi Technological University. He holds a Bachelor's degree in Mechanical Engineering from Kurukshetra University. He has robust expertise in data analytics, visualization, and business intelligence, leveraging tools such as Python, SQL, and Tableau. His academic projects include sustainable last-mile logistics and predicting insurance premiums using linear regression models. As a teaching assistant at Delhi Technological University, he assisted in lectures, and has interned at NHPC Ltd. and PWD, Jammu and Kashmir.