AN OPTIMIZATED & CLOSED LOOP DECISION-MAKING FRAMEWORK FOR E-COMMERCE TEXTILE LEFTOVER

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THESIS ACCEPTANCE CERTIFICATE

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ABSTRACT

As the e-commerce industry becomes increasingly competitive, there is a growing need for smoother and more sustainable integrated logistics frameworks that account for both environmental and managerial implications. There is a major environmental concern of textile leftovers too with significant contribution to waste, making their recycling a pressing issue for both the environment and business sustainability. The paper presents a two-stage integrated and optimized decision support framework designed to address the escalating complexities within textile leftover e-commerce supply chains, which are experiencing rapid growth. In the first stage of the proposed framework, supplier selection is accomplished using the Analytic Hierarchy Process (AHP), with cost, quality, and lead time as primary criteria. The second stage involves the development of a mixed-integer integrated optimization model with quality as the primary sorting criterion. A scenario-based analysis is utilized to validate the framework's effectiveness, demonstrating its potential to assist decision-makers in e-commerce firms in optimizing their logistics while efficiently utilizing textile leftovers as a primary input for business operations.

Keyboards: Closed Loop Supply Chain, Optimization, E commerce, Textile Leftovers, Supplier Selection, AHP, Mathematical Modeling, Mixed Integer Linear Programming

Chapter 1: Introduction

Two decades ago, the inception of the World Wide Web (WWW) marked the beginning of a paradigm shift in the internet world. Its transformative impact on daily life and the subsequent business opportunities it would usher in, were beyond difficult to wrap head around (Moon & Kim, 2001). The globalization of the business landscape, driven by relentless technological advancements, has played a pivotal role in this transformation (Sagi et al., 2004). With technology progressing rapidly, the use of digital media for transactions has become imperative for nearly every company offering products or services (Sun and Finnie, 2004). E-commerce, defined as the exchange or facilitation of goods and services via computer networks like the internet or online social platforms (Buettner, R. 2017), has evolved into an inescapable facet of our daily lives. The United States Census Bureau reported a remarkable surge in e-commerce sales in the United States, amounting to $791.7 billion in 2020, marking a substantial 32.4% increase from the preceding year (U.S. Census Bureau, 2021). Turning to Pakistan, a nation ranking as the world's fifth most populous country with a staggering 227 million inhabitants in South Asia, it boasts a remarkable e-commerce market valued at an impressive $6 billion. Globally, Pakistan holds the 37th position, surpassing Iran and trailing just close behind Israel. An astounding 37% surge has been witnessed in the domestic e-business sector, contributing a substantial 29% to the worldwide landscape (Khan, 2022).

Extensive work has been dedicated to the realm of E-commerce, as researchers have delved into various facets of this dynamic field. Hussain et al. (2022) conducted an in-depth examination, shedding light on the mediating role of e-commerce utilization and the moderating impact of entrepreneurial competencies in shaping the performance of small and medium enterprises (SMEs). Furthermore, Mashalah et al. (2022) presented a comprehensive conceptual framework, intricately weaving together the different stages of the supply chain with a firm's business strategy, digital transformation strategy, and its overall performance. This framework offered valuable insights into the multifaceted dynamics of supply chain management in the E-commerce domain. In a different avenue of exploration, Zhou and Liu (2022) embarked on a systematic review that focused on the utilization of blockchain technology in cross-border E-commerce supply chain management. Their approach employed bibliometric data-driven analysis, offering a holistic perspective on this burgeoning aspect of E-commerce supply chain dynamics. Moreover, Li et al.

(2022) delved into the intricate relationships among business model design, supply chain resilience (SCR), and firm performance within the E-commerce sector. Their study took into consideration the disruptive potential of blockchain technology in redefining these relationships.

Logistics has remained a significant focal point in the realm of E-commerce Supply Chain management. In simpler terms, it encompasses the intricate process of transporting goods from their source to the end customers. This concept has evolved to encompass the strategic planning, execution, and control of the efficient movement of products, services, and information within an economic ecosystem (Christopher, 2016, p. 2; Lummus et al., 2001). The logistics field comprises two crucial aspects: forward logistics and reverse logistics.

Forward logistics pertains to the unidirectional flow of goods from their origin to the ultimate customer, ensuring seamless supply chain operation. Conversely, reverse logistics deals with the reverse flow – from the point of consumption back to the point of origin. The primary goal of reverse logistics is to recapture value from returned goods or facilitate proper disposal. The growing prevalence of e-commerce has intensified the significance of reverse logistics in modern supply chain management (Rogers & Tibben-Lembke, 2020). In a contemporary context, scholars like Lee et al. (2010) have introduced innovative stochastic programming-based approaches to address the sustainable design of forward logistics networks, especially in uncertain environments. The surge in e-commerce activities has led to an uptick in product returns, thereby necessitating a robust reverse logistics framework. Himanshu et al. (2022) have conceptualized reverse logistics to manage the flow of goods upstream within the supply chain, encompassing the movement from customers to suppliers. Subsequently, these goods may be returned to inventory, restocked, or sent back to sellers. To handle the complexities of e-commerce returns, Nanayakkara et al. (2022) have proposed a three-stage, circular reverse logistics framework. This framework incorporates a novel approach, employing ward-like hierarchical clustering with geographical constraints on return data to discern return patterns.

Furthermore, the Combination of forward and reverse of both forward and reverse logistics has emerged as a critical imperative in the e-commerce landscape (Achimugu, Oni, Ogunlana, & Singh, 2020). The harmonious Combination of these two facets holds the potential to yield cost reductions, heighten customer satisfaction, and enhance environmental sustainability (Achimugu et al., 2020). This synergy between forward and reverse logistics can be actualized through a variety of strategies, such as the incorporation of reverse logistics processes within the framework of forward logistics networks (Wang & Zou, 2019).

A pioneering approach was developed by Prajapati et al. (2022) in the form of a mixed-integer nonlinear programming (MINLP) model. This model aims to optimize the total cost, maximize revenue, and prioritize sustainability in the forward and reverse flow of goods within a B2C E-commerce closed-loop supply chain. Their research signifies a significant step forward in enhancing the efficiency and sustainability of logistics within the e-commerce sector.

Recent environmental and sustainability concerns have raised the issue of waste management and substantial waste reduction to save the planet. In all industry innovative methods have been adopted to cater to this issue. In the textile sector also, major steps have been taken at each supply chain level to minimize the waste and save the costs of the supply chain. Fashion and textile upcycling (When discarded materials converted into something of equal or greater value, it is Upcycled) is often perceived as a labor-intensive endeavor, primarily due to the scarcity of textile waste as a readily accessible secondary resource. Sourcing pre- and post-consumer textile waste can be a demanding and time-consuming task, frequently leading to a significant variation in the materials available for the upcycling process (Hanusa, 2021). In the review paper Antonov et al. (2021) analyzed commercial postconsumer textile materials, their recycling, and applications. Using textile postconsumer raw materials as primary product for retailers. Khara et al. (2020) developed mathematical model to find out optimum acceptance quality level of the used manufactured product for recycling to overcome the lost sale situation due to unsatisfied demand of remanufactured (manufactured) product at the time of manufacturing (remanufacturing) process and to obtain optimum number of deliveries from supplier to manufacturer, from manufacturer to retailer and from collector to manufacturer that maximize total integrated profit.

Supplier selection is a significant challenge for e-commerce businesses (Pratap et al., 2021). Establishing long-term relationships with top-performing suppliers is crucial for their success. Efficient supplier selection can improve an e-commerce company's overall performance and productivity by minimizing input costs and maximizing output quality. When choosing suppliers, e-commerce enterprises consider various factors, including traditional aspects like quality, delivery, price, and service, as well as newer considerations such as JIT communication, process improvement, and supply chain management (Cheraghi et al., 2011).

The nature of the products being purchased also plays a major role in supplier selection (Cheraghi et al., 2011). The critical success factors for selecting suppliers have evolved over time due to increased competition and the globalization of markets through internet-based technologies. Cheraghi et al. (2011) recommend that companies consider both traditional and non-traditional factors when choosing suppliers and be ready to adapt their criteria based on changing market conditions and internal business needs. Supplier selection has been a subject of ongoing research, with various methods proposed in the literature. Representative selection methods include Multi Attribute Utility Theory, Analytic Hierarchy Process, and Outranking Method, with many variations of these methods discussed in the literature (Lee et al., 2006). These methods help e-commerce firms make informed decisions when selecting suppliers.

In summary, the discussion above highlights the extensive research carried out by various scholars in the domains of integrated forward and reverse supply chain, leftover supply chain, and supplier selection within the realm of E-commerce and other domains. This research has been marked by its twists and turns, leading to various valuable insights. However, it's noteworthy that, to the best of our knowledge, no one has hitherto ventured into creating a model that leverages textile factory leftovers as the primary input in this context. Furthermore, the critical aspect of supplier selection has been largely overlooked in the context of textile leftovers.

Moreover, the Combination of forward and reverse of forward and reverse flows, while essential, has often been treated in isolation due to its inherent complexity. The primary objective of this paper is to bridge these gaps by introducing innovative models that seamlessly blend the forward and reverse flows of E-commerce units while also incorporating textile leftovers as the primary input from carefully selected suppliers. This closed loop combination is achieved through the application of the AHP decision-making technique, ensuring a comprehensive approach to the supply chain.

It's important to note that the proposed model's validity is established through the development of a mixed-integer linear programming model. To demonstrate its practical application, a numerical example is used, with Microsoft Excel Solver serving as the tool for implementation. This comprehensive approach promises to advance understanding of E-commerce textile leftover supply chains and their sustainable management.

This research is further divided into 6 sections. In chapter 2 literature review has been provided while chapter 3 presents the problem Statement & mathematical Model and chapter 4 is all about the methodology and results are in section 5. The last chapter is conclusion and managerial implications.

Chapter 2: Literature Review

2.1 E-commerce

The emergence of E-commerce has significantly transformed supply chain strategies and operations (Christopher, 2016). As customers increasingly shift from brick-and-mortar retail to online shopping, businesses face new challenges and opportunities. E-commerce's impact on supply chain management underscores the need for optimization to meet evolving customer demands. In the digital age, E-commerce has blurred the lines between various supply chain elements (Chopra & Meindl, 2015). The rise of digital technologies has led to a greater focus on agile, responsive, and customer-centric supply chain models. This transformation in the supply chain landscape requires businesses to adapt and adopt strategies that can keep up with the pace of E-commerce operations. Fulfillment models in E-commerce have become a critical aspect of supply chain management. Yuan and Tang (2018) delve into various fulfillment models, encompassing factors such as warehouse locations, inventory management, and last-mile delivery strategies. E-commerce companies must carefully consider these factors to optimize their operations for efficient and timely order fulfillment. The fashion and apparel industry occupies a prominent place within E-commerce. Characterized by rapidly changing consumer preferences and the need for agile inventory management, this sector faces unique challenges (Fan et al., 2017). Ensuring a seamless online shopping experience while maintaining effective and efficient supply chain operations is imperative.

2.2 E Commerce Supplier Selection

Supplier selection is the process of finding the appropriate suppliers who can provide the buyer with the right quality products and/or services at the right price, in the right quantities, and at the right time (Alkahtani & Kaid, 2018). Selecting the right e-commerce supplier is a critical decision for businesses in today's digital age. The choice of a supplier can significantly impact various aspects of an e-commerce operation, from product quality and customer satisfaction to operational efficiency and profitability. The study by Kuo and Chen highlights the crucial link between e-commerce technology and supplier selection in supply chain management. It underscores how supplier selection decisions can affect both forward and reverse and efficiency of e-commerce systems. A well-chosen supplier can provide the necessary technology and support for seamless e-commerce operations (Kuo, Y. F., & Chen, K. S. (2019). Athawale et al. (2009) concludes that the application of Multi Criteria Decision Making methods can enhance the supplier selection process by providing a structured and objective approach to evaluate and choose the most suitable suppliers based on various criteria. Several methods and approaches have been developed to facilitate this process, ensuring the selection of suppliers who align with a company's strategic goals and requirements. The Analytic Hierarchy Process is a widely used method that allows decision-makers to evaluate suppliers based on multiple criteria and sub-criteria. This method employs pairwise comparisons and mathematical calculations to determine the relative importance of these criteria (Saaty, 1980). There is another most common method used for supplier selection. The TCO method considers not only the purchase price, but also other costs associated with a supplier, such as transportation, inventory, and quality control expenses. This approach offers a comprehensive view of the cost implications of supplier selection decisions (Lancioni & Smith, 2003). Supplier scorecard is also one of the commonly used supplier selection techniques. Supplier scorecards involve the creation of performance metrics and key performance indicators (KPIs) to assess supplier performance regularly. This method ensures transparency and accountability in the supplier selection process (Lamming, Caldwell, & Harrison, 2011). Furthermore, Quality function deployment is effective for organizations that link supplier selection criteria with customer satisfaction parameters. QFD is a method that focuses on aligning supplier capabilities with customer needs and expectations. It helps prioritize supplier attributes and characteristics that are most relevant to customer satisfaction (Akao, 2011). When there is ambiguity and imprecision in data, a Fuzzy logic approach is used. Literature is full of techniques that are used for supplier selection with twists and turns.

Chen and Paulraj (2004) proposed a comprehensive theory of supply chain management, including the role of supplier selection. Their research work underscores the strategic importance of aligning supplier selection decisions with a company's overall supply chain strategy. It emphasizes the need to select suppliers that complement and enhance the company's supply chain performance, which is pivotal in the e-commerce sector. Furthermore, Bag and Asosheh (2019) proposed a decision-making framework tailored for e-commerce supplier selection. Their research work provides a practical approach to supplier selection in the e-commerce environment, addressing its unique complexities. The framework serves as a valuable resource for businesses looking to make well-informed supplier selection decisions in the e-commerce landscape.

2.3 E-Commerce Forward Logistics

Supply chains can be categorized into two primary types: forward and reverse supply chains. A forward supply chain encompasses the traditional process of product manufacturing, distribution, and delivery to the end consumer. On the other hand, the reverse supply chain manages product returns, recycling, remanufacturing, and disposal. The forward supply chain primarily deals with the flow of goods from manufacturers to consumers. Forward logistics, an essential component of the supply chain, plays a pivotal role in the success of e-commerce businesses. In an e-commerce context, this involves sourcing products, warehousing, order fulfillment, and transportation. With the booming e-commerce industry, optimizing forward logistics has become imperative to meet customer expectations, reduce operational costs, and ensure timely and efficient delivery. It has witnessed significant changes with the advent of e-commerce, as online retailers often rely on a network of suppliers and third-party logistics providers to streamline their operations (Hugos, 2018). Forward logistics has various fundamental aspects and literature is filled with models and methodologies that help in effective and efficient forward logistics flow. Efficient inventory management is a fundamental aspect of forward logistics in e-commerce. Maintaining the right balance of inventory levels is crucial to meet customer demand without excessive holding costs (Simchi-Levi et al., 2014). Warehouses are the backbone of forward logistics. The location, design, and operations of warehouses significantly impact the speed and cost of order fulfillment. Implementing strategies like multi-location warehousing, automation, and streamlined picking and packing processes can enhance efficiency (Frazelle, 2002). Employing route optimization software and tracking systems ensures the timely and transparent movement of goods (Göb & Stummer, 2018). Collaboration with suppliers, manufacturers, carriers, and third-party logistics providers can lead to cost savings and efficiency improvements. Establishing strong relationships and partnerships can ensure a seamless flow of goods in the supply chain (Ivanov et al., 2018).

2.4 E-Commerce Reverse Logistics

In contrast to the forward supply chain, the reverse supply chain manages the return, recycling, and disposal of products. E-commerce has played a pivotal role in reshaping this aspect as well. In e-commerce, return rates are typically higher than in traditional retail. Efficient returns management is crucial for customer retention and cost control. Offering easy return processes and integrating reverse logistics into the supply chain is essential (Rogers et al., 2019). The convenience of online shopping has led to increased return rates. As a result, e-commerce companies have had to establish efficient reverse logistics processes (Fernie & Sparks, 2018). Online retailers have introduced lenient return policies, facilitating a hassle-free return process. They may also incorporate reverse logistics partners who specialize in handling returned goods. Returned items can be restocked, refurbished, or recycled, reducing waste and environmental impact (Mollenkopf et al., 2010). One of the key trends in modern supply chain management is the Combination of forward and reverse supply chains. E-commerce businesses have recognized the benefits of a holistic approach that considers both sides of the supply chain simultaneously. This Combination of forward and reverse allows for a more sustainable, cost-effective, and customer-centric approach (Fawcett et al., 2013). E-commerce platforms integrate forward and reverse supply chains by designing flexible systems capable of handling both outbound and return logistics efficiently. This not only reduces operational costs but also enhances customer satisfaction through improved return processes (Stock et al., 2018). Furthermore, the use of advanced analytics and artificial intelligence in e-commerce platforms allows for better decision-making regarding product returns. Predictive analytics can identify potential return issues, allowing companies to take proactive measures to minimize returns and manage them more effectively (Rogers et al., 2020).

2.5 Forward and Reverse Supply Chain

The combination of both forward and reverse supply chains in e-commerce is essential for efficient and sustainable operations (Chopra & Meindl, 2018). E-commerce businesses must balance the complexity of these supply chains with the benefits of improved customer satisfaction, cost reduction, and reduced environmental impact. One key strategy is the establishment of real-time data sharing and visibility between the forward and reverse supply chains (Chopra & Meindl, 2018). Additionally, optimizing warehouse layouts for dual-purpose operations, considering both forward and reverse logistics, enhances efficiency in handling returns and restocking returned items (Stock & Lambert, 2001). Clear and well-defined return policies and procedures are essential to guide customers on what to expect when returning a product (Stock & Lambert, 2001). Providing clarity in return processes reduces customer frustration, boosts satisfaction, and promotes brand loyalty. E-commerce companies often establish return centers or hubs that are strategically located to facilitate efficient and cost-effective returns processing. This network reduces the distance and time products need to travel during the reverse supply chain, minimizing delays and costs.

2.6 Textile Leftover Supply Chain

The textile industry is known for its massive environmental impact, and one of the significant concerns is the generation of textile leftovers or waste. Managing the supply chain of textile leftovers is critical to reducing the industry's environmental footprint. Textile leftovers refer to the various materials that are discarded during textile production, including fabric remnants, off-cuts, defective pieces, and unsold inventory. The manufacturing process itself generates leftovers in the form of cuttings and off-cuts (Textile Exchange, 2021). Managing unsold inventory is crucial in the textile industry. Brands are working towards reducing overproduction and implementing efficient inventory management systems (Dobrucka, 2020). Unsold garments, end-of-season collections, and returns can accumulate as leftovers in the retail stage (Sodhi & Tang, 2019). Overproduction is a significant issue in the textile industry, leading to a surplus of unsold inventory that ends up as waste. This not only strains resources but also contributes to environmental degradation (Jain et al., 2018). The current economic structure often discourages brands from implementing sustainable practices. The cost of sustainable production and disposal methods can be higher, deterring many businesses (Lundquist et al., 2020).

2.7 Summary of Literature and Gap Analysis Table.

To the authors' knowledge, no prior literature has addressed the closed loop supply chain of the e-commerce industry, including supplier selection, forward and reverse logistics optimization, and textile leftover management. These challenges underscore the demand for a decision support system that can seamlessly combine supplier selection and enhance the efficiency of both forward and reverse logistics, with a particular focus on the context of e-commerce and textile leftover management.

This paper aims to bridge these gaps by proposing an innovative model that integrates the forward and reverse flows of E-commerce units, while also incorporating textile factory leftovers as the primary input from carefully selected suppliers. Additionally, the paper addresses the critical aspect of supplier selection in the context of textile leftovers. The primary objective of this research is to develop a comprehensive model that leverages textile factory leftovers in E-commerce supply chains, with a focus on cost minimization. Furthermore, the Combination of forward and reverse of forward and reverse flows in E-commerce supply chains has often been treated in isolation, neglecting the complexity and potential synergies between these two aspects. To address these gaps, the research paper proposes the use of the Analytic Hierarchy Process decision-making technique to create a comprehensive model that incorporates the quality, cost and lead times as decision criteria, while also considering textile factory leftovers as the primary input in integrated forward and reverse loop logistics network model. Through the application of this model, the research aims to demonstrate how E-commerce companies can effectively manage their supply chains by cost-effectively integrating textile leftovers. The proposed model will be validated through the development of a mixed-integer linear programming model. To demonstrate the practical application of the proposed model, a real-world case study will be conducted. Also, Microsoft Excel Solver will be used as the tool for implementation. The comprehensive approach presented in this research paper promises to advance the understanding of E-commerce textile leftover supply chains and their effective cost management.

Chapter 2 Table 1 Gap Analysis

S.No	Tittle	Supplier Selection	Forward/ Reverse / Closed Logistics	Mathematical Model	Methodology	Industry	Domain
1	Cheraghi et al. (2011b)	✓			Literature Review	Non-Textile	Non-E commerce
2	Rajesh and Malliga (2013)	✓			AHP Quality Function Deployment (QFD)	Textile	Non-E commerce
3	Deretarla et al. (2023)	✓			Combination of AHP and Complex Proportional Assessment (COPRAS)	Non-Textile	Non-E commerce
4	Lin et al. (2023)	✓			AHP	Textile	Non-E commerce
5	Kumar et al. (2017)		**Closed**	Multi-period, multi-echelon, vehicle routing, forward-reverse logistics Model	Artificial Immune System (AIS) and Particle Swarm Optimization (PSO) algorithms	Manufacturing	Non-E commerce
6	Sangwan (2017b)		Reverse		Literature Review	Textile	Non-E commerce
7	Dutta et al. (2020)		Reverse	Multi Objective Optimization	Weighted goal programming (WGP)	Non-Textile	E-Commerce
8	Zarbakhshnia et al. (2020)		**Closed**	Multi-product, multi-stage, multi-period, and multi-objective,	Non-dominated sorting genetic algorithm (NSGA-II)	Manufacturing	Non-E commerce

				probabilistic Mixed-integer linear programming model			
9	Fu et al. (2021)		**Closed**		Modified Projection Method	Non-Textile	Non-E commerce
10	Nanayakkara et al. (2022c)		Reverse	MILP		Textile	Non-E commerce
	This Paper	✓	**Closed Loop Supply Chain**	**Mixed-integer linear programming model**	**AHP**	**Textile Leftover**	**E-Commerce**

Chapter 3: Problem Statement & Mathematical Model

3.1 Research Objectives

- To design a novel integrated forward and reverse logistics framework that maximizes the utilization of textile factory leftovers as the primary input for an e-commerce business.
- To develop an integrated decision-making framework that combines supplier selection and logistics model optimization in the context of e-commerce integrated forward and reverse supply chains using textile factory leftovers.
- To validate the proposed integrated framework through mixed integer linear mathematical modeling on a numerical example to demonstrate its effectiveness and potential for achieving optimized results in textile leftover-based E commerce supply chains.

3.2 Research Questions

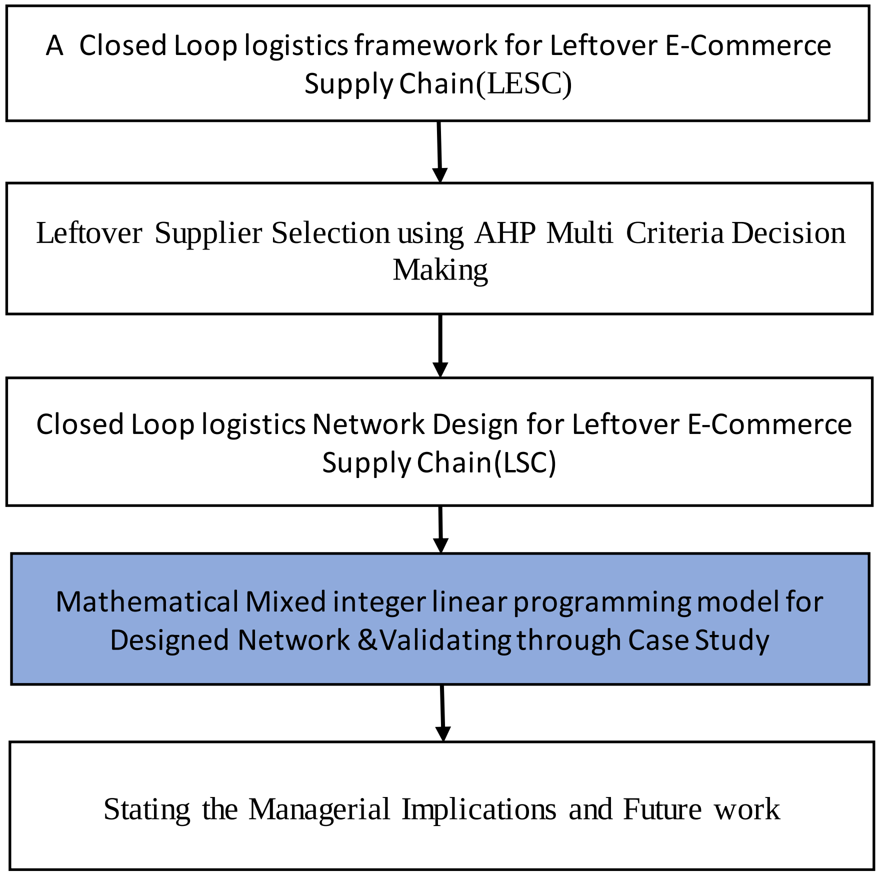
1. How can a novel integrated forward and reverse logistics framework be designed to effectively utilize textile factory leftovers as the primary input for an e-commerce business?
2. How can the effectiveness and potential of the proposed integrated framework be validated through mixed integer linear mathematical modeling to have optimized facility selection for textile leftover-based e-commerce supply chains?

3.3 Research Framework

This research adopts a two-step integrated decision-making approach aimed at addressing the intricate challenges associated with selecting the most suitable supplier for residual materials and optimizing the integrated forward and reverse network. The selection process demands a comprehensive multi-criteria methodology, which necessitates the identification and utilization of specific criteria and sub-criteria to guide the decision-making process. As elucidated in previous studies (Smith et al., 2020; Johnson & Brown, 2021), supplier evaluation entails the meticulous selection of these criteria to facilitate the decision-making process. To execute this decision-making process effectively, the Analytic Hierarchy Process (AHP) will be employed, a well-established methodology for ranking and selecting suppliers (Anderson et al., 2018; White & Jones, 2021).

Moving to the subsequent phase, this research introduces an innovative integrated forward and reverse logistics network tailored specifically for E-commerce operations dealing with leftover materials. The development of such a network is poised to explore the intricate dynamics that exist between forward and reverse logistics. This endeavor is driven by the overarching goal of creating an efficient, and cost-effective network capable of optimizing the utilization of leftovers. This network will be designed with careful consideration of established best practices in the field, as outlined in seminal works such as the studies by (Nanayakkara et al., 2022)

To operationalize this intricately designed logistics network, a mathematical mixed-integer linear programming model will be formulated. This model will serve as a systematic approach for integrating the logistics network and optimizing resource utilization. The efficacy and viability of this model will be put to the test through a comprehensive case study analysis. The case study will serve as a validation process, ensuring that the developed model performs in real-world scenarios, thus confirming its practical applicability and relevance within the E-commerce industry.



Chapter 3 Figure 1 Research Framework

3.4 Mathematical Model

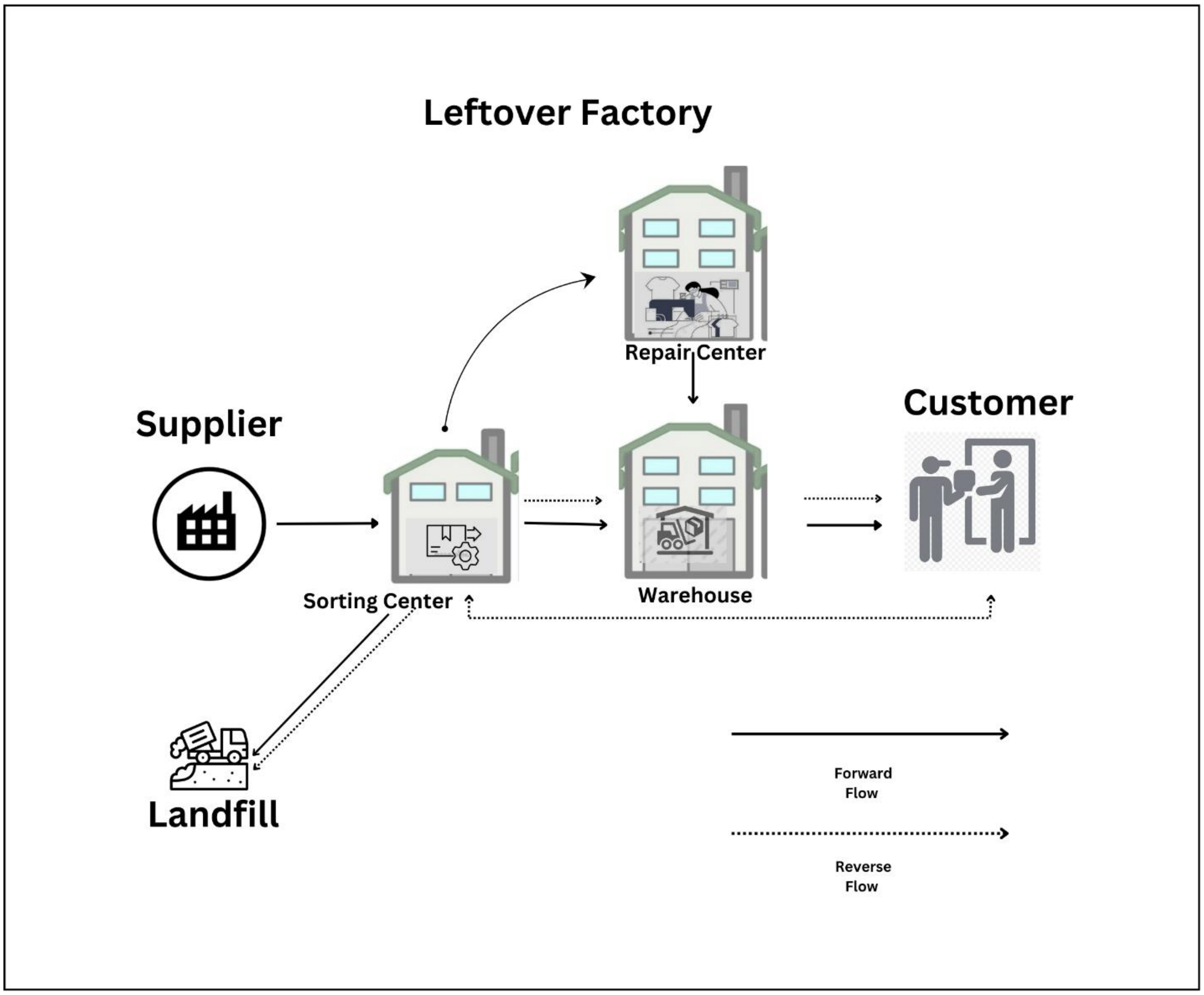
In this model we are considering an E commerce firm that uses textile leftovers as input and further processes it in factory and send to customer as demanded. The described logistics flow is an extension of prior research done by (Nanayakkara et al., 2022). While the original article primarily focused on the reverse flow in handling e-commerce returns, the flow described here incorporates significant modifications to align it with a textile leftover framework, effectively integrating both forward and reverse logistics aspects. This adaptation enhances the framework's applicability and effectiveness within the context of e-commerce leftover supply chain.

The logistics flow commences with the careful selection of suppliers providing textile leftovers, which serve as the foundational material for the e-commerce firm's product line. These textile leftovers are transported to designated sorting centers. Here, they undergo a meticulous quality assessment to determine their fitness for use. Based on this assessment, the products are categorized into three groups: B, A, and C quality. Subsequently, the sorted products are routed to their respective destinations.

Products of B quality is directed to the repair center, where they undergo necessary refurbishment and alterations to bring them up to the desired A quality level. Once the products meet the A quality standard, they are sent to the warehouse for storage. However, any product that fails to meet this quality benchmark is routed to landfill centers for proper disposal.

Concurrently, products of A quality are directly sent to the warehouse, where they are systematically managed and stored. These products, originating from both the repair center and the sorting center, are dispatched to customer markets as per demand, ensuring efficient distribution.

The reverse logistics flow is activated when customers return products for various reasons, necessitating a structured process for handling these returns. Returned products are conveyed to the sorting center for a secondary quality check. Here, they are once again categorized into B, A, and C quality based on their condition. B quality products from customer returns are subsequently sent to the repair center, where they undergo necessary repairs and alterations to restore them to an A quality standard. Once refurbished, they are routed to the warehouse for potential resale. Any product that does not meet the quality standard is directed to the landfill. A quality product returned by customers is returned to the warehouse for storage and potential resale. Efficient inventory management ensures these products are dispatched to customer markets as per the demand resulting from customer returns.



Chapter 3 Figure 2 Network Model

3.5 Assumptions

- **Demand is Known**: The model assumes that the demand for products is known and does not vary during the planning period. Any fluctuations in demand are not considered in the initial model.
- **Returns Percentage:** The approximate percentages of returns are estimated based on previous studies and historical data. These estimates are considered fixed and do not change dynamically based on real-time data.
- **Known Capacity:** The capacity for various facilities, including warehouses, repair centers, sorting centers, and landfills, is known and constant. There are no capacity constraints due to sudden changes or unexpected events.

- **Known Cost:** The transportation cost per kilometer per item obtained from secondary sources. It does not account for dynamic changes in fuel prices or transportation market fluctuations.
- **Limited Logistic Cost Components**: The logistics cost components considered in the model are limited to fixed costs, and transportation costs. Other potential cost factors such as taxes, tariffs, or regulatory changes are not included.
- **Known Product Quality Levels:** The product quality levels are known and assumed to remain constant throughout the planning period. Any variations in product quality or defects are not considered in the initial model.

Sets	
Z	Set of Supplier indexes, $z \in Z$
S^f	Set of Sorting Center indexes, $s \in S$
R^f	Set of Repair Center indexes, $r \in R$
W^f	Set of Warehouse indexes, $w \in W$
L^f	Set of Landfill Center indexes, $l \in L$
M^f	Set of Customer Markets indexes, $m \in M$
S^r	Set of Sorting Center indexes in reverse flow, $s \in S$
R^r	Set of Repair Center in reverse flow indexes, $r \in R$
W^r	Set of Warehouse indexes in reverse flow, $w \in W$
L^r	Set of Landfill Center in reverse flow indexes, $l \in L$

Parameters	
	Fixed Costs
F_s	Fixed Cost of Selecting Sorting Center
F_r	Fixed Cost of Selecting Repair Center
F_w	Fixed Cost of Selecting Warehouse Center
F_z	Fixed Cost of Selecting Supplier
F_l	Fixed Cost of Selecting Landfill
	Variable Costs

Forward Flow	
$Demand_{m}$ =	Demand for m customer market(s)
$Capacity_{z}$ =	Capacity of Supplier(s) Z
$Capacity_{s}$=	Capacity of Sorting center(s) S
$Capacity_{w}$=	Capacity of Warehouse(s) W
$Capacity_{r}$=	Capacity of Repair Center(s) R
C^{f}_{zs}	Transportation Cost per unit from Supplier Z to sorting center
C^{f}_{sw}	Transportation Cost per unit from sorting center to Warehouse in forward flow
C^{f}_{sr}	Transportation Cost per unit from sorting center to repair in forward flow
C^{f}_{sl}	Transportation Cost per unit from sorting center to landfill in forward flow
C^{f}_{rw}	Transportation Cost per unit from repair center to Warehouse in forward flow
C^{f}_{rl}	Transportation Cost per unit from repair center to landfill in forward flow
C^{f}_{wm}	Transportation Cost per unit from Warehouse to customer market in forward flow
Reverse Flow	
C^{r}_{ms}	Transportation Cost/ Km for moving units from Customer Markets to sorting center
C^{r}_{sw}	Transportation Cost per unit from sorting center to Warehouse in reverse flow
C^{r}_{sr}	Transportation Cost per unit from sorting center to repair in reverse flow
C^{r}_{sl}	Transportation Cost per unit from sorting center to landfill in reverse flow
C^{r}_{rw}	Transportation Cost per unit from repair center to Warehouse in reverse flow
C^{r}_{rl}	Transportation Cost per unit from repair center to landfill in reverse flow

Decision Variables	
Binary Variables	
Y_s	If Sorting Center selected or not
Y_r	If repair Center selected or not Selecting
Y_w	If Warehouse Center selected or not
Y_z	If Supplier selected or not
Y_l	If Landfill selected or not

Integer Variables	
Forward Flow	
X_{zs}	Number of units moved from Supplier to Sorting center
X^{f}_{sr}	Number of units moved from Sorting center to repair Center
X^{f}_{sw}	Number of units moved from Sorting center to Warehouse Center
X^{f}_{sl}	Number of units moved from Sorting center to landfill Center
X^{f}_{rw}	Number of units moved from repair center to Warehouse Center
X^{f}_{rl}	Number of units moved from repair center to landfill Center
X^{f}_{wm}	Number of units moved from Warehouse center to Customer Markets
Reverse Flow	
X^{r}_{ms}	Number of units returned from Customer Markets to Sorting Center
X^{r}_{sr}	Number of units moved from Sorting center to repair Center in reverse flow
X^{r}_{sw}	Number of units moved from Sorting center to Warehouse Center in reverse flow
X^{r}_{sl}	Number of units moved from Sorting center to landfill Center in reverse flow
X^{r}_{rw}	Number of units moved from repair center to Warehouse Center in reverse flow
X^{r}_{rl}	Number of units moved from repair center to landfill Center in reverse flow

3.6 Objective function

Minimize Z=

$$\sum_{z=1}^{Z} F_z Y_z + \sum_{s=1}^{S} F_s Y_s + \sum_{r=1}^{R} F_r Y_r + \sum_{w=1}^{W} F_w Y_w \sum_{l=1}^{L} F_l Y_l + \sum_{z=1}^{Z}\sum_{s=1}^{S} C^{\,f}_{\,zs} X_{zs} + \tag{1}$$

$$+ \sum_{s=1}^{S}\sum_{r=1}^{R} C^f_{sr} X^f_{sr} + \sum_{s=1}^{S}\sum_{w=1}^{W} C^f_{sr} X^f_{sw} + \sum_{s=1}^{S}\sum_{l=1}^{L} C^f_{sl} X^f_{sl} +$$

$$+ \sum_{r=1}^{R}\sum_{w=1}^{W} C^f_{rw} X^f_{rw}$$

$$+ \sum_{r=1}^{R}\sum_{l=1}^{L} C^f_{rl} X^f_{rl}$$

$$+ \sum_{w=1}^{w}\sum_{m=1}^{M} C^f_{wm} X^f_{wm} + \sum_{m=1}^{M}\sum_{s=1}^{S} C^r_{ms} X^r_{ms} + \sum_{s=1}^{S}\sum_{\alpha=1}^{R} C^r_{sr} X^r_{sr}$$

$$+ \sum_{s=1}^{S}\sum_{w=1}^{W} C^r_{sr} X^r_{sw} + \sum_{s=1}^{S}\sum_{l=1}^{L} C^r_{sl} X^r_{sl} + \sum_{r=1}^{R}\sum_{w=1}^{W} C^r_{rw} X^r_{rw}$$

$$+ \sum_{r=1}^{R}\sum_{l=1}^{L} C^r_{rl} X^r_{rl} + \sum_{w=1}^{w}\sum_{m=1}^{M} C^r_{wm} X^r_{wm}$$

The objective function minimizes the cost included. fixed cost of selecting sorting center, repair center warehouse center and landfill center. The variable cost part includes transportation cost for unit movement from supplier(s) Z to sorting center(s). Equation (1.3) includes the total cost of Units moment from sorting center to repair center in forward flow. Equation (1.4) includes the total cost of unit moment from sorting to warehouse. It is calculated based on distance from sorting center to warehouse. Equation (1.5) includes the total cost of moving units from sorting to landfill. The X unit moment from sorting to landfill multiplied by cost per unit from sorting center to landfill in forward flow. Equation (1.6) includes the total cost of unit's moment from repair to warehouse. The cost factor includes the transportation cost per unit from repair to warehouse multiplied by number of units moved in forward flow. Equation (1.7) includes the total cost of moving units from repair to landfill. The X unit moment from repair to landfill multiplied by cost per unit from repair center to landfill in forward flow. Equation (1.8) includes the total cost of moving units from warehouse to customer markets. The X unit moment from warehouse to customer markets multiplied by cost per unit from sorting center to landfill in forward flow. Equation (1.9) includes the total cost of moving units from customer markets to sorting centers. The X unit moment from customer markets to sorting center multiplied by cost per unit from customer markets to sorting center in reverse flow. Equation (1.10) includes the total cost of Units moment from sorting center to repair center in reverse flow. Equation (1.11) includes the total cost of unit moment from sorting to warehouse. The cost factor includes the cost per unit multiplied by number of units moved in reverse flow. Equation (1.12) includes the total cost of moving units from sorting to landfill. The X unit moment from sorting to landfill multiplied by cost per unit from sorting center to landfill in reverse flow. Equation (1.13) includes the total cost of unit's moment from repair to warehouse. The cost factor includes the cost per unit multiplied by number of units moved from repair center to warehouse in reverse flow. Equation (1.14) includes the total cost of moving units from repair to landfill. The X unit moment from repair to landfill multiplied by cost per unit from repair center to landfill in reverse flow. Equation(1.15) includes the total cost of moving units from warehouse to customer markets. The X unit moment from warehouse to customer markets multiplied by cost per unit from warehouse to customer markets in reverse flow.

$$\sum_{s=1}^{S} F_s Y_s + \sum_{r=1}^{R} F_r Y_r + \sum_{w=1}^{W} F_w Y_w + \sum_{l=1}^{L} F_l Y_l \tag{1.1}$$

$$\sum_{z=1}^{Z} \sum_{s=1}^{S} \boldsymbol{C}^{\boldsymbol{f}}_{zs} X_{zs} \tag{1.2}$$

$$\sum_{s=1}^{S} \sum_{r=1}^{R} C_r^f X_{sr}^f \tag{1.3}$$

$$\sum_{s=1}^{S}\sum_{w=1}^{W} C_{sr}^{f} X_{sw}^{f} \tag{1.4}$$

$$\sum_{s=1}^{S}\sum_{l=1}^{L} C_{sl}^{f} X_{sl}^{f} \tag{1.5}$$

$$\sum_{r=1}^{R}\sum_{w=1}^{W} C_{rw}^{f} X_{rw}^{f} \tag{1.6}$$

$$\sum_{r=1}^{R}\sum_{l=1}^{L} C_{rl}^{f} X_{rl}^{f} \tag{1.7}$$

$$\sum_{w=1}^{w}\sum_{m=1}^{M} C_{wm}^{f} X_{wm}^{f} \tag{1.8}$$

$$\sum_{m=1}^{M}\sum_{s=1}^{S} C_{ms}^{r} X_{ms}^{r} \tag{1.9}$$

$$\sum_{s=1}^{S}\sum_{r=1}^{R} C_{r}^{r} X_{sr}^{r} \tag{1.10}$$

$$\sum_{s=1}^{S}\sum_{w=1}^{W} C_{sr}^{r} X_{sw}^{r} \tag{1.11}$$

$$\sum_{s=1}^{S}\sum_{l=1}^{L} C_{sl}^{r} X_{sl}^{r} \tag{1.12}$$

$$\sum_{r=1}^{R}\sum_{w=1}^{W} C_{rw}^{r} X_{rw}^{r} \tag{1.13}$$

$$\sum_{r=1}^{R}\sum_{l=1}^{L} C_{rl}^{r} X_{rl}^{r} \tag{1.14}$$

$$\sum_{w=1}^{w}\sum_{m=1}^{M} C_{wm}^{r} X_{wm}^{r} \tag{1.15}$$

3.7 Constraint

Demand

$$\sum_{w=1}^{W} X_{wm}^{f} + \sum_{w=1}^{W} X_{wm}^{r} \geq Demand_{m} \ \forall\ M \tag{2}$$

This demand constraint is all about unit moved from warehouse to customer must fulfill the customer demand in forward flow and in reverse flow combined. The flow should incorporate all units moved from all the warehouses to all the customer markets.

Capacity

$$\sum_{z=1}^{Z} X_{zs} + \sum_{m=1}^{M} X_{ms}^{r} \leq Capacity_{s} * Ys \qquad \forall\ S \tag{3}$$

This constraint equation (3) says unit moved from supplier (s) to sorting centers in forward flow plus unit moved from customer markets to sorting centers in return must be less than equal to the capacity of sorting centers. This limits the unit flow keeping the consideration of sorting center capacity.

$$\sum_{s=1}^{S} X_{sr}^{f} + \sum_{s=1}^{S} X_{sr}^{r} \leq Capacity * Y_R \ \forall \ R \tag{4}$$

This constraint equation (4) says unit moved from sorting center (s) to repair centers in forward flow plus unit moved from sorting center (s) to repair centers in reverse must be less than equal to the capacity of repair center(s). This limits the unit flow keeping the consideration of repair center capacity.

$$\sum_{s=1}^{S} X_{sl}^{f} + \sum_{s=1}^{S} X_{sl}^{r} + \sum_{r=1}^{R} X_{rl}^{f} + \sum_{r=1}^{R} X_{rl}^{r} \leq Capacity_l * Y_L \ \forall \ L \tag{5}$$

This constraint equation (5) says unit moved from sorting center (s) to landfill centers plus unit moved from repair center (s) to landfill centers in forward flow also unit movement in reverse flow must be less than equal to the capacity of landfill center(s). This limits the unit flow keeping the consideration of landfill center(s) capacity.

$$\sum_{r=1}^{R} X_{rw}^{f} + \sum_{s=1}^{S} X_{sw}^{f} + \sum_{s=1}^{S} X_{sw}^{r} + \sum_{r=1}^{R} X_{rw}^{r} \leq Capacity_w * \ Y_W \forall \ W \tag{6}$$

This constraint equation (6) says unit moved from repair center (s) to warehouse plus unit moved from sorting center (s) to warehouse in forward flow as well as unit movement in reverse flow must be less than equal to the capacity of warehouse. This limits the unit flow keeping the consideration of warehouse(s) capacity.

Transshipment

$$\sum_{z=1}^{Z} \sum_{s=1}^{S} X_{zs} = \sum_{s=1}^{S} \sum_{w=1}^{W} X_{sw}^{f} + \sum_{s=1}^{S} \sum_{r=1}^{R} X_{sr}^{f} + \sum_{s=1}^{S} \sum_{l=1}^{L} X_{sl}^{f} \tag{7}$$

This constraint equation (7) is a transshipment constraint that aims to balance the flow of units. It says units moved from supplier to sorting center must be equal to units further transferred to repair, warehouse, and landfill centers. This constraint manages the flow of units in a way that optimizes units must be flown in the network and minimize the costs.

$$\sum_{m=1}^{M}\sum_{s=1}^{S} X_{ms}^{r} = \sum_{s=1}^{S}\sum_{w=1}^{W} X_{sw}^{r} + \sum_{s=1}^{S}\sum_{r=1}^{R} X_{sr}^{r} + \sum_{s=1}^{S}\sum_{l=1}^{L} X_{sl}^{r} \tag{8}$$

This constraint equation (8) is a transshipment constraint that aims to balance the flow of units. It says units moved from customer market to sorting center from return must be equal to units further transferred to repair, warehouse, and landfill centers. This constraint manages the reverse flow of units in a way that optimizes units must be flown in the network and minimize the costs.

$$\sum_{s=1}^{S}\sum_{r=1}^{R} X_{sr}^{f} = \sum_{r=1}^{R}\sum_{w=1}^{W} X_{rw}^{f} + \sum_{r=1}^{R}\sum_{l=1}^{L} X_{rl}^{f} \tag{9}$$

This constraint equation (9) is a transshipment constraint that aims to balance the flow of units. It says units moved from sorting center to repair center must be equal to units further transferred to warehouse and landfill centers. This constraint manages the forward flow of units in a way that optimizes units must be flown in the network and minimize the costs.

$$\sum_{s=1}^{S}\sum_{r=1}^{R} X_{sr}^{r} = \sum_{r=1}^{R}\sum_{w=1}^{W} X_{rw}^{r} + \sum_{r=1}^{R}\sum_{l=1}^{L} X_{rl}^{r} \tag{10}$$

This constraint equation (10) is a transshipment constraint that aims to balance the flow of units. It says units moved from sorting center to repair center in return must be equal to units further transferred to warehouse and landfill centers. This constraint manages the reverse flow of units in a way that optimizes units must be flown in the network and minimize the costs.

$$\sum_{s=1}^{S}\sum_{w=1}^{W} X_{sw}^{f} + \sum_{r=1}^{R}\sum_{w=1}^{W} X_{rw}^{f} = \sum_{w=1}^{W}\sum_{m=1}^{M} X_{wm}^{f} \tag{11}$$

This constraint equation (11) is a transshipment constraint that is to balance the flow of units. It is all about units moved from sorting center to warehouse plus units moved from repair center to warehouse must be equal to units further transferred to customer market from warehouse(s). This constraint manages the reverse flow of units in a way that optimizes units must be flown in the network and minimizes the costs in forward flow.

$$\sum_{s=1}^{S}\sum_{w=1}^{W} X_{sw}^{r} + \sum_{r=1}^{W}\sum_{w=1}^{W} X_{rw}^{r} = \sum_{w=1}^{W}\sum_{m=1}^{M} X_{wm}^{r} \tag{12}$$

This constraint equation (12) is a transshipment constraint that is to balance the flow of units. It is all about units moved from sorting center to warehouse plus units moved from repair center to warehouse must be equal to units further transferred to customer market from warehouse(s) in reverse flow. This constraint manages the reverse flow of units in a way that optimizes units must be flown in the network and minimizes the costs in reverse flow.

Return

$$\sum_{m=1}^{M}\sum_{s=1}^{S} X_{ms}^{r} = Return\ rate * Demand_{m}\ \forall\ M \qquad (13)$$

This is a special constraint this bridges the reverse flow gap and limits the return units flow to sorting center(s) from customer market(s). This constraint in equation (13) is unit flow from customer market(s) in reverse flow to sorting center must equal to the return rate for each customer market. Return rate is an assumed parameter in this model.

Quality Constraints

$$Q_{a} = \sum_{s=1}^{S}\sum_{w=1}^{W} X_{sw}^{f} \Big/ \sum_{z=1}^{z}\sum_{s=1}^{S} X_{zs} \qquad (14)$$

This quality constraint equation (14) is about the number of units transferred from the sorting center to the warehouse should be precisely equal to the Alpha quality ratio of units transferred from the supplier to the sorting center. This constraint is essential so that alpha quality units should move to the warehouse so that units can be repaired and then moved to the customer demand.

$$Q_{\beta} = \sum_{s=1}^{S}\sum_{r=1}^{R} X_{sr}^{f} \Big/ \sum_{z=1}^{z}\sum_{s=1}^{S} X_{zs} \qquad (15)$$

This quality constraint equation (15) pertains to ensuring that the quantity of units moved from the sorting center to the repair exactly matches the Beta quality ratio of units transferred from the supplier to the sorting center. This constraint is of utmost importance as it ensures that units of beta quality are appropriately routed to repair centers, facilitating their storage and subsequent distribution to customers based on demand.

$$Q_{\gamma} = \sum_{s=1}^{S}\sum_{l=1}^{L} X_{sr}^{f} \Big/ \sum_{z=1}^{z}\sum_{s=1}^{S} X_{zs} \qquad (16)$$

Quality constraint equation (16) specifically concerns the alignment of the quantity of units transferred from the sorting center to the landfill with the gamma quality ratio of units sent from the supplier to the sorting center. This constraint holds significant significance, as it guarantees the proper disposal of gamma-quality units at landfill centers.

$$\sum_{s=1}^{S}\sum_{r=1}^{R} X_{sr}^{r} = Q_{a}^{r} * \sum_{m=1}^{M}\sum_{s=1}^{S} X_{ms}^{r} \qquad (17)$$

This quality constraint equation (17) is about the number of units transferred from the customer market center to the warehouse center should be precisely equal to the Alpha quality ratio of units transferred from the customer market to the sorting center in return flow to manage the quality checks.

$$\sum_{s=1}^{S}\sum_{w=1}^{W} X_{sw}^{r} = Q_{\beta}^{r} * \sum_{m=1}^{M}\sum_{s=1}^{S} X_{ms}^{r} \qquad (18)$$

This quality constraint equation (18) is about the number of units transferred from the sorting center to the repair center should be precisely equal to the beta quality ratio of units transferred from the customer market to the sorting center in return flow to manage the quality checks.

$$\sum_{s=1}^{S}\sum_{w=1}^{W} X_{sl}^{r} = Q_{\gamma}^{r} * \sum_{m=1}^{M}\sum_{s=1}^{S} X_{ms}^{r} \qquad (19)$$

Quality constraint equation (19) specifically concerns the alignment of the quantity of units transferred from the sorting center to the landfill in reverse flow with the gamma quality ratio of units sent from the customer market to the sorting center. This constraint holds significant significance, as it guarantees the proper disposal of gamma-quality units at landfill centers.

$$Y_A \leq Y_B \qquad (20)$$

Equation 20 is a conditional equation to incorporate the supplier preference as provided from the ranking from supplier selection stage. Equation (21), (22) and (23) is about fixed cost of selecting sorting, warehouse, and repair center(s).

Binary

$$F_s \in Binary \tag{21}$$

$$F_r \in Binary \tag{22}$$

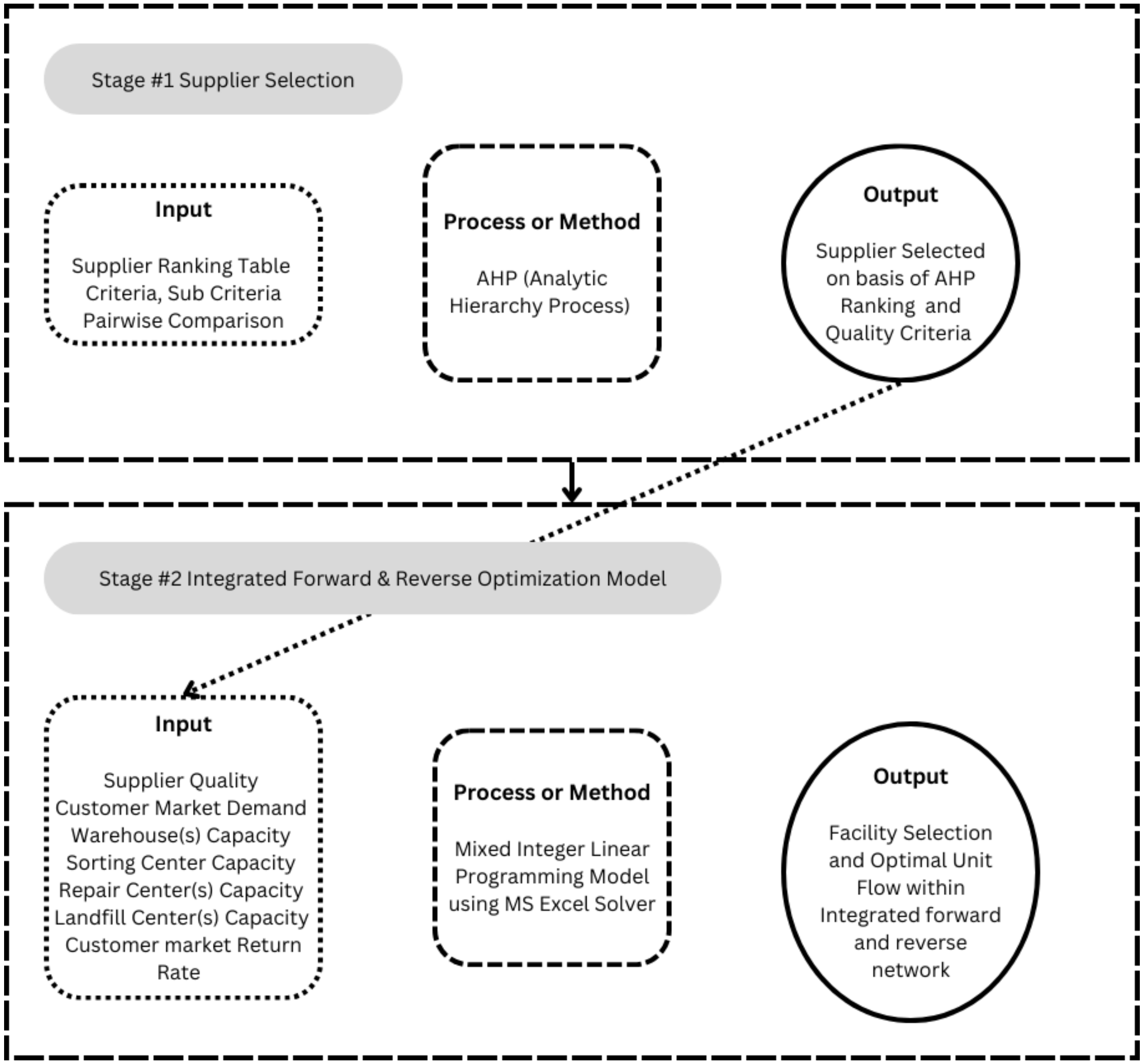
$$F_w \in Binary \tag{23}$$

Chapter 4: Methodology

4.1 Two Stage Decision making framework.

This research considers an e-commerce enterprise with a distinctive goal of harnessing export-quality leftovers as its primary input, repairing them, and subsequently making them available to the local market at competitive prices. This strategic direction necessitates that the company's decision-makers leverage their historical supplier knowledge, considering factors such as product quality, cost, and lead times. This is imperative for meeting the forecasted demand and efficiently managing product movement within the integrated forward and reverse supply chain. Furthermore, it entails a meticulous consideration of facility options to ensure seamless operations.

To address these multifaceted challenges, we have devised a comprehensive two-stage strategic decision-making model. In the development of this model, we were greatly inspired by insights gleaned from our earlier research endeavors. Our use of the Analytical Hierarchy Process (AHP) for the supplier selection process finds its foundation in the work of Tavana et al. (2015). This decision-making framework is designed to empower decision-makers within the e-commerce firm to make informed choices, harmonizing supplier selection with the company's overarching objectives. This innovative approach embraces the company's strategic vision, reflecting the commitment to utilizing high-quality surplus materials, maximizing their value through repairing, and ultimately offering them to local consumers at competitive prices. Such a comprehensive approach is essential for aligning supplier decisions with the company's ability to fulfill demand projections and manage product movement effectively in the integrated forward and reverse supply chain.



Chapter 4 Figure 1 Two Stage Decision making framework.

4.2 Analytical Hierarchy Process

Supplier selection in E-commerce is a multifaceted decision-making process that involves various criteria and alternatives. AHP can effectively handle complex decision problems (Saaty, 1980). AHP accommodates subjective judgments and preferences, which are often prevalent in supplier selection, allowing decision-makers to express their preferences in a structured manner (Forman & Gass, 2001). E-commerce supplier selection often involves the consideration of multiple criteria such as cost, quality, and lead time. AHP allows for the integration of these diverse criteria (Tavana et al., 2015). Literature is fill with other multi criteria decision making processes for supplier selection. Every method has its contribution and limitations. AHP is a robust and widely accepted method for supplier selection due to its ability to handle complex decision problems with multiple criteria and alternatives. It provides a structured framework for decision-makers to evaluate and prioritize suppliers effectively. AHP's capacity to incorporate subjective judgments, perform consistency analysis, and generate clear rankings makes it a valuable tool for supplier selection in various industries (Saaty, 2008).

AHP accommodates the integration of subjective judgments and preferences. Decision-makers can explicitly express their preferences through pairwise comparisons, promoting transparency and ensuring that all stakeholders' inputs are considered, particularly in situations where qualitative factors play a significant role (Forman & Gass, 2001). Along with this AHP includes a built-in consistency check that ensures the logical soundness of judgments made during pairwise comparisons. This feature enhances the reliability of the decision-making process, reducing the likelihood of errors in the assessment of suppliers (Saaty, 2008). AHP can integrate diverse criteria, including both quantitative and qualitative factors, making it versatile for supplier selection in a variety of contexts. This flexibility allows organizations to consider a wide range of factors when evaluating potential suppliers (Tavana et al., 2015).

Like all other methods AHP has its limitations. AHP involves pairwise comparisons of criteria and alternatives, which can become overwhelmingly complex as the number of criteria and alternatives increases. The process can be time-consuming, especially in supplier selection scenarios with many potential suppliers (Dulaimi, Vaghefi, & Kumaraswamy, 2018). Furthermore, AHP becomes less scalable as the number of criteria and alternatives increases. Aggregating the pairwise comparison matrices can become unwieldy, making the method less practical for extensive supplier selection problems (Vaidya & Kumar, 2006)

Analytic Hierarchy Process (AHP) is being used as decision-making methods, can be justified by several key factors. First, AHP is a suitable choice due to the limited number of available suppliers, which requires a more thorough and systematic evaluation process. Research by (Triantaphyllou, 2000) highlights AHP's ability to manage complex and multifaceted decisions effectively. Additionally, AHP's capacity to handle varying supplier rankings and its robustness in aggregating diverse perspectives from decision-makers make it a pragmatic choice. Furthermore, the model employed in this study prioritizes crucial criteria for decision-making, namely cost, quality, and lead time. Saaty (2008) emphasizes AHP's proficiency in weighting and comparing these critical factors, ensuring that the final decision is based on a comprehensive assessment.

Lastly, AHP is a well-recognized technique for incorporating decision-maker rankings into the evaluation process, enhancing decision credibility. A study by L. Tavana et al. (2015) reinforces AHP's effectiveness in managing subjective input and pairwise comparisons, making it a sensible choice when evaluating suppliers with varying opinions and preferences.

4.3 Forward and reverse Mixed integer linear programming model.

Mixed Integer Linear Programming (MILP) models are widely acknowledged and employed in operational research due to their versatility and ability to address complex decision-making challenges. MILP formulations prove invaluable when dealing with discrete decision variables, such as supplier selection, production scheduling, and resource allocation, all of which are prevalent in supply chain management (Papageorgiou & Nikolos, 2017). The utilization of MILP in supply chain optimization aids in enhancing cost-efficiency, resource allocation, and risk mitigation (Liu, Kuo, & Wu, 2018). Furthermore, MILP models allow for the integration of both linear and non-linear constraints, thereby accommodating a diverse range of real-world supply chain scenarios and uncertainties (Shen, Wang, & Xie, 2016). By providing a systematic and rigorous approach to decision-making, MILP models enable organizations to make informed and optimized choices in their supply chain operations, contributing to improved performance and competitiveness.

To solve mixed integer linear programming model this paper uses MS solver. Solving Mixed Integer Linear Programming (MILP) models is a critical task in supply chain management, and decision optimization. MILP models involve a combination of linear equations with integer decision variables, making them particularly challenging to solve. In this context, the use of optimization software tools such as Microsoft Solver is highly justified. Microsoft Solver offers several advantages that facilitate the solution of MILP models. Microsoft Solver offers a user-friendly interface that is particularly well-suited for beginners and non-experts in optimization. This makes it a valuable choice for those who may not have a strong background in mathematical programming (Bertsimas & Tsitsiklis, 1997).

Chapter 5: Results

To validate proposed decision support framework several numerical examples are tested in this section.

5.1 Supplier Selection

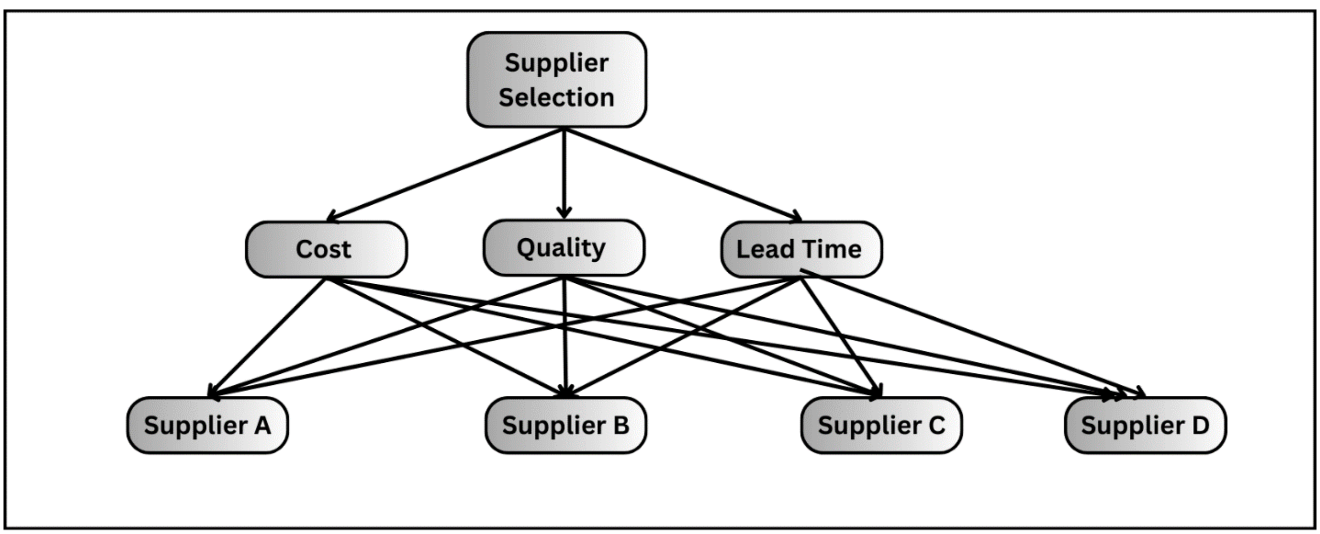
Literature is filled with various criteria and sub criteria for supplier selection. One of the primary criteria is quality, which can be divided into product quality, focusing on conformance to specifications and reliability, and process quality, which considers manufacturing processes and compliance with industry quality standards (Monczka et al., 2015). Cost-related criteria, including price negotiations and the consideration of total cost of ownership, play a pivotal role in supplier selection, as do life-cycle costs, encompassing maintenance and operating expenses (Carter & Rogers, 2008). Reliability criteria, such as the supplier's reputation and their capacity and capability, are also crucial factors to consider (Narasimhan & Das, 2001). Lead time criteria, which encompass order fulfillment time and response time, help ensure efficient supply chain operations (Nahmias, 2015). Moreover, environmental criteria, including sustainability practices and the measurement of the carbon footprint, are increasingly relevant in supplier selection as organizations strive for sustainability (Seuring & Müller, 2008).

Deretarla et al. (2023b) mentioned in their paper the following criteria's that are essential for supplier selection and being used by industry and academicians based on information gained from the literature review and the opinions of industry experts.

Chapter 5 Table 1: Supplier Selection Criteria by Deretarla et al. (2023b)

Criteria	
C1: Cost/Price	C12: Environmental
C2: Quality	C13: Geographical Location
C3: Lead/Delivery Time	C14: Sustainability
C4: Technology	C15: Performance
C5: Service	C16: Reputation
C6: Flexibility	C17: Cooperation
C7: Distance	C18: Green Design
C8: Variety	C19: Green Manufacturing System
C9: Technical Competence/ Capability	C20: Management System
C10: Economic	C21: Other Criteria
C11: Social	

To keep this case study scope narrow and relevant to Textile leftover as inputs we are considering Cost, Quality, and lead time selection criteria. Cost, quality, and lead time are very important criteria for textile leftover industry. As per research done by Cheraghi et al. (2011c) Quality, cost and delivery time are the top three top supplier selection criteria's quality at 1st, delivery on second and cost on third for major customer centric industries i-e E-commerce firms. Numerical Data has been adopted from Deretarla et al. (2023) for supplier selection considering four suppliers.



Chapter 5 Figure 1 Supplier Selection Hierarchical Structure

Chapter 5 Table 2 Supplier Selection Criteria & Alternatives

Suppliers	**Criteria**
A	Cost
B	Quality
C	Lead Time
D	

Once the criteria and alternatives have been established, pairwise comparison matrices are generated to assess the relative importance levels among them. We have adopted the Saaty's 1–9 scale of pairwise comparisons. Along with this pairwise comparison data tables are adopted from Deretarla et al. (2023).

Chapter 5 Table 3 Saaty's 1–9 scale of pairwise comparisons

Importance Intensity	**Definition**
1	Equal Importance
3	Moderately Important
5	Strongly Important
7	Very Strongly Important
9	Absolutely Important
2, 4, 6, 8	Intermediate Values

A pairwise comparison matrix has been created to evaluate the relative importance of three criteria: Cost, Quality, and Lead Time. The values in the matrix reflect the relative significance of one criterion compared to another. cost is considered three times more important than quality. cost is considered five times more important than lead time. Quality is considered three times more important than lead time.

Chapter 5 Table 4 The Pairwise comparison matrix of the criteria

	Cost	Quality	Lead Time
Cost	1	3	5
Quality	0.33	1	3
Lead Time	0.20	0.33	1

Furthermore, a pairwise comparison matrix of the alternatives based on criteria is adopted. Table 05 serves as a pairwise comparison matrix evaluating the relative importance or preference of suppliers concerning the criterion of "Cost." Within this assessment, four suppliers, denoted as A, B, C, and D are being evaluated primarily based on their cost performance. The values contained within the matrix signify the degree of preference or importance assigned to one supplier over another in terms of cost. In this comparison: Supplier B is considered four times preferable than Supplier A in terms of cost. Supplier C is considered three times preferable than Supplier A in terms of cost. Supplier C is considered two times preferable than Supplier B in terms of cost. Supplier D is considered twice as preferable as Supplier A, four times as preferable as Supplier B, and eight times as preferable as Supplier C in terms of cost.

Chapter 5 Table 5 The pairwise comparison matrices of the alternatives based on cost criteria.

Supplier	**A**	**B**	**C**	**D**
A	1.00	0.25	0.33	0.5
B	4.00	1.00	0.50	0.25
C	3.00	2.00	1.00	0.125
D	2	4	8	1

Table 06 provided is a pairwise comparison matrix designed to assess the relative importance or preference of different suppliers concerning the criterion of "Quality." It involves four suppliers, labeled as A, B, C and D, and evaluates their quality performance in relation to each other. The values in the matrix quantify the degree of preference or importance assigned to one supplier over another in terms of quality. Supplier B's quality is three times preferable than Supplier A. Supplier C's quality is seven times preferable than Supplier A and five times preferable than Supplier B.

Supplier D's quality is about six times as preferable as Supplier A, eight times as preferable as Supplier B, and ten times as preferable as Supplier C.

Chapter 5 Table 6 The pairwise comparison matrices of the alternatives based on Quality criteria.

Quality				
Supplier	A	B	C	D
A	1.00	3.00	7.00	0.167
B	0.33	1.00	5.00	0.125
C	0.14	0.20	1.00	0.1
D	6	8	10	1

Table 07 is a pairwise comparison matrix created to evaluate the relative importance or preference of different suppliers based on their "Delivery Time" performance. This matrix includes three suppliers, denoted as A, B, C, and D and assesses how they compare in terms of delivery time. Supplier B's delivery time is three times faster than Supplier A's. Supplier C's delivery time is seven times faster than Supplier A's and six times faster than Supplier B's. Supplier D's delivery time is two times faster than Supplier A's, four times faster than Supplier B's, and six times faster than Supplier C's.

Chapter 5 Table 7 The pairwise comparison matrices of the alternatives based on Lead time criteria.

Delivery Time				
Supplier	A	B	C	D
A	1.00	3.00	7.00	2
B	0.33	1.00	6.00	4
C	0.14	0.17	1.00	6
D	0.5	0.25	0.167	1

5.1.1 Normalization and Relative weight calculations for criteria and alternatives

In Supplier selection after getting pairwise comparison of criteria and alternative based on each criterion, the first step is to normalize the pairwise comparisons. This normalized matrix is obtained by dividing each element in the original matrix by its corresponding column sum. Cost emerges as the most influential factor, boasting a weightage of 0.63, signifying its relatively higher importance compared to Quality and Lead Time. Within the matrix, Cost receives a score of 0.65 when compared to Quality and 0.56 against Lead Time. This suggests that Cost holds moderate importance, trumping Quality and Lead Time but not overwhelmingly so. Quality, with a weightage of 0.26, is considered less significant than Cost but more so than Lead Time. Its score in comparison with Cost is 0.22 and Lead Time at 0.33, indicating its intermediary position between the two. In contrast, Lead Time carries the least weightage at 0.11, depicting its minimal impact compared to Cost and Quality. Lead Time stands at 0.13 in relation to Cost and 0.08 in comparison to Quality.

Chapter 5 Table 8 Normalized pairwise comparison matrix of the criteria.

Normalized pairwise comparison matrix of the criteria.					
	Cost	Quality	Lead Time		Weightage of Criteria
Cost	0.65	0.69	0.56	Cost	0.63
Quality	0.22	0.23	0.33	Quality	0.26
Lead Time	0.13	0.08	0.11	Lead Time	0.11

Table 08 presents among the suppliers evaluated, Supplier D holds the highest relative importance for cost considerations, boasting a substantial value of 0.52. This signifies that Supplier D is notably influential when evaluating based on cost alone. Following closely behind is Supplier C, with a relative importance value of 0.19, indicating a significant but slightly lesser impact than Supplier D. Supplier B holds the next highest importance with a value of 0.18, showing a moderate influence concerning cost. Lastly, Supplier A presents the least impact on cost considerations among the alternatives, with a relative importance value of 0.11, suggesting a relatively lower significance in the context of cost when compared to the other suppliers assessed.

Chapter 5 Table 9 Normalized Pairwise Cost Comparison for alternatives.

Normalized Pairwise Cost Comparison for alternatives					
Supplier	A	B	C	D	Relative importance of Cost for alternative Supplier
A	0.10	0.03	0.03	0.27	0.11
B	0.40	0.14	0.05	0.13	0.18
C	0.30	0.28	0.10	0.07	0.19
D	0.20	0.55	0.81	0.53	0.52

Table 09 represents a normalized pairwise quality comparison for four different alternatives (A, B, C and D). Normalized Relative importance of Quality for alternative Supplier provides the relative importance or weight assigned to quality when considering these suppliers. Supplier D emerges as the most pivotal option in terms of quality, boasting a high relative importance value of 0.65. This signifies that Supplier D holds significant weightage in quality considerations compared to the other alternatives. Following behind is Supplier A, albeit with notably less influence than Supplier D, holding a relative importance value of 0.20. Supplier A presents itself as moderately important in terms of quality among the options assessed. Supplier B follows next, with a relative importance value of 0.11, signifying a comparatively lower impact on quality considerations. Lastly, Supplier C demonstrates the least influence concerning quality among the alternatives, with a value of 0.04, indicating the least significant in terms of quality compared to the other suppliers evaluated.

Chapter 5 Table 10 Normalized Pairwise Quality Comparison for alternatives.

Normalized Pairwise Quality Comparison for alternatives					
	A	B	C	D	Relative importance of Quality for alternative Supplier
A	0.13	0.25	0.30	0.12	0.20
B	0.04	0.08	0.22	0.09	0.11
C	0.02	0.02	0.04	0.07	0.04
D	0.80	0.66	0.43	0.72	0.65

The delivery time's varying significance across alternative suppliers is evident through their respective relative importance weights. Among these options, Supplier A holds the highest weight at 0.46, indicating a substantial emphasis on timely delivery. Following closely, Supplier B is assigned a weight of 0.28, suggesting a notable but comparatively lower importance placed on delivery time. Supplier C holds a weight of 0.16, signifying a moderate priority attributed to timely deliveries. Lastly, Supplier D has the lowest weight at 0.10, indicating the least emphasis on delivery time among the listed suppliers. These weights offer a clear hierarchy, showcasing the differing degrees of emphasis placed on delivery time across these alternative suppliers.

Chapter 5 Table 11 Normalized Pairwise Delivery Time Comparison for alternatives.

Normalized Pairwise Delivery Time Comparison for alternatives					
Supplier	A	B	C	D	Relative importance of DT for alternative Supplier
A	0.51	0.68	0.49	0.15	0.46
B	0.17	0.23	0.42	0.31	0.28
C	0.07	0.04	0.07	0.46	0.16
D	0.25	0.06	0.01	0.08	0.10

5.2 Supplier ranking

The second step in the Analytical hierarchy process is to use the normalized weights of criteria and sub criteria rank the supplier based on the score. As of previous calculations, the values in the last row of the table (0.63, 0.26, 0.11) represent the total weightage of criteria for each alternative. These values indicate the overall importance of all the criteria for each alternative. for alternative A, cost (0.11), quality (0.20), and delivery time (0.46) have been assigned weightages, for alternative B, cost (0.18), quality (0.11), and delivery (0.28) have been assigned weightages. For alternative C, cost (0.19), quality (0.04), and delivery (0.16) have been assigned weightages. In this case, the cost criterion is also the most important. For alternative D, cost (0.52), quality (0.65), and delivery (0.100) have been assigned weightages.

Chapter 5 Table 12 Weightage of Criteria and Alternatives

	Cost	**Quality**	**Lead Time**	**Weightage of Criteria**
A	0.11	0.20	0.46	0.63
B	0.18	0.11	0.28	0.26
C	0.19	0.04	0.16	0.11
D	0.52	0.65	0.100	

So, a major step here is to score the suppliers and rank them based on weightage on criteria and alternatives. Doing immediate calculations of multiplying respective criteria with each supplier correspondence importance ranking can be achieved Supplier D holds the highest weightage among the group, constituting 51.28% of the total. As a result, it secures the top rank, being positioned at number 1. Supplier B follows with a weightage of 17.25% and secures the second rank with a notable performance. Supplier A holds a weightage of 16.99%, securing the third rank in this assessment. Supplier C, with a weightage of 14.48%, holds the fourth and final rank among the evaluated suppliers.

Chapter 5 Table 13 Supplier Ranking

	Supplier Weightage	**Ranking**
A	16.99%	3
B	17.25%	2
C	14.48%	4
D	51.28%	1

The major contribution of this step is to filter out the supplier that is the best fit. In the next integrated optimization step this supplier cost and quality information will be utilized to optimize the flow and facility selection.

5.3 Integrated Network Optimization

In this step integrated network is tested with multiple scenarios with different number of facilities. The data set nodes include sorting center, repair center, warehouse, landfill, customer markets. The data replicated numerical examples of prior research done by (Nanayakkara et al., 2022). Their paper primarily focused on the reverse flow in handling e-commerce returns, the flow described here incorporates significant modifications to align it with a textile leftover framework, effectively integrating both forward and reverse logistics aspects.

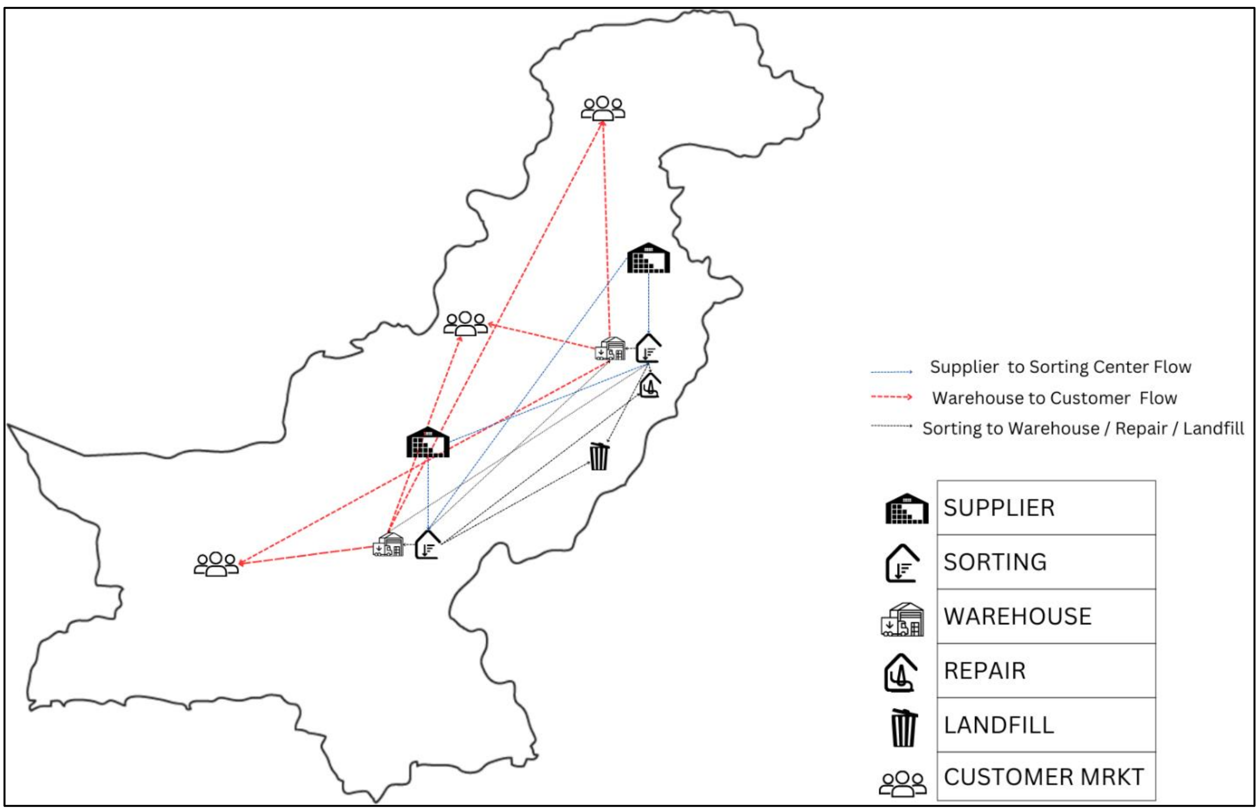
5.3.1 Scenario 1

In this scenario 1 research has considered multiple facilities. It includes two suppliers varying in size and are located at different locations with different transportation costs. Similarly, two sorting facilities vary in size and are located at different locations with different transportation costs. Furthermore, two Warehouses, one Repair facility and one landfill facility is considered.

Customers are divided into three major markets. A more clear and vivid picture of this flow is showed on map of Pakistan in figure 4.

Chapter 5 Table 14 Scenario 1 Number Facilities

SUPPLIER	**2**
SORTING	2
WAREHOUSE	2
REPAIR	1
LANDFILL	1
CUSTOMER MARKET	3



Chapter 5 Figure 2 Scenario 1 Number Facilities

The fixed costs of Suppliers are 100,000 for smaller capacity and 150,000 for larger capacity setups, accommodating 200,000 and 300,000 units, respectively. The Sorting Centers have fixed costs of 200,000 for small capacity and 300,000 for larger capacity, while managing 300,000 and

500,000 units, respectively. The Repair Center, requires a substantial investment of 1,200,000 for its larger capacity, allowing repairs for 100,000 units. Finally, the Warehouse, responsible for storage, sustains fixed costs of 250,000 for smaller capacity and 350,000 for larger capacity, with storage capabilities of 600,000 and 800,000 units, respectively.

Chapter 5 Table 15 Scenario 1 Facilities Fixed Cost and Capacities

	Fixed Cost		**Capacity (In Units)**	
	Small	**Large**	**Small**	**Large**
Supplier	100,000	150,000	200,000	300,000
Sorting Center	200,000	300,000	300,000	500,000
Repair Center		1,200,000		100,000
Warehouse	250,000	350,000	600,000	800,000

The variable costing includes movement of units from various facilities to finally ship to end customer. It starts from supplier to sorting then from sorting to repair, warehouse and landfill facilities where products are repaired and stored and sent to the customer market later when demanded. Below tables includes the transportation cost of movement of units from each facility.

Table 16 includes the transportation costs per unit from Supplier 1 and Supplier 2 to Sorting 1 and Sorting 2 are delineated in a cost matrix. Transporting goods from Supplier 1 to Sorting 1 incurs a cost of 26 units per item, while the cost per unit for moving items from Supplier 1 to Sorting 2 is 27 units. In comparison, the transportation expenses from Supplier 2 to Sorting 1 are slightly lower at 25 units per unit but rise notably to 40 units per unit when delivering to Sorting 2.

Chapter 5 Table 16 Scenario 1 Transportation Cost: Supplier to Sorting Cost

Transportation Cost Supplier to Sorting		
	Supplier 1	Supplier 2
Sorting 1	26	25
Sorting 2	27	40

The transportation costs per unit from Sorting 1 and Sorting 2 to Repair 1, Warehouse 1, Warehouse 2, and Landfill 1 are presented in a cost matrix table 17. Moving goods from Sorting 1 to Repair 1 incurs a cost of 23 units per unit, the same as transporting to Warehouse 1. while transferring to Warehouse 2 totals 39 units per unit and to Landfill 1 costs 10 units per unit. On the other hand, transporting items from Sorting 2 to Repair 1 accumulates a cost of 35 units per unit, 26 units per unit to Warehouse 1, 24 units per unit to Warehouse 2, and 5 units per unit to Landfill 1.

Chapter 5 Table 17 Scenario 1 Transportation Cost: Sorting Cost to Warehouse/ Repair / Landfill

Transportation Cost Sorting to Warehouse/ Repair / Landfill				
	Repair 1	Warehouse 1	Warehouse 2	LANDFILL 1
Sorting 1	23	23	39	10
Sorting 2	35	26	24	5

The transportation costs per unit from Repair 1 to Warehouse 1, Warehouse 2, and Landfill 1 are outlined in a concise matrix table 18. Transporting goods from Repair 1 to Warehouse 1 incurs a cost of 39 units per unit, while transferring items to Warehouse 2 results in a slightly lower cost of 37 units per unit. However, the expense decreases significantly when transporting goods from Repair 1 to Landfill 1, amounting to only 5 units per unit.

Chapter 5 Table 18 Scenario 1Transportation Cost: Repair to Warehouse & Landfill

Transportation Cost Repair to Warehouse & Landfill			
	Warehouse 1	Warehouse 2	LANDFILL 1
Repair 1	39	37	5

The transportation costs per unit from Warehouse 1 and Warehouse 2 to Customer Market 1, Customer Market 2, and Customer Market 3 are detailed in structured table 19. Transporting goods from Warehouse 1 to Customer Market 1 incurs a cost of 33 units per unit, while moving items to Customer Market 2 and Customer Market 3 amounts to 34 units per unit and 26 units per unit, respectively. Comparatively, the costs from Warehouse 2 to these markets differ: it's 32 units per unit to Customer Market 1, 23 units per unit to Customer Market 2, and 27 units per unit to Customer Market 3.

Chapter 5 Table 19 Scenario 1 Transportation Cost: Warehouse to Customer Market

Transportation Cost Warehouse to Customer Market			
	Customer Market 1	Customer Market 2	Customer Market 3
Warehouse 1	33	34	26
Warehouse 2	32	23	27

The transportation costs per unit from Customer Market 1, Customer Market 2, and Customer Market 3 to Sorting 1 and Sorting 2 are displayed in structured table 20. Transporting goods from Customer Market 1 to Sorting 1 incurs a cost of 30 units per unit, whereas the cost to Sorting 2 is 24 units per unit. For Customer Market 2, the expenses are slightly lower at 29 units per unit for Sorting 1 and 26 units per unit for Sorting 2. Conversely, from Customer Market 3, the costs vary, with 35 units per unit to Sorting 1 and a reduced expense of 22 units per unit to Sorting 2.

Chapter 5 Table 20 Scenario 1Transportation Cost: Customer Market to Sorting

Transportation Cost Customer Market to Sorting		
	Sorting 1	Sorting 2
Customer Market 1	30	24
Customer Market 2	29	26
Customer Market 3	35	22

Table 1 Scenario 1Transportation Cost: Customer Market to Sorting

Demand is from 3 customer markets, and it is considered known along with the return percentage from each customer market. For scenario 2 Demand is considered 50,000 for each market with return percentage of 20%.

Chapter 5 Table 21 Scenario 1 Customer Markets Demand and Return Rate

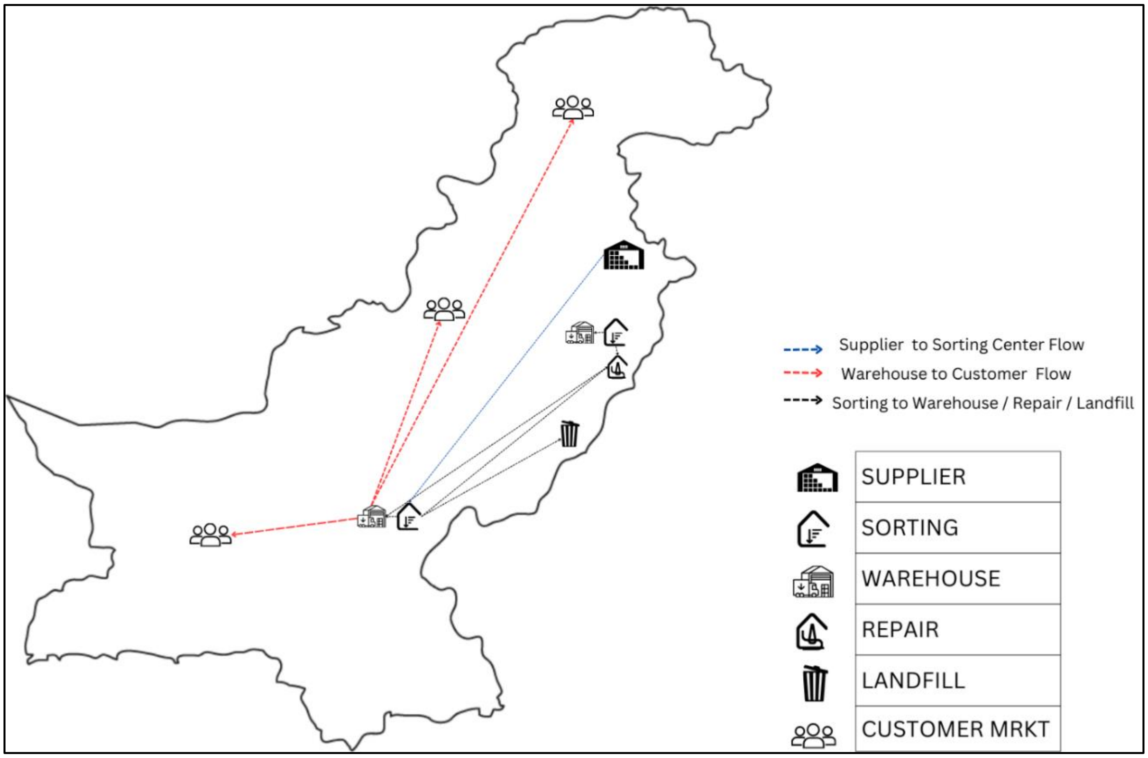
Market	Demand	Return rate
Customer Market 1	50000	20%
Customer Market 2	50000	
Customer Market 3	50000	

5.3.1. Scenario 1: Results

Using MS solver model is solved model and results provide optimal units flow in network and selected facilities that achieve low-cost objective. Supplier 1 is selected, Sorting Center 2 is selected, both Warehouse 1, and Warehouse 2 is selected as shown in table 22. Optimal Cost is 14,985,758.

Chapter 5 Table 22 Scenario 1 Facilities Selection

Facilities Selection		
	1	2
Supplier	✓	
Sorting Center		✓
Warehouse	✓	✓
Repair Center		✓



Chapter 5 Figure 3 Scenario 1 Selected Facility Map

The optimal unit flow in forward is from selected supplier 1 to sorting center is 100503. Then units further forwarded to warehouse 1, 2, repair and landfill center. 36364, 100000, 13636 and 1515 respectively as shown in table 23 and 24.

Chapter 5 Table 23 Scenario 1 Supplier to Sorting Forward Flow

	Supplier 1
Sorting 1	×
Sorting 2	100503

Chapter 5 Table 24 Scenario 1 Sorting to Repair Warehouse & Landfill in Forward Flow

		Sorting	
		1	2
Warehouse	1	×	36,364
	2	×	100,000
Repair Center	1	×	13,636
landfill	1	×	1,515

Now the repair center must move forward repaired and landfill units downstream. So, units received from sorting centers are out of them 13,636 units transported to warehouse 2 while no units sent to landfill center.

Chapter 5 Table 25 Scenario 1Repair to Warehouse and landfill Unit Flow

	Warehouse			Landfill
Repair	1	2		1
1	×	13,636		×

In forward flow markets unit moment is from warehouse to customer market to fulfill the demand for each customer market. Demand is fulfilled for each customer market through optimal unit moment for each warehouse. 50,000 units moved to customer market 1, 2 and 3 from warehouse 2.

Chapter 5 Table 26 Scenario 1 Warehouse to Customer Forward Flow

	Warehouse 1	**Warehouse 2**
Customer Market		
1	×	50,000
2	×	50,000
3	×	50,000

Reverse flow has been optimized by model by effectively handling returns from customer markets to sorting centers. Sorting centers accommodated returns as well from customer markets. As sorting center 1 has enough capacity and costs are lower for processing at sorting center 1. Model has transferred all returned units to sorting center 1 from customer market 1, 2 3 and 4 respectively.

Chapter 5 Table 27 Scenario 1Return from customers to sorting.

	Sorting 1	Sorting 2
Customer Market		
1	×	10000
2	×	10000
3	×	10000

Furthermore, units sorted on the quality criteria and moved downstream. Sorted units 1320,14850,330 moved from sorting center 1 moved to repair center 2, warehouse 1 and landfill 1 respectively.

Chapter 5 Table 28 Scenario 1Reverse Flow of units from Sorting to Warehouse / Repair centers

	Repair1	Warehouse 1	Warehouse 2
Sorting 1	×	×	
Sorting 2	5000	×	25000

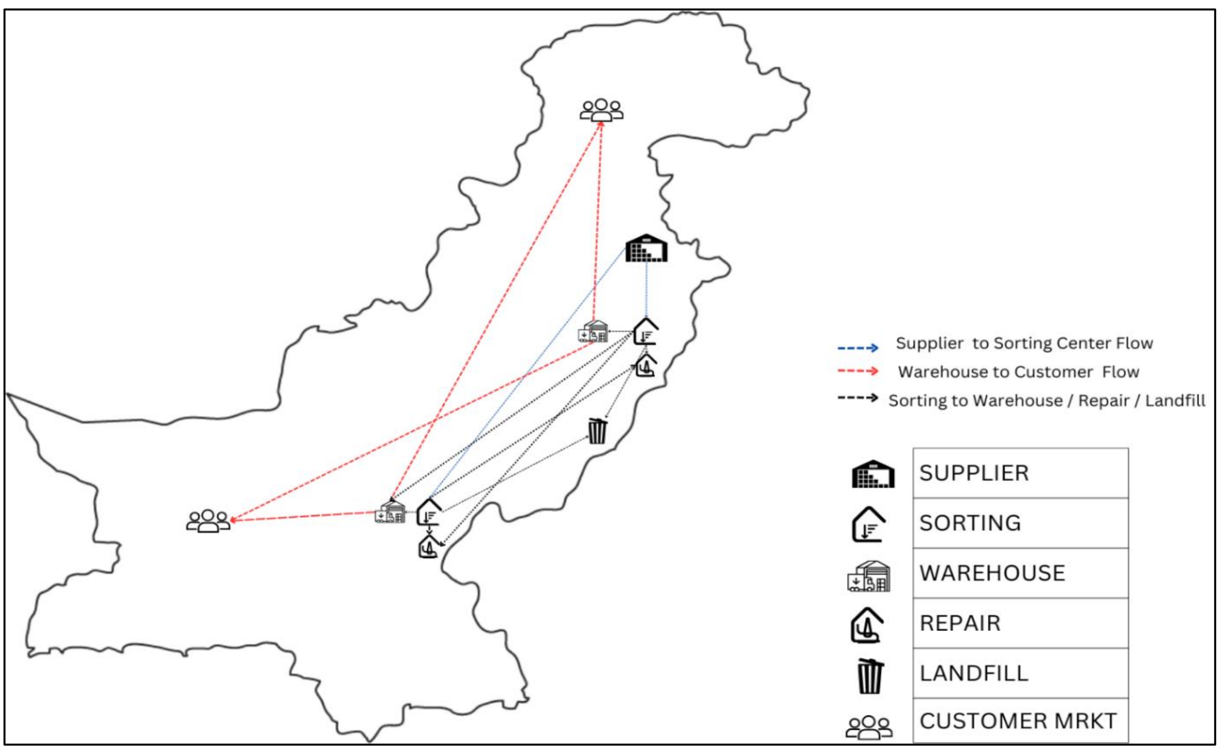
Lastly the warehouse units moved again to the customer to meet customer demand completely and customer satisfaction achieved. Unfilled demand for the first cycle will be considered as new demand for cycle two.

5.3.2 Scenario 2

In scenario 2, research study has encompassed multiple facilities. This encompasses one supplier. Similarly, there are two sorting facilities, varying in size, and positioned at different locations with diverse transportation expenses. Additionally, the consideration involves two warehouses, two repair facilities differ in size and situated at separate locations with distinct transportation costs, and one landfill facility. The customer base is segmented into two major markets.

Chapter 5 Table 29 Scenario 2 Number Facilities

Supplier	1
Sorting	2
Warehouse	2
Repair	2
Landfill	1
Customer market	2



Chapter 5 Figure 4 Scenario 2 Facility Map

The Supplier, comprising are of large scale, operates with capacities of 150,000 units while specific fixed costs are 300,000. The Sorting Center exhibits substantial capacities, handling 100,000 units for the small center and 150,000 units for the large center, with fixed costs of 1,000,000 and

1,500,000. The Repair Center operates with fixed costs of $80,000 for the small center and $100,000 for the large center, managing capacities of 40,000 units and 60,000 units, respectively. Additionally, the Warehouse operates with capacities of 120,000 units for the small warehouse and 150,000 units for the large warehouse with fixed costs of 1,000,000 for the small center and 1,500,000 for the large center respectively.

	Fixed Cost		Capacity (In Units)	
	Small	Large	Small	Large
Supplier	×	150,000	×	300,000
Sorting Center	1,000,000	1,500,000	100,000	150,000
Repair Center	80,000	100,000	40,000	60,000
Warehouse	1,000,000	1,500,000	120,000	150,000

Chapter 5 Table 30 Scenario 2 Facilities Fixed Cost and Capacities

The variable costing includes movement of units from various facilities to finally ship to end customer. It starts from supplier to sorting then from sorting to repair, warehouse and landfill facilities where products are repaired and stored and sent to the customer market later when demanded. Below tables includes the transportation cost of movement of units from each facility. Table 31 includes Transporting costs from Supplier 1 to Sorting 1 incurs a cost of 22 units, while the cost increases to 34 units when delivering items from Supplier 1 to Sorting 2. These specific unit costs represent the expenses associated with logistics between Supplier 1 and the sorting locations.

Chapter 5 Table 31 Scenario 2 Transportation Cost: Supplier to Sorting Cost

	Supplier 1
Sorting 1	22
Sorting 2	34

Table 32 outlines the transportation costs involved in moving materials from two sorting locations, sorting 1 and Sorting 2, to different destinations: Repair centers, Warehouses, and a Landfill. For Sorting 1, the cost to transport materials to Repair 1 and Repair 2 is 34 and 31, respectively. Moving materials from Sorting 1 to Warehouse 1 and Warehouse 2 incur costs of 33 and 31 per unit, while transporting them to Landfill 1 costs 29 per unit. Furthermore Sorting 2 demonstrates different transportation costs per unit: 25 and 23 to Repair 1 and Repair 2, 27 and 22 to Warehouse 1 and Warehouse 2, and 34 to Landfill 1.

Chapter 5 Table 32 Scenario 2: Transportation Cost: Sorting Cost to Warehouse/ Repair / Landfill

Transportation Cost Sorting to Warehouse/ Repair / Landfill					
	Repair 1	**Repair 2**	**Warehouse 1**	**Warehouse 2**	**LANDFILL 1**
Sorting 1	34	31	33	31	29
Sorting 2	25	23	27	22	34

For Repair 1, the transportation cost per unit to Warehouse 1, Warehouse 2, and Landfill 1 is 27, 28, and 22, respectively. Conversely, Repair 2 incurs costs of 24, 30, and 26 per unit when transporting materials to Warehouse 1, Warehouse 2, and Landfill 1.

Chapter 5 Table 33 Scenario 2: Transportation Cost: Repair to Warehouse & Landfill

Transportation Cost Repair to Warehouse & Landfill			
	Warehouse 1	Warehouse 2	LANDFILL 1
Repair 1	27	28	22
Repair 2	24	30	26

From Warehouse 1, the transportation cost per unit to Customer Market 1 and Customer Market 2 is 30 and 27, respectively. Meanwhile, materials transported from Warehouse 2 incur costs of 28 and 32 per unit when sent to Customer Market 1 and Customer Market 2, respectively.

Chapter 5 Table 34 Scenario 2: Transportation Cost: Warehouse to Customer Market

Transportation Cost Warehouse to Customer Market		
	Customer Market 1	**Customer Market 2**
Warehouse 1	30	27
Warehouse 2	28	32

When transporting materials in reverse flow from Customer Market 1, the cost per unit to Sorting 1 and Sorting 2 is 23 and 22, respectively. Similarly, materials transported from Customer Market 2 incur costs of 22 and 33 per unit when sent to Sorting 1 and Sorting 2, respectively.

Chapter 5 Table 35 Scenario 2: Transportation Cost: Customer Market to Sorting

Transportation Cost Customer Market to Sorting		
	Sorting 1	Sorting 2
Customer Market 1	23	22
Customer Market 2	22	33

For scenario 2 Demand is from customer markets is considered known along with the return percentage from each customer market. Demand is considered 50,000 for each market with return percentage of 10%

Chapter 5 Table 36 Scenario 2 Customer Markets Demand and Return Rate

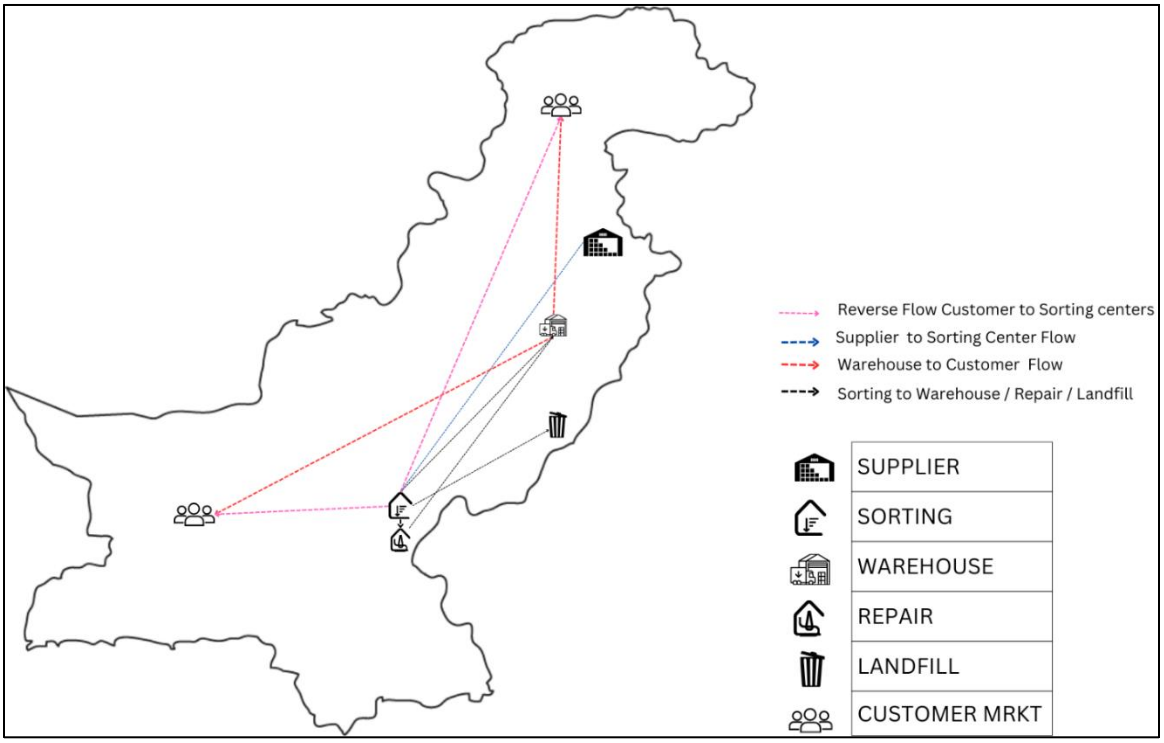
Market	Demand	Return rate
Customer Market 1	**50000**	10%
Customer Market 2	**50000**	

5.3.2 Scenario 2: Results

Using MS solver model is solved model and results provide optimal units flow in network and selected facilities that achieve low-cost objective. Supplier 1 is selected, Sorting Center 2 is selected, Warehouse 1 is selected and repair center 1 is selected. as shown in table 37. Optimal Cost is 12,957,236.

Chapter 5 Table 37 Scenario 2 Facilities Selection

Facilities Selection		
	1	2
Supplier	✓	
Sorting Center		✓
Warehouse	✓	
Repair Center	✓	



Chapter 5 Figure 5 Scenario 2 Selected Facility Map

The optimal unit flow in forward is from selected supplier 1 to sorting centers is 100,503. Then units further forwarded to warehouse 2, repair 1 and landfill center 1. 92,462, 7,538, and 503 respectively as shown in table 38 and 39.

Chapter 5 Table 38 Scenario 2 Supplier to Sorting Forward Flow

	Supplier 1
Sorting 1	
Sorting 2	100,503

Chapter 5 Table 39 Scenario 2 Sorting to Repair Warehouse & Landfill in Forward Flow

		Sorting	
		1	2
Warehouse	1		92462
	2		
Repair Center	1		7538
	2		
landfill	1		503

Furthermore, the repair center must move forward repaired and landfill units downstream. So, units received from sorting centers are out of them 7,538 units transported to warehouse 1 while no units sent to landfill center. Last in the forward flow markets unit moment is from warehouse to customer market to fulfill the demand for each customer market. Demand is fulfilled for each customer market through optimal unit moment for each warehouse. 50,000 units moved to customer market 1, 2 from warehouse 1.

Chapter 5 Table 40 Scenario 2 Repair to Warehouse and landfill Unit Flow

	Warehouse			**Landfill**
Repair	1	2		1
1		7,538		
2				

	Warehouse 1	Warehouse 2
Customer Market		
1	50000	
2	42462	
2 (Repaired Units)	7538	

The model efficiently improved reverse logistics for scenario 2 by managing returns from customer markets to sorting centers. Sorting centers accepted returns from these markets, with Sorting Center 2 having sufficient capacity and lower processing costs. Consequently, the model directed all returned items from Customer Markets 1 and 2 to Sorting Center 2 for processing as shown in table 41.

Chapter 5 Table 41 Scenario 2: Return from customers to sorting.

	Sorting 1	Sorting 2
Customer Market		
1		10000
2		10000

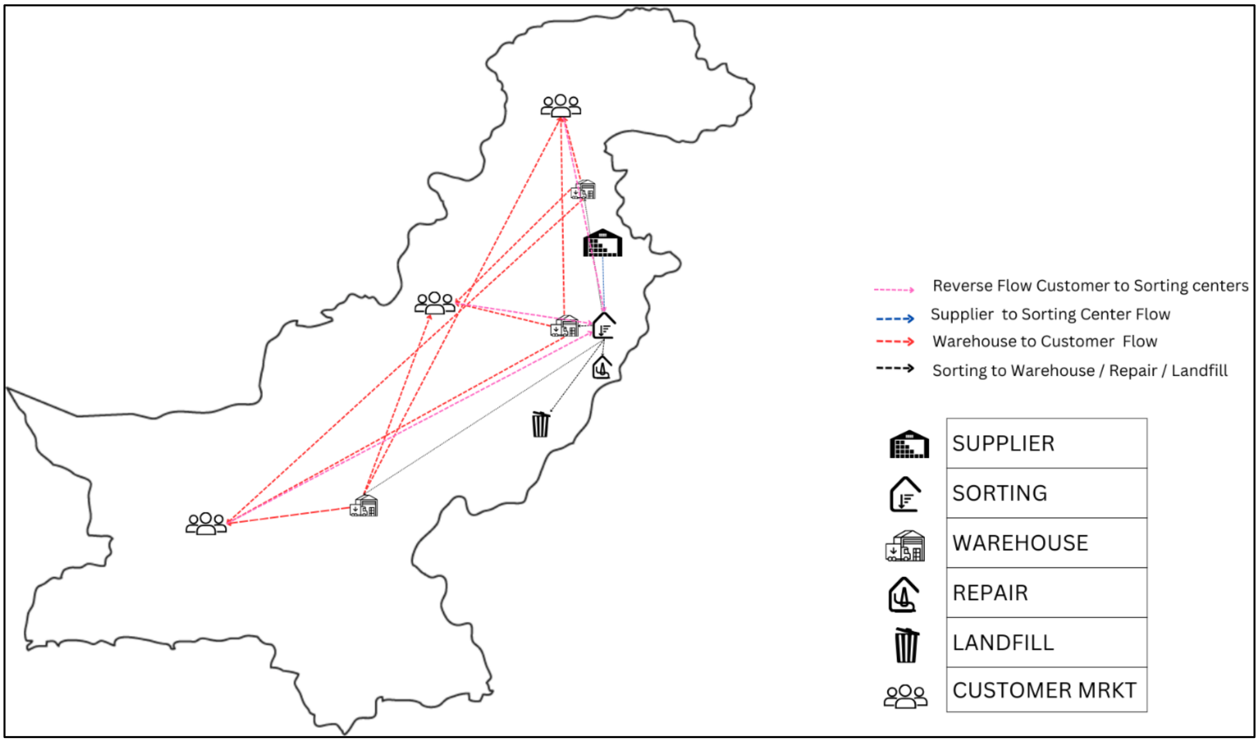
Furthermore, units sorted on the quality criteria and moved downstream. Lastly the warehouse units moved again to the customer to meet customer demand completely and customer satisfaction achieved.

5.3.3 Scenario 3

In this scenario 3 research has considered multiple facilities. In this scenario research is trying to test model feasibility in terms of warehouse facility selection. It includes one supplier, supplier D, that has ranked on top among various suppliers. Similarly, the one large sorting facility is considered at central location. Furthermore, one central Repair and one landfill facility is considered. Customers are divided into three major markets. And three warehouses are considered to meet customer market demand cost effectively. A more clear and vivid picture of this flow is showed on map of Pakistan in figure 6.

Chapter 5 Table 42 Scenario 3 Number Facilities

Supplier	1
Sorting	1
Warehouse	3
Repair	1
Landfill	1
Customer Market	3



Chapter 5 Figure 6 Scenario 3 Facility Map

As there is one supplier the fixed costs of Supplier are 5,000 accommodating 500,000 units, respectively. The Sorting Centers has fixed cost of 100,000 while managing 300,000 units. The Repair Center, requires a substantial investment of 150,000, allowing repairs for 200,000 units. Finally, the Warehouse, the Small-sized one incurs a fixed cost of 100,000 units and has a capacity of 120,000 units. The Medium-sized Warehouse has a fixed cost of 200,000 units and a capacity of 200,000 units. Lastly, the Large-sized Warehouse has a fixed cost of 300,000 units and a capacity of 300,000 units.

Chapter 5 Table 43 Scenario 3 Facilities Fixed Cost and Capacities

		Fixed Cost			**Capacity (In Units)**	
	Small	Medium	Large	Small	Medium	Large
Supplier	×	×	5,000	×	×	500,000
Sorting Center	×	×	100,000	×	×	300,000
Repair Center	×	×	150,000	×	×	200,000
Warehouse	100,000	200,000	300,000	120,000	200,000	300,000

Variable costing involves the transfer of units through different locations before reaching the end customer. This process begins with suppliers, moves through sorting and repair facilities, warehouses, and finally to landfill sites where products are repaired, stored, and eventually dispatched to the customer market upon demand. Transporting goods from Supplier 1 to Sorting 1 incurs a cost of 22 units per item.

Table 44 illustrates transportation costs associated with sorting items to different destinations: Warehouse 1, Warehouse 2, Warehouse 3, Repair Center 1, and Landfill 1. Transportation cost from Sorting 1 to Warehouse 1 is 31. The cost of transporting from Sorting 1 to Warehouse 2 is 32. To transport from Sorting 1 to Warehouse 3, the cost is 34. There's a cost of 32 to transport items from Sorting 1 to Repair Center 1. Lastly, the cost of transporting from Sorting 1 to Landfill 1 is also 32.

Chapter 5 Table 44 Scenario 3 Transportation Cost: Sorting Cost to Warehouse/ Repair / Landfill

Transportation Cost Sorting to Warehouse/ Repair / Landfill					
	Repair 1	**Warehouse 1**	**Warehouse 2**	**Warehouse 3**	**Landfill 1**
Sorting 1	31	32	34	32	32

Table 45 outlines transportation costs incurred while moving items from a repair center to different destinations: Warehouse 1, Warehouse 2, Warehouse 3, and Landfill 1. The cost of transporting items from Repair 1 to Warehouse 1 is 35. The transportation cost from Repair 1 to Warehouse 2 is 36. There's a cost of 32 to move items from Repair 1 to Warehouse 3. Lastly, the cost of transporting items from Repair 1 to Landfill 1 is 31.

Chapter 5 Table 45 Scenario 3Transportation Cost: Repair to Warehouse & Landfill

Transportation Cost Repair to Warehouse & Landfill				
	Warehouse 1	**Warehouse 2**	**Warehouse 3**	**Landfill 1**
Repair 1	35	36	32	31

Table 46 illustrates the transportation costs associated with moving goods from various warehouses to different customer markets. To transport items from Warehouse 1 to Customer Market 1, the cost is 30. The cost of transporting to Customer Market 2 from Warehouse 1 is 39. For Customer Market 3, the transportation cost from Warehouse 1 is 32. From Warehouse 2 to Customer Market 1, the transportation cost is 39. To reach Customer Market 2 from Warehouse 2, the cost is 31. Transporting goods from Warehouse 2 to Customer Market 3 incurs a cost of 38. The cost of transportation from Warehouse 3 to Customer Market 1 is 34. To reach Customer Market 2 from Warehouse 3, the cost is 36. Product transported from Warehouse 3 to Customer Market 3 incurs a cost of 40.

Chapter 5 Table 46 Scenario 3 Transportation Cost: Warehouse to Customer Market

Transportation Cost Warehouse to Customer Market			
	Customer Market 1	**Customer Market 2**	**Customer Market 3**
Warehouse 1	30	39	32
Warehouse 2	39	31	38
Warehouse 3	34	36	40

Table 47 showcases reverse flow and transportation costs for moving goods from various customer markets (Customer Market 1, Customer Market 2, Customer Market 3) to Sorting center 1. The transportation cost from Customer Market 1 to Sorting 1 is 35. To transport items from Customer Market 2 to Sorting 1, the cost is 30. The cost of transporting from Customer Market 3 to Sorting 1 is 37.

Chapter 5 Table 47 Scenario 3 Transportation Cost: Customer Market to Sorting

	Sorting 1
Customer Market 1	35
Customer Market 2	30
Customer Market 3	37

Demand is from 3 customer markets, and it is considered known along with the return percentage from each customer market is considered known assuming E-commerce firm has enough data from market and can find these rates to manage the product flow in forward in reverse network.

Chapter 5 Table 48 Scenario 3 Customer Markets Demand and Return Rate

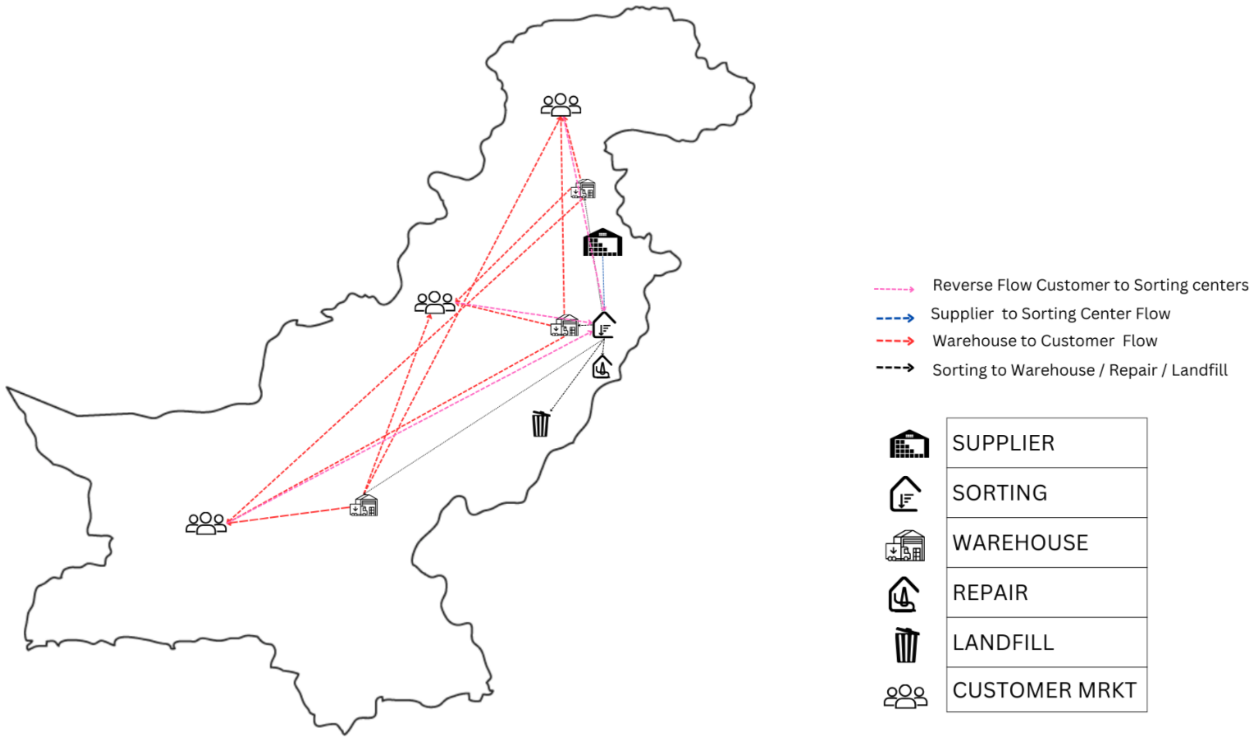
Market	**Demand**	**Return rate**
Customer Market 1	**50000**	20%
Customer Market 2	**60000**	
Customer Market 3	**100,000**	

5.3.3 Scenario 3: Results

In Scenario 3 selected facilities are Supplier 1 is selected, Sorting Center 2 is selected, Warehouses 1,2 and 3 are selected and repair center 1 is selected. as shown in table 49. Optimal Cost is 27,150,939.

Chapter 5 Table 49 Scenario 3Facilities Selection

Facilities Selection			
	1	2	3
Supplier	✓		
Sorting Center	✓		
Warehouse	✓	✓	✓
Repair Center		✓	



Chapter 5 Figure 7 Scenario 3 Selected Facility Map

The optimal unit flow in forward is from selected supplier 1 to sorting center is 212,121. Then units further forwarded to warehouse 1, warehouse 2, warehouse 3, repair 1 and landfill center 1. 120,000,60,000,10,909,19,091 and 2,121respectively as shown in table 50 and 58. Furthermore, the repair center must move forward repaired and landfill units downstream. So, units received from sorting centers are out of them 19,091units transported to warehouse 3.

Chapter 5 Table 50 Scenario 3 Supplier to Sorting Forward Flow

	Supplier 1
Sorting 1	212,121

Chapter 5 Table 51 Scenario 3 Sorting to Repair Warehouse & Landfill in Forward Flow & Repair to Warehouse and landfill Unit Flow

		Sorting Center
		1
Warehouse	**1**	120,000
	2	60,000
	3	10,909
Repair Center	**1**	19,091
landfill	**1**	2,121

	Warehouse			Landfill
Repair	1	2	3	1
1	×	×	19,091	×

Last in the forward flow markets unit moment is from warehouse to customer market to fulfill the demand for each customer market. Demand is fulfilled for each customer market through optimal unit moment for each warehouse. Table 52 shows the flow of units from warehouse to customer markets.

Chapter 5 Table 52 Scenario 3: Warehouse to Customer Forward Flow

	Warehouse 1	**Warehouse 2**	**Warehouse 3**
Customer Market			
1	**39091**	×	**10909**
2	×	**60000**	×
3	**80909**	×	**19091**

The model efficiently improved reverse logistics for scenario 3 by managing returns from customer markets to sorting centers. Sorting centers accepted returns from these markets, with Sorting Center 2 having sufficient capacity and lower processing costs. Consequently, the model directed all returned items from Customer Markets 1 and 2 to Sorting Center 2 for processing as shown in table 53.

Chapter 5 Table 53 Scenario 3: Return from customers to sorting.

	Sorting 1
Customer Market	
1	10,000
2	12,000
3	20,000

.

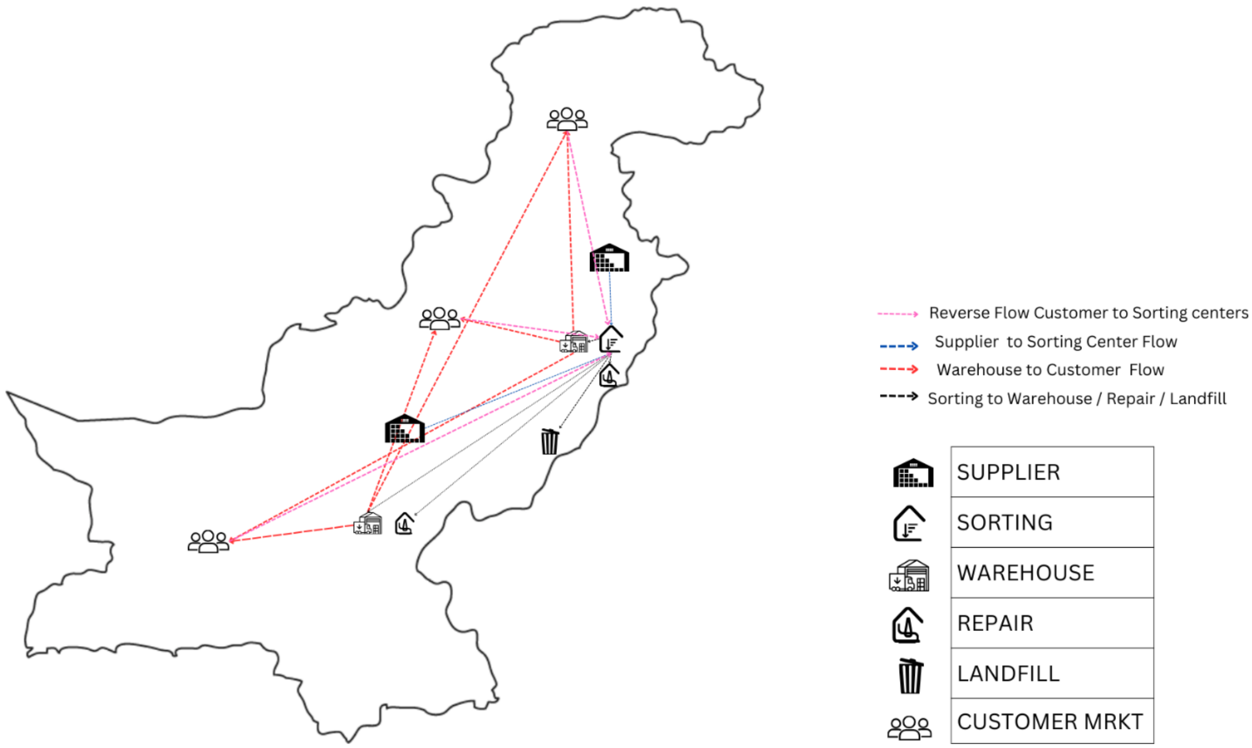
Furthermore, units sorted on the quality criteria and moved downstream. Lastly the warehouse units moved again to the customer to meet customer demand completely and customer satisfaction achieved.

5.3.4 Scenario 4

In scenario 4, research study has encompassed multiple facilities. This encompasses two suppliers. And there is one central sorting facility. Additionally, the consideration involves two warehouses, two repair facilities differ in size and situated at separate locations with distinct transportation costs, and one landfill facility. The customer base is segmented into three major markets.

Chapter 5 Table 54 Scenario 4 Number Facilities

Supplier	2
Sorting	1
Warehouse	2
Repair	2
Landfill	1
Customer market	3



Chapter 5 Figure 8 Scenario 4 Facility Map

The Supplier, comprising are of large and small scale, operates with capacities of 10,000 and 200,000 units while specific fixed costs are 100,000 and 150,000. The Sorting Center exhibits capacity of handling 200,000 units, with fixed costs of 300,000. The Repair Center operates with fixed costs of 100,000 for the small center and 150,000 for the large center, managing capacities of 50,000 and 100,000 units, respectively. Additionally, the Warehouse operates with capacities of 50,000 units for the small warehouse and 100,000 units for the large warehouse with fixed costs of 100,000 for the small center and 200,000 for the large center respectively.

Chapter 5 Table 55 Scenario 4 Facilities Fixed Cost and Capacities

	Fixed Cost		**Capacity (In Units)**	
	Small	**Large**	**Small**	**Large**
Supplier	100000	150,000	100000	200,000
Sorting Center	×	200000	×	300,000
Repair Center	100,000	150,000	50,000	100,000
Warehouse	100,000	150,000	100,000	200,000

Table 56 includes Transporting costs from Supplier 1 to Sorting 1 incurs a cost of 22 units, while the cost from Supplier 2 to Sorting 1 is 24. These specific unit costs represent the expenses associated with logistics between Supplier 1 and supplier 2 to the sorting locations.

Chapter 5 Table 56 Scenario 4 Transportation Cost: Supplier to Sorting Cost

	Supplier 1	Supplier 2
Sorting 1	23	24

Table 56 showcases transportation costs associated with moving items from Sorting 1 to various destinations including Repair 1, Repair 2), Warehouse 1, Warehouse 2 and a Landfill center. The transportation cost from Sorting 1 to Repair 1 is 24. For items transported from Sorting 1 to Repair 2, the cost is 26. The transportation cost from Sorting 1 to Warehouse 1 is 30 and Sorting 1 to Warehouse 2, the cost is 23. Lastly, the cost of transporting items from Sorting 1 to Landfill 1 is 25.

Chapter 5 Table 57 Scenario 4: Transportation Cost: Sorting Cost to Warehouse/ Repair / Landfill

Transportation Cost Sorting to Warehouse/ Repair / Landfill					
	Repair 1	Repair 2	Warehouse 1	Warehouse 2	Landfill 1
Sorting 1	24	26	30	23	25

For Repair 1, the transportation cost per unit to Warehouse 1, Warehouse 2, and Landfill 1 is 27, 21, and 25, respectively. Conversely, Repair 2 incurs costs of 30, 29, and 29 per unit when transporting materials to Warehouse 1, Warehouse 2, and Landfill 1. From Warehouse 1, the transportation cost per unit to Customer Market 1 and Customer Market 2 is 30 and 27, respectively. Meanwhile, materials transported from Warehouse 2 incur costs of 28 and 32 per unit when sent to Customer Market 1 and Customer Market 2, respectively.

Chapter 5 Table 58 Scenario 4: Transportation Cost: Repair to Warehouse & Landfill & Warehouse to Customer Market

Transportation Cost Repair to Warehouse & Landfill			
	Warehouse 1	Warehouse 2	Landfill 1
Repair 1	27	21	25
Repair 2	30	29	29

Transportation Cost Warehouse to Customer Market			
	Customer Market 1	**Customer Market 2**	**Customer Market 3**
Warehouse 1	20	21	22
Warehouse 2	22	24	25

When transporting materials in reverse flow from Customer Market 1, the cost per unit to Sorting 1 is 26. Similarly, materials transported from Customer Market 2 incur costs of 20 and 30 per unit when sent to Sorting 1. For scenario 4 Demand is from customer markets is considered known along with the return percentage from each customer market. Demand is considered 50,000 for each market with return percentage of 20%.

Chapter 5 Table 59 Scenario 4: Transportation Cost: Customer Market to Sorting

	Sorting 1
Customer Market 1	26
Customer Market 2	20
Customer Market 3	30

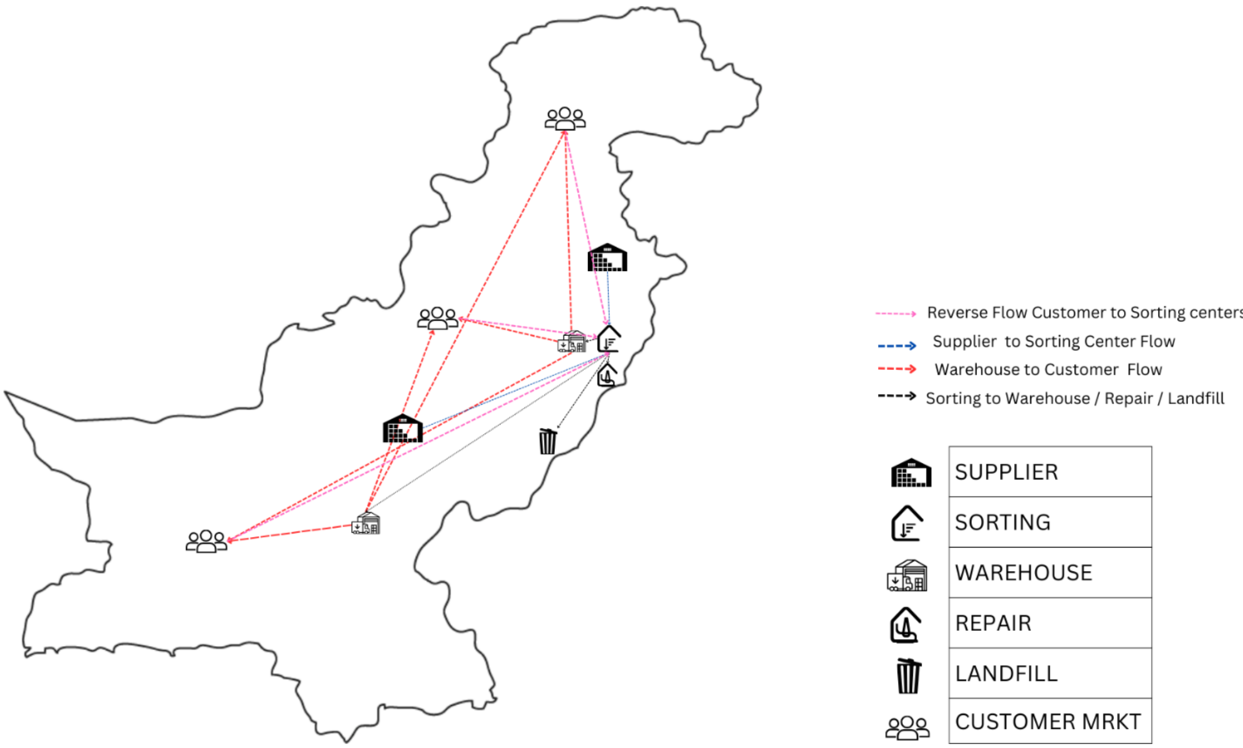
Market	Demand	Return rate
Customer Market 1	**50000**	20%
Customer Market 2	**50000**	
Customer Market 3	**50000**	

5.3.4 Scenario 4: Results

Using MS solver model is solved model and results provide optimal units flow in network and selected facilities that achieve low-cost objective. Supplier 1 is selected, Sorting Center 2 is selected, Warehouse 1 is selected and repair center 1 is selected. as shown in table 60. Optimal Cost is 13,828,632.

Chapter 5 Table 60 Scenario 4 Facilities Selection

Facilities Selection		
	1	2
Supplier	✓	✓
Sorting Center	✓	✓
Warehouse	✓	✓
Repair Center		✓



Chapter 5 Figure 9 Scenario 4 Selected Facility Map

The optimal unit flow in forward is from selected supplier 1 and 2 to sorting centers is 100,000 and 54737 respectively. Then units further forwarded to warehouse 1, Warehouse 2, repair 1 and landfill center 1 is 46,526, 90,000,13,474,4,737 respectively as shown in table 61. Furthermore, the repair center must move forward repaired and landfill units downstream. So, units received from sorting centers are out of them 5474 units transported to warehouse 1 while 8000 units sent to landfill center. Last in the forward flow markets unit moment is from warehouse to customer market to fulfill the demand for each customer market. Demand is fulfilled for each customer market through optimal unit moment for each warehouse. 50,000 units moved to customer market 1, 2 and 3 from warehouse 1 and 2 respectively.

Chapter 5 Table 61 Scenario 4 Forward Flow

	Supplier 1	Supplier 2
Sorting 1	100,000	54737

		Sorting 1
		1
Warehouse	**1**	46526
	2	90000
Repair Center	**1**	×
	2	13474
landfill	**1**	4737

	Warehouse		Landfill
Repair	1	2	1
1	×	×	×
2	5,474	8,000	×

	Warehouse 1	Warehouse 2
Customer Market		
1	×	50000
2	×	50000
3	46526	3474

To handle returns effectively, models effectively move returns from each customer market to sorting center to sort the returns and do the need to effectively recycle the return in effective way. Customer Markets 1 2 and 3 to Sorting Center for processing as shown in table 62. Lastly, units sorted on the quality criteria and moved downstream. Lastly the warehouse units moved again to the customer to meet customer demand completely and customer satisfaction achieved.

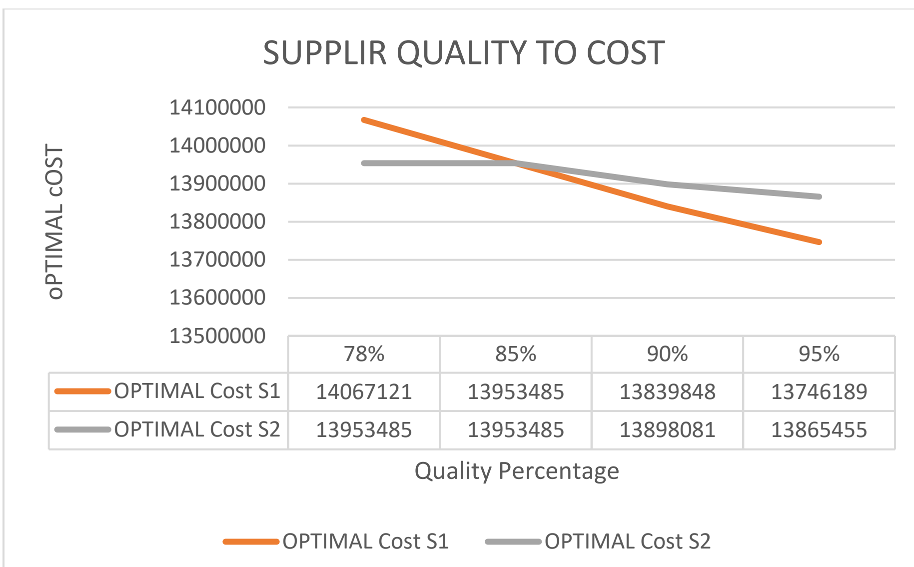
Chapter 5 Table 62 Return from customers to sorting.

	Sorting 2
Customer Market	
1	10000
2	10000
3	10000

5.4 Sensitivity Analysis

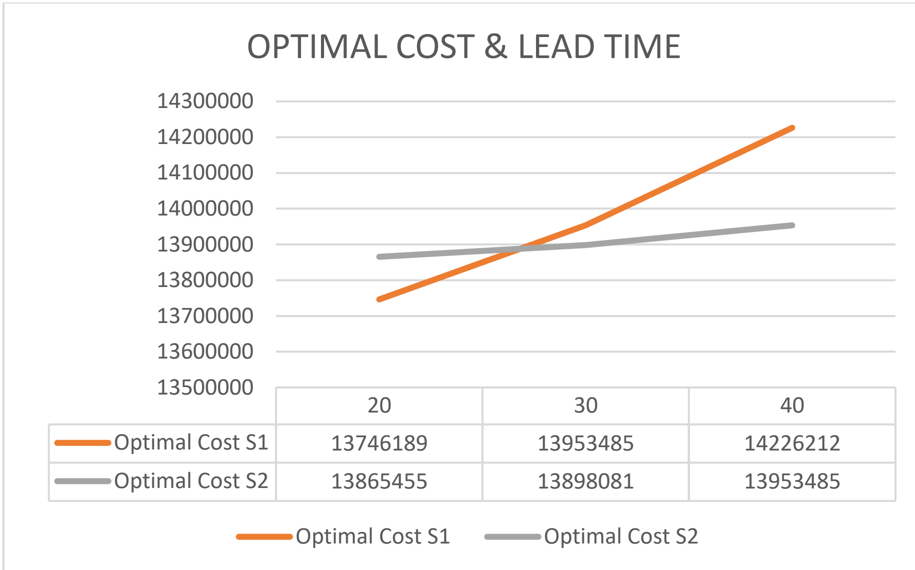
To expand the understanding of how parameters affect cost minimization, this research conducted sensitivity analysis. This analysis aimed to assess the overall impact on the model when altering the quality, cost and return rate and sensitivity to them. A comprehensive examination of sensitivity was carried out for each scenario within this section.

Quality to cost relationship. Optimal cost is sensitive to Quality of supplier 1 as it is preferred and has higher rank in overall weightage. Higher volumes are assigned to supplier 1 while lower volume to supplier 2 that's why optimal is less sensitive to quality of supplier 2. This provides insights that influence decision making while choosing the right supplier and minimize supply chain costs at the most optimal level. As shown in graphs 1. Also graph 2 presents a result that shows preferred supplier is sensitive to the lead time as well. Changing the lead time of supplier 1 makes a visible increase in the optimal cost graph while optimal cost is less sensitive to change in the lead time of supplier 2 as its weightage is lower than supplier 1 and ranked less than supplier 1.



	78%	85%	90%	95%
OPTIMAL Cost S1	14067121	13953485	13839848	13746189
OPTIMAL Cost S2	13953485	13953485	13898081	13865455

Chapter 5 Figure 10 Sensitivity Analysis: Supplier Quality to Cost



Chapter 5 Figure 11 Sensitivity Analysis Optimal Cost & Lead

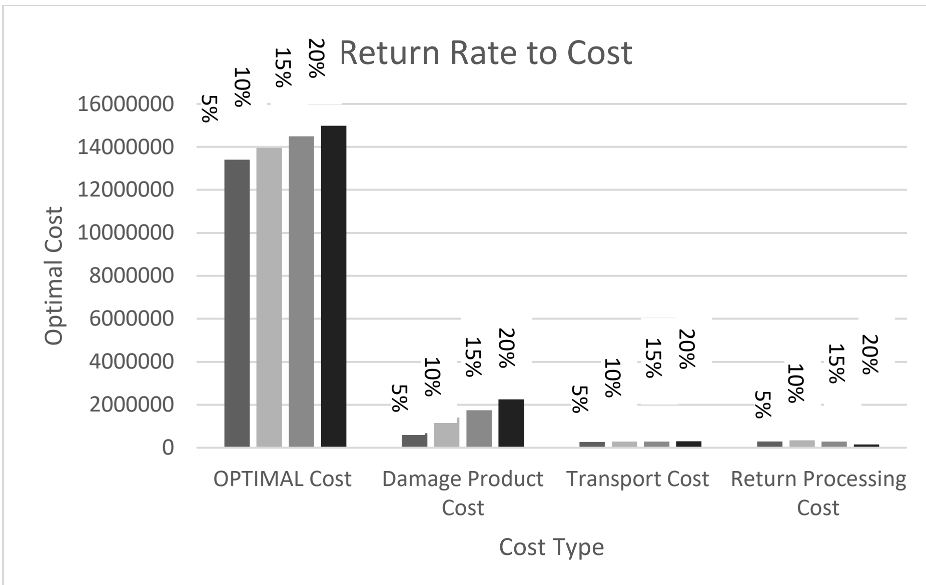
Moreover, the impact of return rates on optimal costs extends beyond the direct expenses associated with processing products, transportation, and damages. The intricate cost breakdown analysis, as depicted in graph 3, unravels nuanced insights into the dynamics of optimal costs with varying return rates.

Graph 3 clearly illustrates the sensitivity of overall optimal costs to changes in the return rate. As the return rate escalates, the optimal costs exhibit a corresponding increase. This upward trend is particularly pronounced in the context of damage costs, which rise in tandem with the surge in return rates. This correlation suggests that a higher return rate may be attributed to an influx of lower-quality and damaged products, necessitating additional expenses for rectification.

Simultaneously, the rise in return rates leads to an escalation in transportation costs. Interestingly, this increase occurs at a constant rate, indicating that transportation costs are less susceptible to fluctuations in return rates. The steady rise in transportation costs underlines the consistency of this factor in the overall cost structure.

Contrastingly, the analysis reveals a counterintuitive trend in return processing costs. As the return rate climbs, the per-unit return processing costs decrease. This phenomenon is attributed to the realization of economies of scale, wherein the efficiency of processing returns improves with a higher volume of returns. Consequently, the cost per unit decreases, mitigating the impact of increased return rates on this specific aspect of the overall costs.

In essence, the comprehensive examination of optimal costs in relation to return rates portrays a multifaceted scenario. While damage and transportation costs exhibit positive correlations with rising return rates, the return processing costs display a mitigating effect due to economies of scale. Collectively, these findings underscore the intricate interplay between return rates and optimal costs, providing valuable insights for strategic decision-making in supply chain management.



Chapter 5 Figure 12 Sensitivity Analysis Return Rate to Cost

Chapter 6: Conclusion and Managerial implications

Optimizing an e-commerce firm's operations when dealing with textile leftovers involves a multifaceted problem. This novel two stage decision framework has various managerial implications. Optimizing the decision-making process regarding refurbishment or disposal based on quality assessments reduces waste and increases the potential for resale. Practically this model helps businesses to sustainably manage their ecosystem in ways that creates a win-win situation for all stakeholders. The combination of both forward and reverse logistics enhances decision-making capabilities to look at broader picture while facility selection. Strategically locating facilities, considering factors like supplier proximity, transportation routes results in Operational Efficiency. Along with this Running scenarios aids in comparing different options, such as facility locations or technological investments, allowing managers to identify the most cost-effective strategies while maintaining operational efficiency. In addition to these Simulating variations in demand assists in optimal resource allocation across sorting centers, repair facilities, and warehouses, preventing excess capacity or shortages, thereby improving operational efficiency. Most importantly, the flexibility of framework allows decision makers to make informed decisions for market expansion considering customer demand, competitive landscape, and resource requirements, facilitating strategic growth. Finally, Regular scenario running promotes adaptability, enabling managers to make agile decisions based on changing market dynamics, fostering continuous improvement in supply chain operations.

In conclusion this research bridge existing research gaps, introduces a groundbreaking model that integrates forward and reverse flows in e-commerce while incorporating textile leftovers as the primary input from carefully selected suppliers. The use of the AHP decision-making technique and the development of a mixed-integer linear programming model provide a comprehensive decision support framework to the E-commerce industry. A scenario-based analysis demonstrates the practical application of this innovative model, promising to advance the understanding of e-commerce textile leftover supply chains and their sustainable management. This research underscores the dynamic nature of e-commerce and the need for continuous innovation and adaptation in the face of evolving challenges and opportunities. The findings and insights presented in this paper contribute to our collective knowledge and provide valuable guidance for e-commerce companies looking to enhance their supply chain practices and sustainability efforts especially in utilizing Textile leftovers as primary input. This pioneering study offers significant managerial implications for Supply Chain Managers and online retailing company leadership. It introduces an integrated network design tailored to the unique demands of e-commerce textile leftover management, providing managers with a customizable model to optimize their supply chains by aligning objectives with their specific needs. Implementation of this approach holds the promise of substantial environmental benefits through waste reduction. The provided scenario analysis serves as a practical guide for effectively utilizing facility selection into business operations, enabling managers to simultaneously enhance supply chain efficiency and contribute to a more sustainable and eco-friendlier operational framework.

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