Project Dissertation Report on

Enhancing Circular Economy Practices in Supply Chains through AHP-based Decision Support Systems and Multi-objective Optimization

Submitted by:

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C E R T I F I C A T E

This is to certify that **Mr Prateek Diwan** has satisfactorily completed the project titled **" Enhancing Circular Economy Practices in Supply Chains through AHP-based Decision Support Systems and Multi-objective Optimization",** under the guidance of Dr Vikas Gupta as a part of Master of BusinessAdministration (MBA) curriculum of Delhi School of Management, New Delhi. This is an original piece of work and has not been submitted elsewhere.

Dr Vikas Gupta

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DECLARATION

I, **PRATEEK DIWAN** student Executive M.B.A Delhi School of Management, Delhi Technological University, Bawana Road, Delhi-42 hereby declare that the Project Report on "Enhancing Circular Economy Practices in Supply Chains through AHP-based Decision Support Systems and Multi-objective Optimization" has been result of my own work and has been carried out under supervision of **Dr Vikas Gupta.**

I declare that this submitted work is done solely by me and to the best of my knowledge.

I also declare that all the information collected from various secondary sources has been duly acknowledged in this project report.

PLACE: New Delhi
DATE: 02/05/2024

Dr Vikas Gupta

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Prateek Diwan

Executive Summary

Supply chain management plays a vital role in business processes and economic performance. The supply chain management ensures continuous operation of supply and demand cycles in the business operation and aims to maximize the profitability and customersatisfaction for the firm. However, the industries in both developing and developed nations are currently facing increasing pressure to consider environmental aspects in managing theirbusiness operations because of the increased awareness of environmental issues worldwide. Thus, the increasing environmental concerns particularly carbon emissions, environmental degradation and climate change are putting increasing onus on the industries to be more sensitive to environmental issues and adopt advanced technologies and proactive environmentally friendly business operations and strategies. The other major emerging concern in supply chain process is regarding how to deal with the disruptions resulting from natural disasters such as cyclones, floods, earthquakes, tsunamic, etc., pandemic situations like covid-19, and war scenarios as they affect the supply chain process badly and it may bring sometimes even breakdown. These situations are highly unpredictable and cause large uncertainties and disruptions that affect the business and economy severely. These disruptions and environmental impacts may be long lasting and global and may even sweep across all industries. Thus, it becomes essentially imperative to develop strategic models for the integrated planning and management that also accounts such challenging issues of environment and disruptions and are not targeted only on the profitability and customer satisfaction.

The literature review reveals that there are very limited studies and business models that efficiently guide the supply chain process how to respond to environmental concerns and disruptions for the success and sustainability of business. Globalization has already increased the challenges of supply chains and the decision-making in emerging scenarios of environment and disruptions has become very complex involving multi-faceted criteria and

goals. Keeping the above viewpoints, the present study is aimed to develop a resilient green supply chain model using AHP and multi-objective optimization that accounts the drivers and barriers of environmental and disruptions aspects besides the profitability and customer satisfaction in the overall framework of supply chain management. The study includes empirical evaluation, model development, case study and model application to a pilot demonstrative study through numerical analysis and interpretation. The study is important to find out the strategic enablers which can be taken up by an organization related to environmental aspects and supply chain disruptions to ensure future readiness and sustainable development of the organization. Thus, such a model will ensure to remain competitive by reducing manufacturing and operational cost as well as enhancing environmental performance, reliability, customer satisfaction, societal acceptance, and overall profit.

CONTENT

CHAPTER 1

INTRODUCTION

1.1 Context

Supply chain is essential for small and large economies to ensure smooth flow of goods. By carefully planning and controlling these flows, companies are more profitable and managed by supply chain management (SCM) focused on customer satisfaction. As concerns about the environment and climate change grow, all types of businesses are taking a more active role in reducing their impact on the environment. This environmentally friendly company adopts practices to prevent pollution, reduce waste, facilitate recycling, save energy, reuse materials, find spare parts, and reduce carbon and water emissions.

Manufacturing firms frequently procure identical raw materials or components from various suppliers, each with distinct economic, production capacity, reliability, and risk characteristics. Hence, it's crucial for manufacturers to assess the environmental commitments and accountability of these suppliers, as they can significantly influence the sustainability and environmental strategies of the entire supply chain. These considerations underscore the significance and pertinence of Green Supply Chain Management (GSCM).

GSCM endeavors to tackle both operational and environmental facets within the supply chain by merging logistics and financial data. This integration aims to harmonize all supply chain stages, enhancing product or service competitiveness. Such an approach advocates for sustainable development, leading to improved environmental and economic results.

Recent global events, particularly the COVID-19 pandemic, have highlighted the vulnerability of supply chains to disruption. Natural disasters such as floods, hurricanes, earthquakes, tsunamis, and climate change, as well as man-made events such as the Russia-Ukraine war and the blockage of the Suez Canal, cause significant instability in the supply chain. Since critical suppliers are often irreplaceable, such disruptions can have a serious impact on a company's survival, sustainability and growth, leading to significant profit losses. For example, the study by Simchi-Levi et al. (2014) and Hosseini et al. (2019) highlight the severe impact of supply chain disruptions .

Given the unpredictability, complexity and inherent challenges of supply chain disruptions, choosing the right vendor has become critical. As global supply chains grow and become more complex, things are more likely to go wrong. This could be due to problems with suppliers, unforeseen events, or companies moving production overseas. That's why it's more important than ever to choose your vendor carefully. Supply chain disruptions can have a major impact on many businesses. It is very important to make a careful decision when choosing a vendor.

Choosing a vendor or supplier is a multifaceted decision-making process that includes countless tangible and intangible factors. Because cost reduction, environmental protection and bottleneck avoidance are important, this research creates a new way to choose suppliers. This approach makes it ideal for a flexible and flexible supply chain, taking into account unexpected problems and environmental impacts. By implementing such a model, organizations can develop optimal sourcing strategies, simplify various components of the supply chain, and strengthen themselves for future challenges.

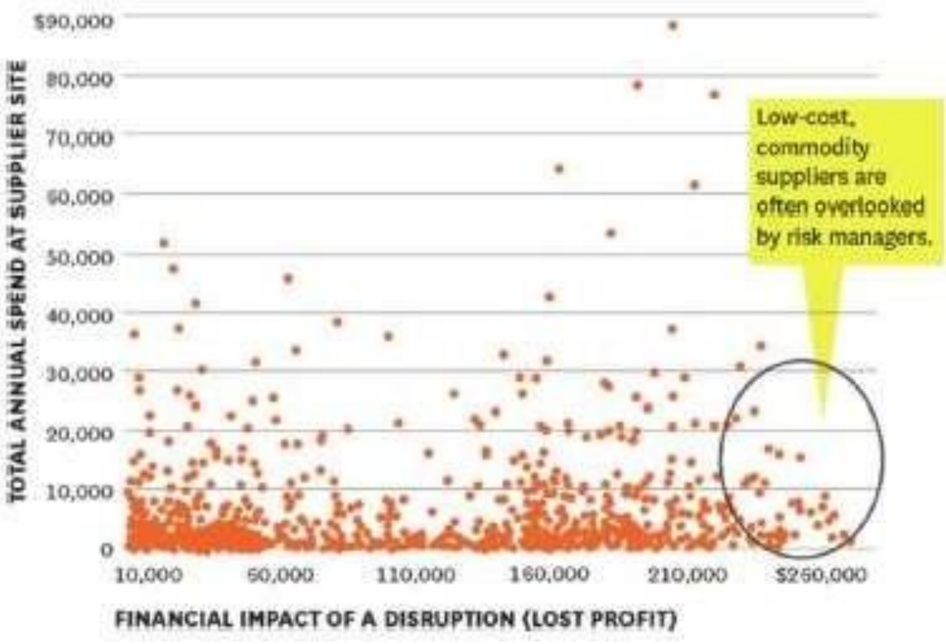

Fig. 1.1 Impact of supplier disruption on profit of Ford company (Simchi-Levi et al. 2015)

1.2 Problem Statement

This study focuses on addressing environmental issues and disruptions at different stages of the supply chain, including purchasing, supplier selection, negotiation, design collaboration, sourcing, and resource analysis. With increasing environmental concerns and frequent disruptions, the process of vendor selection and order allocation is becoming increasingly complex. These factors have a significant impact on business operations, productivity and profitability.

To thrive in today's dynamic business environment, companies must prioritize environmental initiatives, resilience to disruptions, and long-term sustainability within their supply chain strategies. Disruptions and environmental concerns are no longer isolated issues, but inherent challenges faced by local, regional, and global supply chains. These factors can have complex and unforeseen consequences, impacting everything from production to customer satisfaction.

In this context, selecting the right suppliers for materials has become a critical decision. The rise of globalized supply chains, coupled with frequent disruptions, fluctuating supplier performance, and strategic outsourcing strategies, creates a rapidly evolving and uncertain operational landscape. Companies must carefully evaluate their vendors to ensure they can navigate these complexities.

1.3 Scope of Study

Traditional supply chain management often prioritizes cost and speed of delivery. This research aims to go beyond that by developing a new mathematical model for vendor selection and purchase order allocation. This model incorporates established factors as well as new criteria such as environmental impacts and resilience to disturbance.

The complexity of these multi-criteria decisions requires a multi-objective optimization approach. This "Flexible Green Supply Chain Management" model identifies the best vendors, optimizes procurement strategies and contributes to efficiency throughout the supply chain.

The research includes a pilot program using real-world data analysis, model development, case studies, and numerical analysis. By considering both environmental concerns and potential disruptions, this approach helps companies find ways to be more sustainable and successful in the long run.

1.4 Aim & Objectives of Study

This project addresses the important challenge of creating more sustainable and flexible supply chains. Our goal is to develop a development model that goes beyond traditional approaches that focus solely on profit and customer satisfaction. This new model integrates environmental concerns and potential disruptions into the decision-making process.

To achieve this goal, we design and implement a decision support system. This system combines Analytic Hierarchy Process (AHP) and multi-objective optimization techniques. Result? It is a powerful tool that enables companies to make informed choices that not only benefit them, but also promote circular economy practices in their supply chains.

This study addresses several key areas to achieve more flexible and sustainable supply chains.

• Vulnerability Identification: Identify the parts of your supply chain that are most susceptible to disruption and environmental impacts.

• Mapping the Context: Explore the factors that drive or hinder green initiatives and a company's ability to withstand disruptions throughout the supply chain. This analysis also identifies key factors influencing circular economy practices.

• Optimize for Success: Integrate multi-objective optimization techniques to streamline supply chain operations while maximizing the effectiveness of circular economy practices.

• Choosing eco-friendly and reliable suppliers: This step uses a method called AHP (Analytical Hierarchy Process) to figure out how important different green and disruption-resistant factors are. This helps create a clear decision-making model that prioritizes these factors based on their significance.

• Building the model: Finally, we develop a complex mathematical model that's specifically designed for flexible and sustainable supply chains. This model takes into account both environmental limitations and potential disruptions for a more well-rounded approach.

CHAPTER 2

LITERATURE REVIEW

This chapter explores the important role of research in three areas of supply chain change: green sourcing, resilience strategies to disruptions, and the use of optimization techniques. These areas are critical to addressing emerging challenges that can significantly impact business operations and growth.

This chapter addresses existing research through a focused literature review and considers two main issues:

Environment and Disruptors:- Explore how environmental concerns and potential disruptions affect supply chains and how research addresses these challenges.

Resource Management Optimization:- This section reviews research on the use of multi-objective optimization techniques for resource management in supply chains to improve efficiency and sustainability.

The chapter concludes by identifying the limitations of current research and outlining potential areas for future research. This discovery paves the way for the development of a stronger and more sustainable supply chain.

2.1 Research on Environmental Factors and Supply Chain Disruptions

Walker conducted surveys and interviews in the private and public sectors to investigate the factors influencing the adoption of green supply management. Their findings revealed internal and external barriers to implementation.

Shaw et al. (2012) proposed an integrated approach that integrates fuzzy theory, AHP and multi-objective linear programming for supplier selection. They demonstrated the effectiveness of their model in handling fuzzy information using real-world data.

Apolloni et al. (2014) conducted an extensive systematic literature review to scrutinize contemporary research on green procurement. They reviewed 86 research publications from 1996 to 2013 and classified them into five groups, as shown in Figure 2.1. Looking at the research done so far, it seems that most of the research relies on surveys to collect data. This suggests that more research is needed to build a mathematical model to analyze the supply chain. A 2014 study looked specifically at green procurement in private companies. They establish a framework for future research based on real-world data and identify important areas for further research.Their analysis included motivations, drivers, and barriers to green procurement adoption, along with an assessment of the performance impact of adopting green procurement practices.

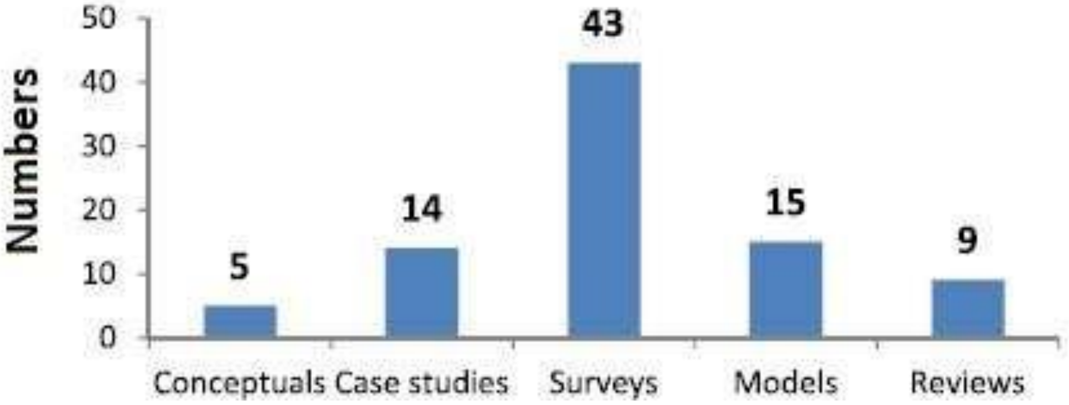

Fig. 2.1 Research methods used by different researchers in green procurement (adapted from Apolloni et al. 2014)

Researchers such as Hamdan and Chito (2017) proposed innovative decision-making tools for supplier selection. Their model combines fuzzy TOPSIS and AHP techniques to identify the optimal supplier considering various criteria and preferences. This approach goes beyond simple cost considerations and integrates optimization to solve the complex problem of supplier allocation.

As green procurement gains attention, Lau et al. (2018) highlighted gaps in research. According to their analysis, most studies focus on the use of green criteria for supplier selection, but few examine green evaluation and order allocation in detail. This suggests opportunities for further research to fill this gap.

Disruption management is another important aspect of the supply chain. Hosseini et al. (2019) developed a model that addresses this challenge. Their approach involves calculating the probability of disruption and its impact on supplier performance. This probabilistic model is based on stochastic mixed integer programming and provides valuable insights for developing strategies to mitigate disruptions and ensure supply chain resilience.

2.2 Application of multi-objective optimization method in resource management

In the real world, we often confuse different needs and perspectives, making it difficult to determine a perfect answer. This is particularly common in resource management, where environmental health can conflict with economic and practical goals. This is where multi-objective optimization comes into play.

Multi-objective optimization is a powerful tool for dealing with problems with competing objectives. Imagine that instead of a single "best" answer, there is a set of good options that balance different priorities. Researchers such as Keshari and Datta (1996) have developed models that can address these situations. These models consider several factors including environmental effects along with other limitations.

The key idea is to find the "sweet spot" - a solution that balances all goals. These "sweet spots," called Pareto-optimal or indifference solutions, involve trade-offs. While there is no perfect answer, these models can help identify the best compromise that takes into account all important aspects.

Let's take a look at how multi-objective optimization solves real-world challenges. Take, for example, water resource management. Chengani's (2017) model considers the needs of farmers, businesses and cities. Evaluate different water management strategies, adjusting for social, economic and environmental factors. The flexibility to consider different priorities allows decision makers to find sustainable solutions.

This field is always evolving! Zhang et al. (2019) proposed a new method, MOF-DE, which combines existing algorithms to find a better solution. This method improves how well the algorithm can explore possibilities (convergence) while preserving the variety of solutions (diversity). Similarly, Sharma and Sharma (2020) introduced a hybrid approach that combines genetic algorithms and pattern search. Their work shows that this method can provide a wider range of potential solutions (more diverse Pareto optimal solutions) while finding a better compromise (more convergence).

Deb and Gupta (2020) proposed a decomposition-based multi-objective optimization (ODMOO) method, which uses a decomposition-based approach to decompose a multi-objective optimization problem into a set of single-objective subproblems. This method provides a variety of Pareto optimal solutions by optimizing this subproblem. Chan et al. (2021) introduced multi-objective optimization with orthogonal decomposition (MOOD), where the multi-objective optimization problem is divided into orthogonal subproblems, all of which are solved simultaneously to obtain a Pareto front.

2.2 Concluding Remarks

Green supply chain management (GSCM) is an approach that balances environmental and social responsibility with economic viability. This movement has gained more momentum due to consumers' concern about the environmental effects of the way products are produced and delivered.

More and more companies are going green! Green supply chain management (GSCM), also known as sustainable supply chain management, is all about reducing the environmental and social impact of manufacturing and delivering products. This means focusing on practices that do not harm the environment for future generations.

Green logistics focuses on making transport, containers and fleets more environmentally friendly. That means finding ways to reduce shipping pollution, such as reducing how often containers are moved and how much space is available on cargo ships. For this reason, logistics companies are looking for ways to use carriers that produce less carbon dioxide (CO_2). Manufacturing and transportation are the biggest contributors to CO_2 emissions, but packaging is another challenge. Packaging protects products during shipping and storage, but most are thrown away after one use. This creates challenges for everyone involved in the supply chain—suppliers, logistics companies, and even the consumers who use the product. They all need to work together to find ways to responsibly reuse, recycle or dispose of packaging.

Green supply chain management (GSCM) comes from your company. This covers all suppliers from manufacturing raw materials to finished products to you, including packaging and even taking back old products. GSCM can benefit your company, the environment, and society at large by using recyclable materials, finding the best ways to recycle, reducing waste and pollution, and working closely with suppliers. Focusing on the environment is not only good for the planet, but also for business! Companies rely on green sourcing strategies to achieve a truly sustainable supply chain. This means choosing environmentally friendly and efficient suppliers (Appoloni et al., 2014).

Supply chain management is always a balancing act, but unexpected events like a pandemic can throw everything into chaos. These disruptions can create a mismatch between demand and supply, which can have a negative impact on jobs and the economy as a whole.

What makes this situation particularly difficult is the uncertainty. It is difficult to predict what will happen and decision-making has become complex and multifaceted (Hosseini et al., 2019). Disruptions can affect production, business growth, and even the national and social economy.

So how can businesses prepare for the unexpected?

Identify vulnerabilities: Identify which parts of your supply chain are most likely to be affected by disruption.

Anticipate and identify risks: Proactively identify potential issues and assess how they impact your business.

Develop a response plan: Develop a plan to respond quickly and effectively to disruptions. This may include having back-up suppliers or diversifying your shipping options.

Build resilience: The goal is to create supply chains that can adapt and recover from disruptions.

By taking these steps, companies can build more resilient supply chains that can withstand even the most unpredictable storms. This not only helps businesses survive, but also helps maintain economic stability.

Although green sourcing and risk mitigation are both important to a strong supply chain, current practices often treat them as separate issues (Hamadan and Chito, 2017). This creates a gap. Companies need better decision-making tools that take environmental and risk risks into consideration when selecting suppliers and assigning orders, along with cost optimization.

The current lack of integrated business models that address both environmental concerns and potential disruptions is a major barrier to supply chain success and sustainability. Globalization has only increased these challenges and made decision making in these complex scenarios even more important. We need to move toward a system that addresses multiple goals simultaneously: environmental responsibility, readiness for disruption, and affordability.

Simply put, companies must find ways to green their supply chains while preparing for unexpected challenges. This requires better tools and a more integrated approach to decision making.

Based on previous research, this study develops a new model for green supply chain. This model uses two powerful tools: AHP (Analytic Hierarchy Process) and multi-objective optimization. Consider positive forces (drivers) and negative forces (restraints) that can affect the environment and cause problems. But it doesn't stop there! This model also considers the importance of profitability and customer satisfaction in supply chain management. By using this model, companies can gain a competitive advantage. In addition, it can help reduce production and operating costs while increasing environmental responsibility, reliability, customer happiness and social awareness.

Green supply chain management (GSCM) is inspired by the circular economy to address environmental issues such as pollution, waste and climate change. This approach aims to reduce waste and pollution throughout the supply chain, from the procurement of raw materials to the delivery of the final product. It also considers how the product can be reused or recycled at the end of its life, helping to restore the environment. Companies use this principle when choosing suppliers and determining who receives their orders. This approach helps reduce emissions and resource use, encourages innovation in environmentally friendly technologies, and makes the entire supply chain more sustainable – both the environment and the company's bottom line!

CHAPTER 3

METHODOLOGY

This study explores how to create an agile and sustainable supply chain. To achieve this, we do three things:

Industry Studies: We study how different companies run their supply chains.

Build a powerful model: We create a complex mathematical model that takes into account various factors and helps you find the best solution.

Testing the model: We apply the model to real-world examples to see how it works in practice. This approach uses calculations to find the ideal balance between different goals, such as profit and environmental impact. It also helps companies to adapt to changing conditions and become more flexible. Figure 3.1 shows the flow diagram of the method used in this study. The various elements of this method, shown in the figure, are discussed in the next section.

3.1 Recognizing Disruptive Elements and Risks in Supply Chain

A clear survey can help pinpoint weaknesses in your supply chain that could cause problems during everyday operations. It can also show how these issues might affect your company's profits and finances.This approach provides a mathematical framework for empirically examining supply chain risks and evaluating the impact of various risks arising from disruptions. An extensive literature review was conducted to identify the characteristics needed to formulate questions for systematic research on supply chain risks, particularly risks arising from pandemics. Reviewing several sources, Van Hoek (2021) suggested a four-part questionnaire structure: types of supply chain risks, drivers, management methods and responses.

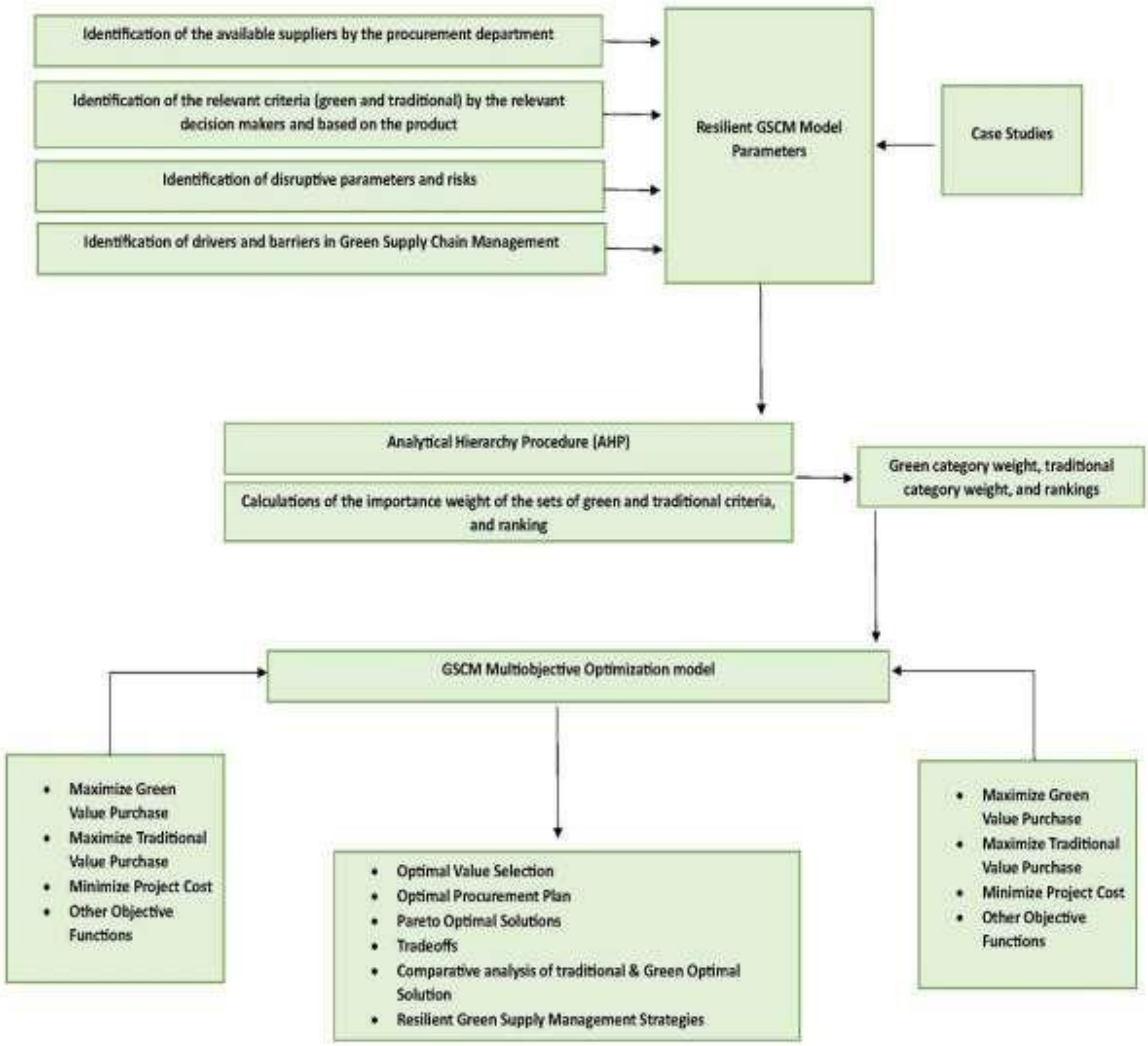

Fig 3.1 Schematic of the Methodology Applied in This Research

Building on our discussion of time horizons, the questionnaire can explore how companies adjust their risk management responses based on the timeframe of the threat (short-term, medium-term, long-term).These answers will help develop dynamic and sustainable risk mitigation strategies and recovery strategies that are appropriate for each time frame. The survey should target a diverse group of supply chain managers in different geographic locations and include manufacturing, logistics, service, and retail. It should also consider companies of different sizes, as risk factors and responses can vary significantly depending on the size of the industry.The primary research should prioritize exploration and discovery over in-depth statistical analysis. Table 3.1 provides a sample data structure for gathering company profile information relevant to developing a supply chain resilience framework.

Table 3.1 Layout for Company Profile Data

Characteristic	Comp N1	Comp N2	Comp N3	… Comp Nn .
• Company type	I	I	I	I
• Geographical location	I	I	I	I
• Company size	I	I	I	I
• Position within the supply chain	I	I	I	I
• Transportation connections	I	I	I	I

In this context, it refers to the nature of the business, which may include manufacturing, manufacturing, logistics services, software, pharmaceuticals, beverages or FMCG. Geography indicates where the company is located and the size of the company classifies it as small, medium or large. Supply chain roles include various functions such as manufacturers, distributors, retailers, logistics providers or e-commerce organizations.The transport aspect assesses the quality of the transport infrastructure at the location of the company, assessing connectivity through various modes such as air, rail and road, which can be characterized as low, medium, high or very high quality. These attributes are essential to the company's supply chain operations.

Table 3.2 shows the structured questionnaire used to gather the views of various stakeholders in the supply chain and wider business processes. This standardized approach facilitates data collection during the study, ultimately facilitating the development of a supply chain sustainability framework that can address disruptive events.Table 3.3 breaks down the companies into categories and provides detailed information for the questionnaire. The risks identified for different supply chain components are presented in Table 3.4 as supply chain risks. This data is then analyzed to identify risks and develop strategic actions aimed at improving supply chain sustainability.

Table 3.2: Typical questionnaire framework for supply chain risk assessment

S.NO	Questionnaire
1	Have you noticed any disruptions affecting your company's supply chain? If so, how were they experienced and what was the nature of their impact?
2	What obstacles has your company faced in its supply chain?
3	What factors are causing your company's supply chain risks to emerge? Please indicate the risk drivers of SCM?
4	What risk management strategies are in place to address potential issues?
5	Did you contemplate making adjustments to the supply base as part of your risk mitigation strategy?
6	If adjustments are being made to the supply base, could you please elaborate on the specific measures being taken?
7	To strengthen supply chain resilience, what specific actions did your company take to diversify its sourcing strategy?
8	Did your company adjust inventory levels in response to the pandemic? If so, how did you determine the changes made to your inventory buffers?
9	Did your company augment inventory buffers? If so, by what percentage was the increase?
10	Describe your company's current approach to collaboration with supply vendors. How does your procurement team contribute to these interactions?
11	What specific actions did your company take to diversify its supply base and mitigate risks? This could include implementing multiple sourcing strategies, local sourcing, or reducing reliance on single vendors.
12	Did your company adjust inventory levels in response to the pandemic? If so, by what percentage or how did you determine the changes?

14	With the lessons learned from the disruption, what are some potential changes your company might explore to strengthen the supply chain?
15	Has there been a recent change in how long it takes to deliver products to your customers?
16	With recent cost increases, has your company implemented any strategies to optimize procurement or streamline delivery processes?
17	What challenges did you encounter in these areas, and how did your procurement and delivery strategies help you overcome them?
18	Did your company experience any difficulties with transporting materials during disruptions or restrictions?
19	Is your company currently facing any supply shortages that are impacting your production or product development activities?
20	Have you experienced any recent challenges with staffing levels or skill gaps within your company?

Table 3.3 : Compiling company profile

Industry :	Production	Consulting	Contracting	Other
Industry Magnitude:	Small	Medium	Large	Very Large
Sector Operations:	International	InterState	National	Locally

Table 3.4: Supply Chain Risk Management Matrix

	No Risk	Low Risk	Medium Risk	High Risk
Supply Risk	X	X	X	X
Demand Risk	X	X	X	X
Manufacturing Risk	X	X	X	X
Transportation Risk	X	X	X	X
Environmental Risk	X	X	X	X
Health Risk	X	X	X	X
Safety Risk	X	X	X	X
Financial Risk	X	X	X	X

3.2 Identifying Facilitators and Barriers to Global Supply Chain Management (GSCM)

A conceptual framework for Green Supply Chain Management (GSCM) is shown in Figure 3.2. The framework identifies various catalysts, rules and performance indicators that influence sustainable practices throughout the supply chain.With the increase in environmental legislation, mandate and awareness, GSCM has gained significant recognition for promoting sustainable organizational development. This focus stems from globalization, cross-border trade, increased complexity, and demands for increased transparency and corporate accountability. Finally, businesses must adopt a GSCM strategy to address market dynamics and demonstrate social responsibility, thus differentiating themselves in their respective industries. Factors affecting green procurement activities and supply chain performance include internal drivers such as organizational dynamics and external drivers including regulatory frameworks, customers, suppliers, competitors and societal influences. These aspects will be explored in detail below sections.

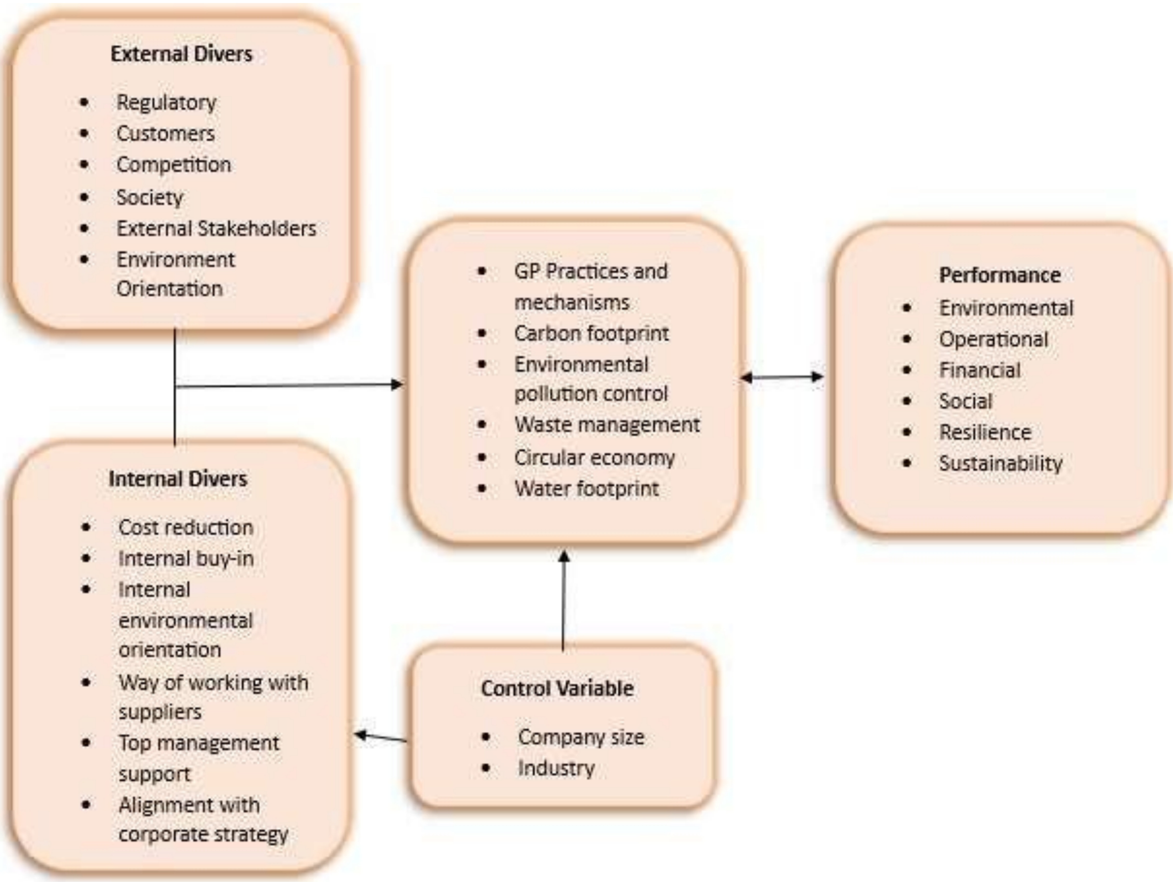

Fig. 3.2 A conceptual model of GSCM (Source from Apolloni et al., version 2014)

3.2.1 Key Factors in Global Supply Chain Management

1. Internal Drivers

(i) Organizational parameters:

Management's personal and ethical values have a significant impact on a company's green supply chain practices. Middle management support is equally important, especially in environmental purchasing. Employee involvement is essential to achieving operational and environmental improvements and highlights the importance of middle management commitment to effective green supply chain management. Cost reduction strategies can lead to a more ecological supply chain. Environmental pollution adds hidden costs throughout the product's life cycle, from raw material extraction to disposal. By implementing pollution prevention strategies such as material replacement and closed-loop processes, companies can save costs, eliminate waste, and even improve product quality.

2. External Drivers

(i) Legal provisions:

Government laws and regulations create a lot of incentive for companies to go green. Compliance with environmental regulations is often considered in green purchasing decisions. However, compliance with these regulations does not necessarily guarantee improved environmental performance, as some organizations do not fully integrate environmental considerations into their value chain processes. Proactive compliance with these rules can foster innovation, reduce environmental impacts, and support green supply chain management (GSCM).

(ii) Customers:

Customer demands that consider long-term supply chain perspectives positively impact environmental management more than those with unreasonable timeframes. Environmentally aware customers pressure companies to supply green and eco-friendly products, driving improvements in environmental performance.

(iii) Competitors:

Many organizations adopt green supply chain practices to differentiate themselves and build trust with society and customers. Improvements in technology and management practices enable the industry to be at the forefront of environmental innovation. A proactive approach in this field can strengthen competitiveness and improve the company's financial performance.

(iv) Suppliers:

Vendors play a very important role in GSCM by providing important and beneficial ideas and collaborating with companies to manage environmental issues more effectively.

(v) Society:

Throughout history, increasing environmental degradation has led to increased public awareness of environmental issues. Today, a company's environmental reputation is a common factor when making purchasing decisions. With increasing awareness of environmental issues, the demand for green and environmentally friendly products increases. This increased awareness is putting pressure on marketing teams and stakeholders to re-evaluate their supply chain practices and ensure they are aligned with environmental considerations. Despite the challenges, this situation also provides an opportunity for companies to expand their consumer base by demonstrating excellence in environmental management.

3.2.2 Constraints in GSCM Implementation

1. Internal Barriers

(i) Costs:

Consumer price sensitivity creates challenges for GSCMs, especially SMEs with limited resources and technology to develop green and environmentally friendly products.

(ii) Lack of Legitimacy:

Some organizations claim to be committed to GSCM but fail to actually implement it. Successfully incorporating environmental concerns into an organization requires the commitment of top and middle management.

2. External Barriers

(i) Regulations:

Regulations can encourage GSCM, but can act as barriers if they impose unrealistic deadlines and prevent the adoption of green supply chain practices.

(ii) Poor Supplier Commitment:

A lack of transparency with suppliers can be a barrier, as companies may be reluctant to share GSCM information for fear of revealing weaknesses or compromising their competitive advantage.

(iii) Industry-Specific Barriers:

Barriers vary by industry sector, depending on the level of responsiveness and proactiveness of companies to environmental issues and the strategies they employ to gain competitive advantage.

3.2.3 Challenges in uncertain disruptions

As emerging events like Covid-19 and conflicts like the Russia-Ukraine war present new challenges to supply chains, industries are still adjusting to their consequences. These prolonged disruptions have had a significant impact on various sectors globally. Additionally, short-term events like the tsunami in South India and cyclones like YAAS and AMPHAN in the eastern region have caused significant disruptions in logistics and supply management. Hence, the challenges and uncertainties that these events bring must be examined and understood so that resilient frameworks that address the associated supply chain risks can be devised.

Several external forces can disrupt supply chains across various industries:

Fluctuating Raw Material Costs: Rising costs of raw materials can squeeze profit margins and necessitate adjustments in production or pricing.

Fuel Price-Driven Logistics Challenges: Increases in fuel costs can lead to disruptions in logistics and transportation, impacting delivery times and potentially raising final delivery costs.

Material Shortages: A lack of readily available supplies and essential consumables can hinder production and delay fulfillment of customer orders.

Concentration of Suppliers: Overdependence on a limited number of suppliers, particularly those located overseas, can create vulnerabilities if these sources experience disruptions.

Delivery Delays and Disruptions: If your company is unable to meet customer needs due to delivery delays or transportation disruptions, it can damage customer trust and potentially lead to lost sales.

Continuation of warehouse operations during covid-19 or other natural disasters

Ensuring the safety of employees in production facilities and on site. Complying with the government's instructions for smooth business continuity.

Efficient inventory management considering transportation costs and holding buffer stock. Minimize human intervention in warehouse operations. Disruption in vendor partner's supply chain processes.

Assessing green suppliers with GSCM combining quantitative and qualitative elements.

Streamline the order allocation process, determine quantities quickly, and distribute more efficiently to vendors.

The five criteria for evaluating green suppliers in GSCM include minimizing costs, maximizing product/service quality, ensuring delivery efficiency, evaluating technical capabilities, and evaluating environmental capabilities (e.g., waste reduction, use of packaging environmentally friendly packaging, implementation). waste reduction methods etc.) opposite actions). The goal of sustainable development is to reduce production and operational costs while improving environmental performance, reliability, customer satisfaction, social acceptance and overall profitability, all of which contribute to the advancement of this sector.

3.2.4 Circular Economy

Use a multidisciplinary approach to risk management to adapt to a dynamic and uncertain business environment. This proactive strategy will promote the development of a green supply chain while ensuring long-term sustainability and resilience.The key decision making categories are:

-Assessing green suppliers with GSCM combining quantitative and qualitative elements.

-Streamline the order allocation process, determine quantities quickly, and distribute more efficiently to vendors.

The five criteria for evaluating green suppliers in GSCM include minimizing costs, maximizing product/service quality, ensuring delivery efficiency, evaluating technical capabilities, and evaluating environmental capabilities (e.g., waste reduction, use of packaging environmentally friendly packaging, implementation). waste reduction methods etc.) opposite actions). The goal of sustainable development is to reduce production and operational costs while improving environmental performance, reliability, customer satisfaction, social acceptance and overall profitability, all of which contribute to the advancement of this sector.

Fig. 3.3 Diagram illustrating the different elements of SCM

Fig. 3.4 Implementing circular economy principles in eco-friendly supply chains
(Source: https://www.freepic.co.in)

- Evolving Consumer Preferences - Society's increasing awareness of environmental issues is reflected in changing consumer behavior. There is a growing preference for products and services that are environmentally friendly and less detrimental to both current society and future generations. Consequently, industries are closely monitoring this shift in purchasing habits and are compelled to innovate and introduce more eco-friendly offerings.
- Regulatory Adherence - Governments around the world have implemented regulations, policies, and laws aimed at banning or restricting the use of products or processes that pose environmental risks or cause pollution. For instance, the widespread ban on plastic bags serves as a pertinent example. Compliance with these regulations is imperative for all organizations, forming a crucial aspect of the ESG (Environmental, Social, and Governance) evaluation criteria across industries.
- Competitive Edge - Investment in innovative green technologies and ongoing research and development not only serves to protect the environment but also enables organizations to differentiate themselves within their respective industries and gain a competitive edge. Consumer pressure for environmentally responsible practices extends to various aspects, including recycling initiatives and reducing energy consumption and waste. Adopting these methods will not only increase the efficiency of your organization but also ensure continuous competition in the market. Adopting these methods will not only increase the efficiency of your organization but also ensure continuous competition .

3.3 Prioritizing risk and green dimensions using the Analytic Hierarchy Process (AHP)

To develop an optimized model for green supply chain management, this study utilizes the Analytic Hierarchy Process (AHP) technique. AHP is valued for its ability to handle complex decision-making, especially when both qualitative and quantitative factors are involved.

Identifying Key Considerations: We categorize various parameters under risk and environmental considerations. These factors represent the criteria that will be used to evaluate different green supply chain options. (Figures 3.5 and 3.6 will illustrate this hierarchical structure in more detail later).

Weighting Criteria: AHP allows us to assign weights to these criteria, reflecting their relative importance in achieving a sustainable supply chain.

Ranking Alternatives: With weighted criteria established, different green supply chain management options can be ranked and compared based on their performance across these criteria. An additional benefit of AHP is its ability to assess the consistency of your judgments in these comparisons. This helps ensure the reliability of your final decision.

- Pairwise comparing decisions are structured within matrix.
- Then the priorities are extracted as original eigenvectors.
- In addition, AHP allows you to evaluate differences in judgments.

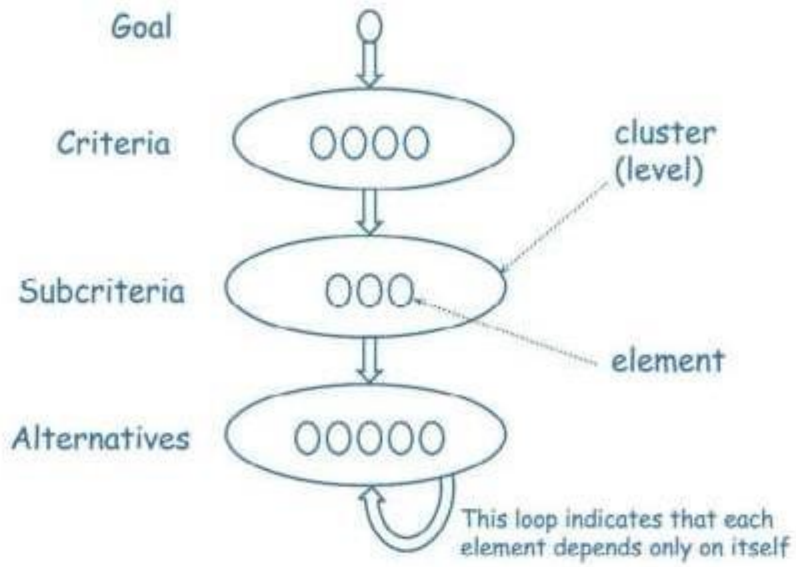

Fig. 3.5 Schematic diagram of processes in AHP (researchgate.net)

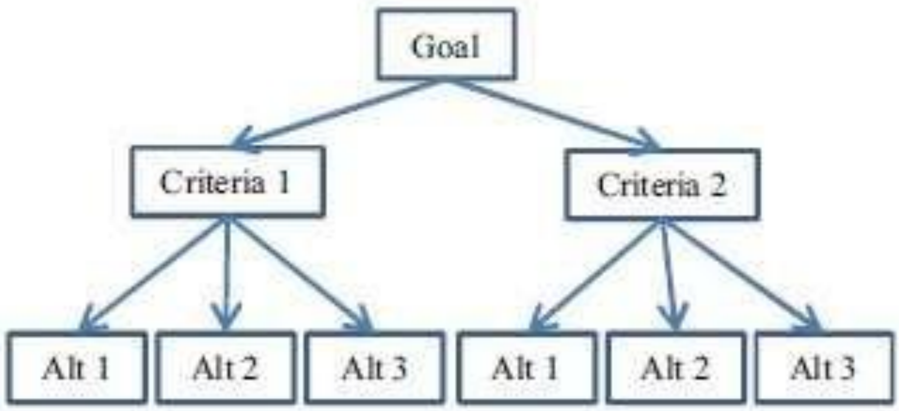

Fig. 3.6 Schematic diagram of implementation of AHP (after Hamdan and Cheaitou 2017)

Table 3
Table 3.5 Satty scale

Importance Level	Description	Example
Equal Importance	Both activities contribute equally to the goal.	Task A and Task B are essential for project completion.
Slight Preference	One activity is marginally more important.	Experience suggests prioritizing data collection (Task A) before analysis (Task B).
Moderate Importance	Clear preference for one activity based on experience.	Prioritize finalizing the report (Task A) as it has a tighter deadline than finalizing the presentation (Task B).
Strong Importance	Significant evidence supports favoring one activity.	Data indicates marketing campaign A is more effective than campaign B.
Very Strong Importance	One activity is demonstrably superior.	Reliability testing confirms system A is significantly more stable than system B.
Extreme Importance	Overwhelming evidence supports one activity.	Safety regulations mandate using only fire-resistant materials (Task A) for building construction.

The application of the AHP technique for the selection process involves the following steps:

1) Creating a hierarchical model involves several steps. First, analyze the relationships between all elements. Start by defining your primary goal and create two levels: a reference row and a sub-reference row. The criteria layer helps you evaluate options, and the subcriteria layer provides an overview of all the choices involved in the selection process.

2) Creating a pairwise comparison matrix involves moving to the second layer of the hierarchical model. We construct a pairwise comparison matrix for each element in this layer using a 1 to 9 comparison scale known as the Saaty scale. This process continues from the top layer to the bottom layer. A summary of the Saaty scales that provide comparative values is shown in Table 3.5. Pairwise comparison of each element results in a pairwise comparison matrix which is a positive reciprocal matrix.

$$Comparison\ Matrix\ R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & r_{22} & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix}$$

The Analytic hierarchy process (AHP) relies on pairwise comparisons to determine the relative importance of different factors. However, it is important to ensure consistency in this comparison. This is achieved by calculating the consistency ratio (CR).

Consistency ratio (CR): This measure compares the consistency index (CI) calculated from the pairwise matrix and the randomness index (RI) based on the number of items compared. A CR of 0.1 or less is generally considered acceptable.

Uses weight vectors to make decisions

n(the order of the matrix)	1	2	3	4	5	6	7	8	...
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	...

If CR meets the consistency limit ($CR \leq 0.1$), the resulting weight vector (ω) can be used as a reliable basis for making decisions. This weight vector represents the relative importance of each factor in the AHP process.

3.4 Multi-Objective Optimization Model for Green Supply Chain Management (GSCM)

Traditionally, business process decisions have been optimized for a single purpose. However, this approach has limitations. In supply chain management, it is a critical area for business processes to consider various factors such as productivity and profitability to achieve optimal results.Typically, supply chain management aims to find the optimal solution that maximizes or minimizes a single objective function, often aimed at minimizing procurement costs. However, in today's real-world scenario, decision making becomes more complex due to the involvement of multiple stakeholders from different perspectives. This complexity shows the need for a new approach: a multi-objective optimization model that can accommodate several goals, so that several goals or goals can be investigated simultaneously. Such models facilitate the evaluation of trade-offs in the implementation of various objectives, each of which represents a specific metric.

Multi-objective optimization (MOO) has become a mainstream approach for solving complex decision-making scenarios. This method allows to determine the optimal trade-offs between competing objectives by simultaneously optimizing several conflicting objectives. Choosing often involves balancing conflicting goals. Multi-objective optimization (MOO) provides a framework for decision makers in such situations to evaluate the costs and benefits of different options. This allows for efficient resolution of complex goals and competing complex goals.A key concept in MOO is Pareto optimality. A solution is considered Pareto optimal if it cannot be improved without sacrificing the other. Imagine a trade-off between price and quality: A Pareto optimal solution will not allow you to reduce costs without sacrificing quality, or vice versa.The set of Pareto optimal solutions forms a Pareto front. This "in front" represents the best trade-off between objectives, clearly representing the optimal choice in the constraints given to decision makers.

The complexity of decision making leads to multi-objective optimization. This powerful method allows decision makers to navigate complex landscapes with multiple, often conflicting, goals. By identifying optimal solutions and carefully examining trade-offs, multi-objective optimization ensures an informed choice.A general multi-objective optimization problem that combines mathematical decision making with various constraints can be described as follows (Keshari and Datta, 1996):

Maximize or minimize $f_m(x)$	$\forall$	$m=1, 2,..M$
subject to		
$G_j(x) \geq 0$	$\forall$	$j=1, 2, ...J$
$H_k(x)=0$	$\forall$	$k=1, 2, ...K$
$x_i \geq x^{lb}$	$\forall$	$i=1, 2, ...N$
$x_i \leq x^{ub}$	$\forall$	$i=1, 2, ...N$

This mathematical model uses decision variables represented by the vector x. These variables can be adjusted to explore different scenarios and potential outcomes.

The model includes three main elements:

Objective function (f(x)): this function represents the desired result we aim to optimize. There may be multiple objective functions representing different objectives that may compete with each other.

Inequality constraint (g(x)): This constraint defines the constraint or limit that the decision variable must obey. They ensure that the solution is feasible and realistic.

Equality Constraints (h(x)): This constraint defines specific conditions that the decision variable must strictly satisfy.

Symbols m, j, and k represent subscripts used to represent specific constraints in the model.

M, J, and K represent the combined form of this constraint, thus for a more concise representation. In addition, lb and ub indicate the lower and upper bounds that can be applied to the decision variable. When dealing with complex problems that require balancing multiple competing objectives, multiobjective optimization offers a powerful approach. In this project, we use the epsilon constraint method in this domain to solve the stability problem.

The epsilon constraint method is a valuable tool for converting algorithms designed for unconstrained problems to constrained scenarios. For one of these purposes, epsilon (ε), which acts as a threshold value, is obtained by introducing an additional parameter. By iteratively tuning epsilon, we can explore trade-offs between different goals while ensuring that all constraints are met.A search point is determined based on pairs of objective values and constraint violations.

When solving complex problems such as stability, which often involve balancing competing objectives, multi-objective optimization has become the preferred approach. This project specifically uses the epsilon constraint method in this context.

The epsilon constraint method offers a valuable solution for adapting algorithms designed for unconstrained problems to handle real-world scenarios with constraints (constraints). This is achieved by introducing an additional parameter, epsilon (ε). This epsilon value is a threshold for one of the goals in the optimization process. By continuously adjusting epsilon, we can explore trade-offs between different objectives while ensuring that all constraints are met.It evaluates detection points by considering pairs of objective values and their corresponding constraint violations. By leveraging Pareto-optimal solutions, this approach enables the identification of trade-offs between different objectives, facilitating the determination of optimal solutions.

The model includes multiple objectives, taking into account green procurement, environmental concerns, disruptive scenarios and factors related to sustainability, along with traditional procurement and business operations. Controls are formulated to accommodate traditional, green and disruptive elements, ensuring that the procurement plan is not only green and optimal but also resilient. The objective functions and constraints are shown below:

3.4.1 Objective function:

1. Cost function:

The main goal is to reduce the total procurement cost, which is a basic and characteristic objective for businesses. It is important to accurately define and prioritize this goal. Mathematically, the objective function to minimize procurement costs can be expressed as:

$$Minimize\ Z_1 = TCP = \sum_{i=1}^{n} \sum_{t=1}^{m} (C_{it}\ x_{it} + OC_{it}\ x_{it}) + \sum_{t=1}^{m} IC_{t} \sum_{i=1}^{n} x_{io}$$

Where,

Z_1	=	First Objective Function
TCP	=	Total Cost of Procurement
C_{ij}	=	Unit cost of item x_{ij} supplied by vendor i in period j
OC_{ij}	=	Unit cost of other cost associated with the purchase of item x_{ij} supplied by vendor i in period j
x_{ij}	=	Quantity of item supplied by vendor i in period j
IC_j	=	Unit inventory holding cost associating with holding item x_{ij} in the store supplied during period j
i	=	index for supplier or vendor
j	=	index for time or period, for example month
m	=	number of periods in planning horizon
n	=	number of suppliers or vendors

2. Quality Assurance and Control Goal

This function focuses on quality control, a critical part of the supply chain where materials must be tested to ensure the quality of the final product. Quality control measures must reduce the number of rejected items to optimize quality assurance while reducing costs. Consequently, the second objective function seeks to reduce procurement costs while maintaining strict quality standards. Mathematically, this objective function can be expressed as:

$$Minimize\ Z_2 = TRQ = \sum_{i=1}^{n} \sum_{j=1}^{m} r_{ij}\ x_{ij}$$

Where,

Z_2	=	Second Objective Function
TRQ	=	Total Rejected Quantity during Quality Control Checking
r_{ij}	=	Percentage of rejection of item x_{ij} delivered by vendor i in period j
x_{ij}	=	Quantity of item supplied by vendor i in period j
i	=	index for supplier or vendor
j	=	index for time or period, for example month
m	=	number of periods in planning horizon
n	=	number of suppliers or vendors

3. Meeting Delivery Deadlines Objective

This function focuses on time management, which is necessary for suppliers to deliver products as quickly as possible to avoid negative impacts on business processes. This is especially important for manufacturing companies and various service industries where vendors must meet fixed lead times. Just-in-time delivery of materials helps maintain adequate inventory levels, prevent shortages, meet operational requirements, and provide backup in case of disruptions. As an important part of the supply chain, this objective function aims to reduce cases of late delivery by suppliers

Mathematically, this objective function can be expressed as:

$$Minimize\ Z_3 = TLDQ = \sum_{i=1}^{n} \sum_{j=}^{m} l_{ij}\ x_{ij}$$

Where,

Z_3	=	Third Objective Function
TLDQ	=	Total Late Delivered Quantity in Planning Horizon
l_{ij}	=	Percentage of late delivery of item x_{ij} delivered by vendor i in period j
x_{ij}	=	Quantity of item supplied by vendor i in period j
i	=	index for supplier or vendor
j	=	index for time or period, for example month
m	=	number of periods in planning horizon
n	=	number of suppliers or vendors

4. Environmental Objective Function:

The fourth objective function includes green supply chain principles with a focus on environmental issues. These include initiatives to reduce greenhouse gas emissions, reduce carbon footprints, reduce waste, conserve water and control pollution.

This objective function is important for the development of green supply chain management strategies, thus the focus of current research. Specifically, the fourth goal aims to reduce overall greenhouse gas emissions associated with procurement. In particular, the fourth objective function aims to reduce the total greenhouse gas emissions associated with procurement. This includes emissions from factors such as the type of vehicles used by vendors to deliver materials, green practices of vendors, carbon footprint of products supplied, packaging, delivery methods and more.

In its simplest form, this objective function can be expressed mathematically as:

$$Minimize\ Z_4 = TGHGE = \sum_{i=1}^{n} \sum_{j=1}^{m} G_{ij}\, x_{ij}$$

Where,

Z_4 = Fourth Objective Function

TGHGE = Total Green House Gas Emissions Equivalent

G_{ij} = Greenhouse gas emission equivalent associated with item x_{ij} delivered by vendor i in period j

x_{ij} = Quantity of item supplied by vendor i in period j

i = index for supplier or vendor

j = index for time or period, for example month

m = number of periods in planning horizon

n = number of suppliers or vendors

5. *Green Value Function:*

The fifth objective function evaluates the green value of different equipment vendors determined through AHP based on the customized green value parameters discussed earlier. This score takes into account factors such as drivers and barriers, bottlenecks, risks and other environmental issues in the green supply chain. When evaluating a supplier's green score, there is also a normative aspect that allows us to assess the combined effect of conventional and green initiatives in SCM.

The objective function is directly related to the main goal of green supply chain management. By optimizing vendor selection or order distribution, we can prioritize suppliers and processes that contribute to environmental sustainability.Therefore, it is important to develop an optimal strategy in this regard. Therefore, this function is the focus of this study. It is calculated by multiplying the seller's AHP score by the amount provided. Mathematically, this objective function can be defined as:

$$Maximize\ Z_5 = TGVP = \sum_{i=1}^{n} GW_i^{AHP} \sum_{j=1}^{m} x_{ij}$$

Where,

Z_5	=	Fifth Objective Function
TGVP	=	Total Green Value of Procurement
GW_i^{AHP}	=	Green weight of vendor or supplier i obtained from AHP
x_{ij}	=	Quantity of item supplied by vendor i in period j
i	=	index for supplier or vendor
j	=	index for time or period, for example month
m	=	number of periods in planning horizon
n	=	number of suppliers or vendors

3.4.2 Constraints:

To achieve optimal performance within a green supply chain framework, this model incorporates a multi-objective linear optimization approach. In addition to the previously described objective function, the model also considers the following constraints to ensure environmentally responsible practices throughout the supply chain.

1.*Demand Constraints*

All requirements within the planning horizon must be met to maintain operational continuity. Ultimately, the total amount purchased or delivered must meet the company's business requirements. It can be configured to meet demand at any time. However, demand constraints are set to cover the planning horizon to allow flexibility in different periods. Therefore, the demand constraint for such a scenario can be defined as follows :

$$\sum_{i=1,2}^{m} x_{tj} = D_j \qquad for\ all\ t = 1, 2, \ldots .\ n$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} = \sum_{i=1}^{n} J_i$$

Where J represents the demand, keeping other variables and indices the same.

1. *Supplier Capacity Restrictions*

The model requires constraints to prevent vendor supply from exceeding their production capacity, which is crucial for finding optimal solutions.Therefore, supplier constraints can be described as follows:

$$\sum_{j=1}^{m} x_{ij} \leq SC_i \qquad for\ all\ i = 1, 2, \dots . n$$

where SCi is the seller's supply capacity i.

2. *Environmental Limitations*

To prioritize environmental issues, different restrictions can be made based on specific environmental issues or initiatives supported by company leaders. In the current scenario, these environmental restrictions are aimed at limiting the carbon footprint. Therefore, the limitations of the environment can be described as follows:

$$\sum_{j=1}^{m} \sum_{i=1}^{n} G_{ij} x_{ij} \leq CF_{limit}$$

CF_{limit} This shows the allowable limit of greenhouse gas emissions as a result of research activities, including emissions produced by many vendors in the planning horizon.

3. *Supplier Budget Allocation Constraints*

Companies may consider limiting the budget allocated to vendors to supply products. This constraint is especially important when dealing with disruptive situations or when dealing with higher priced traders. Additionally, these limitations may arise from cost-cutting initiatives due to financial constraints within the company. Therefore, the limitation of supplier budget allocation can be explained as follows:

$$\sum_{j=1}^{m} C_{ij} x_{ij} \leq B_i \qquad for\ all\ i = 1, 2, \ldots .n$$

where B is the budget constraint for seller i.

4. *Vendor Relation Constraints*

To Setting a minimum order limit may be necessary to develop a positive relationship with a reliable, trustworthy or experienced trader. Therefore, the limitations associated with the vendor relationship can be defined as follows:

$$\sum_{j=1}^{m} x_{ij} \geq S_{min\ i} \qquad for\ all\ i = 1, 2, \ldots .n$$

Smin is the minimum order that must be placed on the seller.

5. *Inventory Constraints*

The procurement of materials should be managed in a manner that prevents both excess inventory in storage and shortages, ensuring the seamless operation of the business without imposing any unnecessary financial strain. Therefore, constraints pertaining to inventory management described as:

$$I_{j-1} + \sum_{i=1}^{n} x_{ij} - I_j = D_j \qquad for\ all\ \mathrm{J} = 1, 2, 3 \ldots . m$$

Study intensity (Ii): this variable represents the number of certain items (i) at a certain point (j). initial inventory (Io): this value represents the number of items that are on hand at the beginning of the planning period (j = 0).This practice ensures the timely fulfillment of material requirements while preventing the accumulation of excess inventory.

$$\sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} + I_o = \sum_{j=1}^{m} D_j$$

6. Non-negative constraints

A linear programming optimization model must satisfy a non-negativity constraint. Therefore, this constraint is applied to the decision variable x_{ij} . A value of zero indicates that a matching vendor was not selected and no quantity was ordered from that vendor during the specified period. Therefore, the non-negative limit can be expressed as follows:

$$x_{ij} \geq 0 \qquad\qquad for\ all\ i, j$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Variation of Risk in Supply Chain Management

The survey was conducted using questionnaires designed for various industries to assess and evaluate supply chain risks. It targets supply chain managers from various companies, covering a range of supply chain operations in India, including both large and small enterprises. Six large companies and representatives of 20 small companies were interviewed to explore supply chain risk and complexity in their businesses. The results of this research are crucial for developing strategies to reduce uncertainty and disruption in supply chains, thereby supporting economic growth. The questionnaire used for the interviews was discussed earlier and company size was assessed based on turnover, employee strength and business vertical. Research data are diverse, reflecting the mixed nature of the field being studied.

Based on research data collected from various sectors, the risks faced by the main industry are assessed and classified into five groups: supply, demand, production, finance and environment. As shown in Figure 4.1, the main industry faces supply risk, which accounts for 42% of the total risk, followed by demand risk and production risk at 23% and 18% respectively. Environmental risk accounts for 9% of total risk. High supply risk costs can be associated with transportation problems, especially during disruptions.

Conversely, risks associated with sub-sectors are shown in Figure 4.2. Among these sub-sectors, supply risk is 25%, while environmental risk is the highest at 30%. A comparative analysis of Figures 4.1 and 4.2 shows that large enterprises are more exposed to supply chain risks, especially supply risks, while small enterprises are more exposed to environmental risks.

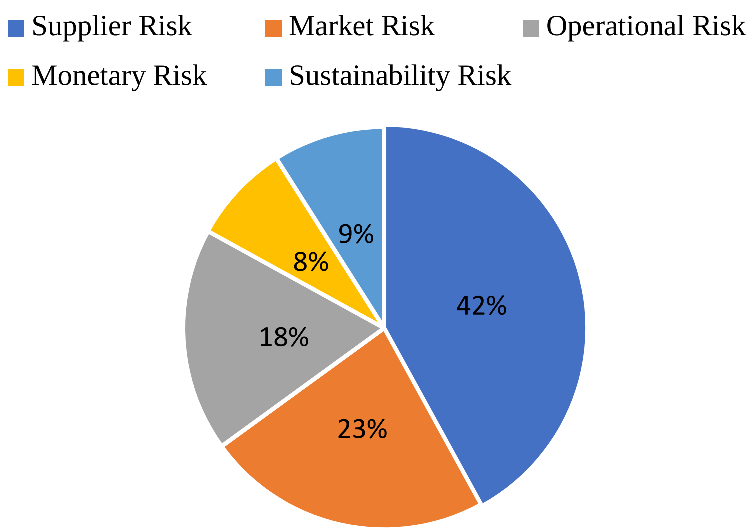

Fig. 4.1 Risks stemming from significant industrial sectors (Complied by the Author)

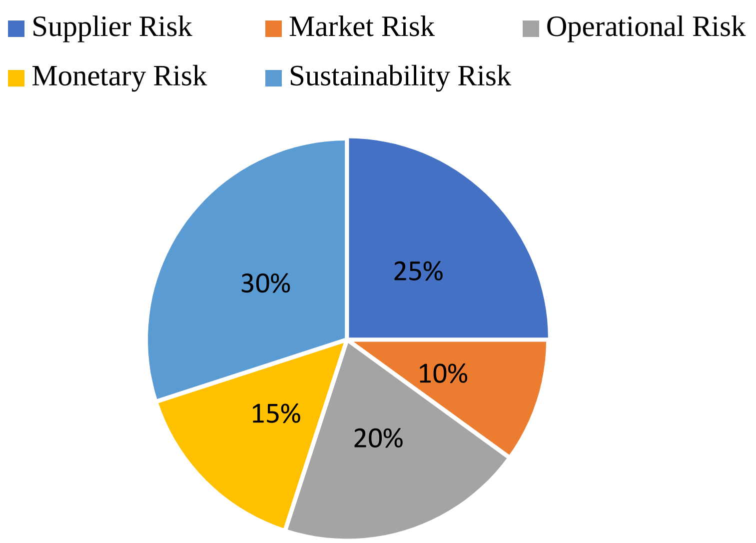

Fig. 4.2 Risks stemming from smaller industrial sectors (Complied by the Author)

4.1 GSCM parameter weights and ratings derived from AHP

This study applies the developed model to assess the green supply chain management (GSCM) practices of five potential suppliers. To perform a numerical analysis, we identified key risks, drivers, and barriers and grouped them into five key parameters: Green Procurement (GP1, GP2, GP3):

Efforts to Reduce Waste (GP1): This parameter evaluates the supplier's initiatives to minimize waste throughout their production processes.

Use of Green Fuels in Transportation (GP2): This parameter assesses the supplier's commitment to using environmentally friendly transportation options to reduce their carbon footprint.

Greenhouse Gas Emissions from Purchasing (GP3): This parameter considers the supplier's overall greenhouse gas emissions associated with their procurement practices.

Supply Chain Performance (GP4, GP5):

On-Time Delivery (GP4): This parameter measures the supplier's reliability in delivering goods on time, minimizing disruptions in the supply chain.

Rejection Rate (GP5): This parameter evaluates the percentage of units rejected due to quality issues, reflecting the supplier's quality control processes.

By analyzing these parameters, the model can compare the green practices and overall performance of the five potential suppliers. This approach allows for a data-driven selection process, favoring suppliers that align with the company's commitment to sustainability and efficiency.

Vendors S1 to S5 were designated and assigned a theoretical classification rating from 1 to 5 based on the parameter values, as shown in Table 4.1. Higher scores indicate better compliance with green principles. This ranking was determined by considering the vendor's green attributes and alignment with SCM principles. For example, high values of the first two parameters have a positive effect on the green value, while high values of the remaining parameters have a negative effect on the green principle, resulting in a lower score.

An iterative version of your content that more clearly describes weighting parameters in the Analytical Hierarchy Process (AHP):

Measuring green supply chain parameters for decision making

We used the Analytic Hierarchy Process (AHP) to compare the previously introduced green supply chain parameters (GP1-GP5). This method involves creating a pairwise comparison matrix to determine the relative importance of each parameter.

Complete pairwise comparison (Table 4.2): this table shows how each parameter compares to others on an hourly scale. For example, a score of 3 in the table may indicate that "Efforts to reduce waste (GP1)" are considered three times more important than "Using green fuel in vehicles" (GP2) when evaluating green purchasing practices.

Normalized matrix (Table 4.3): The raw comparisons in Table 4.2 are then normalized to ensure consistency of analysis.

Weight Matrix (Table 4.4): Based on the normalized comparison, a weight matrix is created in Table 4.4. These weights indicate the relative importance of each parameter in achieving the overall goal of a green supply chain.

Based on the weighted amount, vendors were ranked by green value, as shown in Table 4.6. Figure 4.3 shows the change in seller's green value weights. Supplier Salesperson 3 scored the highest, followed by Supplier Vendor 4 and Supplier Vendor 2 the lowest.

Table 4.1 Pairwise matrix for 5-vendor 5-green attribute problem

	V1	V2	V3	V4	V5
P1	3	2	4	5	2
P2	3	2	3	4	2
P3	4	3	2	5	3
P4	4	3	2	2	4
P5	3	4	4	4	2

Table 4.2 Pairwise matrix for 5-vendor 5-green attribute problem (Complied by the Author)

Matrix					
	P1	P2	P3	P4	P5
P1	**1**	2	6	8	6
P2	0.70	**1**	7	8	3
P3	0.120	0.120	**1**	2	0.178
P4	0.1210	0.1210	0.50	**1**	0.153
P5	0.161	0.3333330	6	7	**1**
(CT)	1.9324	3.76	22.52	26	10.34

Table 4.4 Weight matrix for the 5-vendor 5-green attribute problem (Complied by the Author)

V1	46.35%
V2	30.47%
V3	45.07%
V4	31.92%
V5	15.46%

Table 4.5 Consistency matrix(Complied by the Author)

5.71
5.55
5.02
5.07
5.35

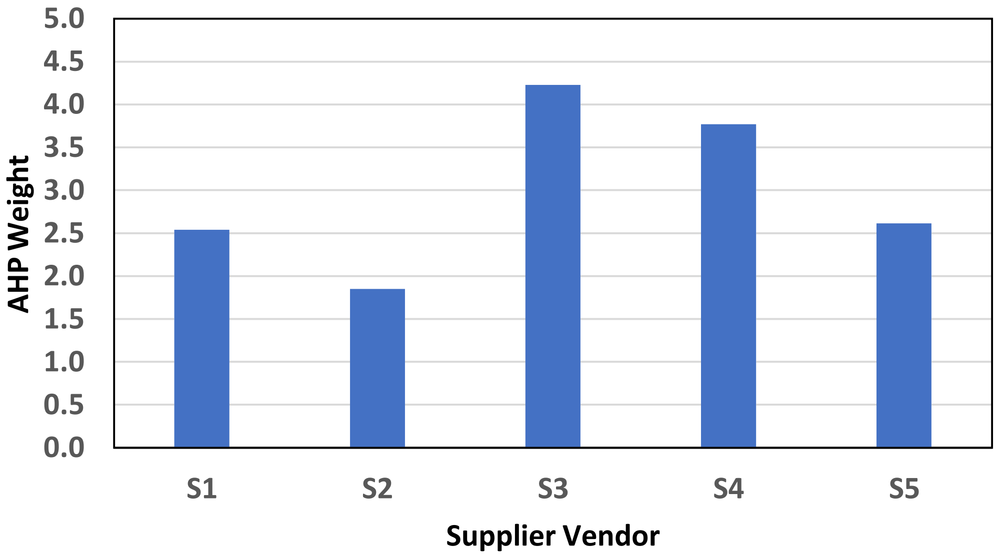

Fig. 4.3 Variation of green value score derived from AHP (Complied by the Author)

4.2 Optimal Solution for Vendor Selection

The numerical solution of the optimization model was derived using a specific data set from the published literature, as outlined in Shaw et al. (2012), as these data were not available from the surveyed companies used to identify and quantify risks. The model considered four first objective functions and the unit price of four suppliers was determined as 6, 7, 4 and 3 units respectively.

Rejection Rates: The rejection rates for these suppliers vary, ranging from 2% (Supplier 4) to 5% (Supplier 1). These rates indicate the percentage of units rejected due to quality issues.

Delivery Failure Rates: Delivery failure rates also differ among suppliers, with the lowest rate at 2% (Supplier 4) and the highest at 8% (Supplier 3). These rates represent the percentage of deliveries that did not arrive on time or according to specifications.

Emission Equivalents: The suppliers' greenhouse gas emissions vary, with Supplier 2 having the highest equivalent (1.6 kg per unit) and Supplier 1 emitting the least (1.3 kg per unit). These figures indicate the estimated greenhouse gas emissions associated with producing one unit from each supplier.

Production Capacity: The production capacities of the suppliers range from 4,000 units (Supplier 4) to 14,500 units (Supplier 2). This information reflects the maximum number of units each supplier can produce in a given timeframe.

Financial Breakdown: The financial breakdown for these suppliers reveals varying costs. Supplier 1 has the lowest cost per unit (24,000 units total), while Supplier 2 has the highest (70,000 units total).

The results of the Prime solution for supplier selection and ordering are shown in Fig. 4.4-4.5. Shape. 4.4 shows that all vendors except the first vendor are selected as purchase orders. Figure 4.5 shows the optimal values for different objective functions. Specifically, as shown in Figure 4.5, vendor S1 received no orders, vendor 2 received the largest supply orders, and had the lowest product rejection and delivery failure rates.

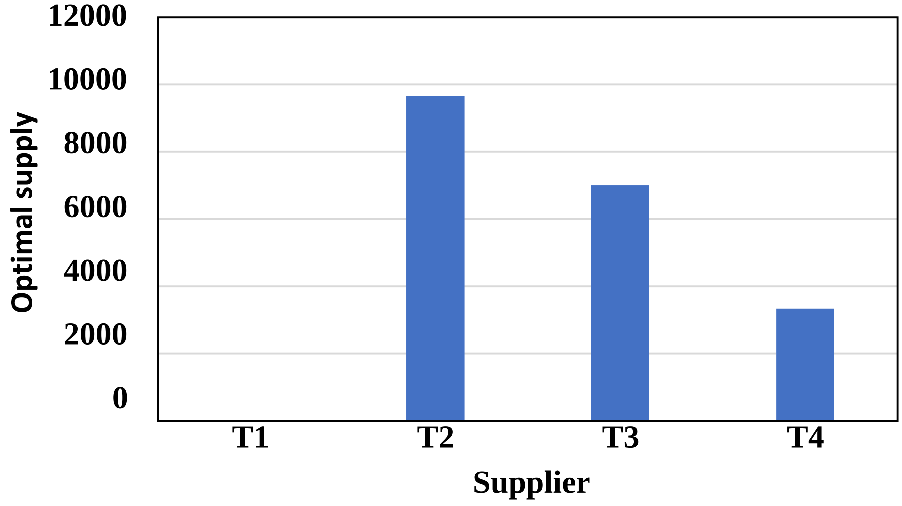

Fig. 4.4 Peak delivery from diverse Supplier (Complied by the Author)

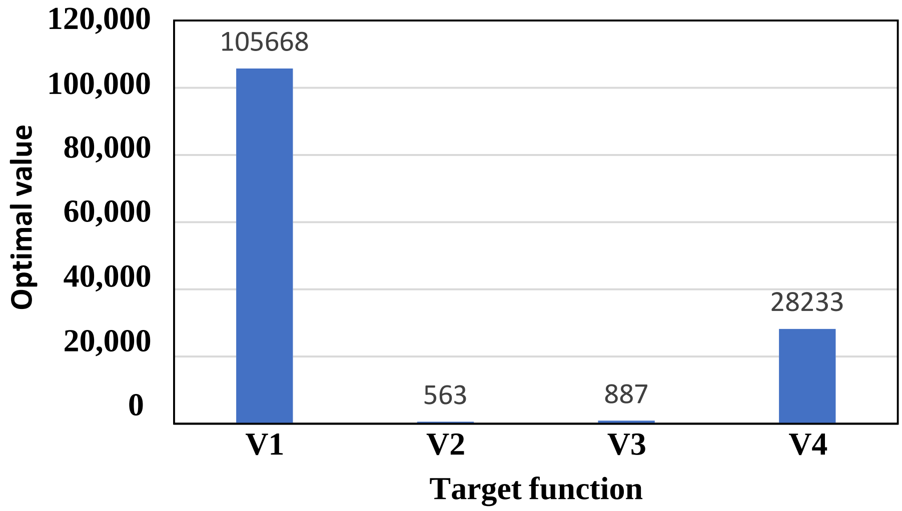

Figure. 4.5 Ideal data of functions (Complied by the Author)

Figure 4.6 illustrates that Vendor 2 possesses substantial supply capacity, enabling it to satisfy demand effectively. Vendors 3 and 4 are nearing their saturation points. Despite having available supply, Vendor S1 isn't receiving any orders.. that align closely with their allocated budgets, whereas Vendors 1 and 3 are falling significantly short of meeting budgetary allocations.

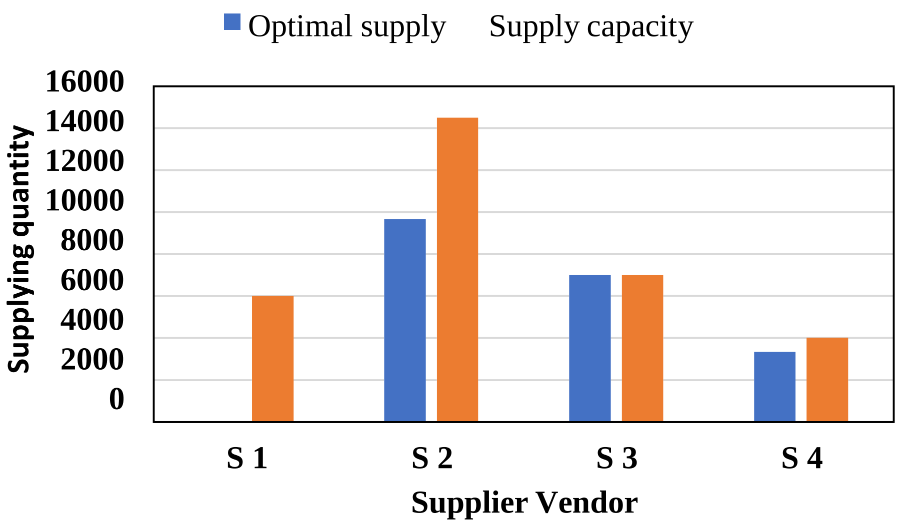

Figure. 4.6 Evaluating the alignment between optimal supply and vendors' supply capacity (Complied by the Author)

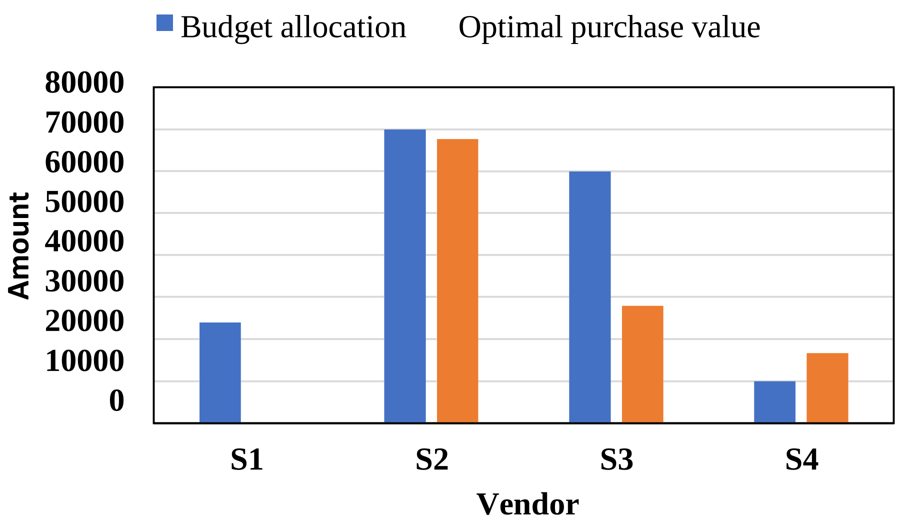

Figure. 4.7 Assessing the ideal purchase value against the allocated budget for vendors (Complied by the Author)

4.4 Strategies for enhancing supply chain resilience

Green supply chain management (GSCM) has emerged as a key strategy for not only industrial development but also environmental sustainability. This concept involves the integration of environmental issues into various supply chain activities, including environmentally friendly practices throughout the product's life cycle until the end of our product's life cycle. This event includes

Conduct: Assess suppliers' performance in the handling of raw materials, packaging and transportation

practices.This event includes Conduct: Assess suppliers' performance in the handling of raw materials, packaging and transportation practices.

Distribution: Set up waste disposal facilities, sell excess stock and learn how to recycle.

Manufacturing: Adopt green manufacturing technologies to reduce pollution and waste.

Major areas for applying GSCM include product design, packaging, transportation of hazardous materials, waste reduction in the manufacturing process, and supplier selection. After supplier selection and order allocation, several supply chain resilience strategies can be developed to address operational risks. These strategies may include:

- Foster collaboration among supply chain stakeholders.
- Diversification of supply sources.
- Implement a system to maintain business continuity.
- Distribution of power among suppliers.
- Share information effectively.

Operational challenges may include rising raw material costs, logistics and transportation bottlenecks, inventory shortages, dependence on single source vendors, space constraints, labor shortages, and operational inefficiencies. These strategies include reducing risk, buying in bulk, negotiating savings and favorable payment terms, prioritizing urgent materials, mapping territories for logistics planning, maintaining buffer stocks, and diversifying the supplier base.

HR challenges require identifying and developing alternative sources, creating skilled labor pools, providing temporary shelters for long-term workers, and ensuring transportation contracts meet business requirements.

Effective communication is essential to disseminate early warning signals, coordinate with suppliers/stakeholders for critical supplies, and preserve knowledge through data storage and visualization techniques.

CHAPTER 5

CONCLUSION

Environmental issues such as carbon emissions, pollution and climate change are pushing industries to adopt a sustainable future. It encourages the development of innovative technologies and the adoption of environmentally responsible business models that focus on environmentally friendly practices.

The unpredictable nature of highly unpredictable supply chain disruptions. This has a serious impact on business and economy. Managing the supply chain in such a volatile environment poses challenges such as disruptions in supply and demand dynamics disrupt business continuity and threaten the company's survival and growth

In response to these challenges, a comprehensive multi-objective optimization framework for green supply chain management (GSCM) has been developed. This model integrates disturbances and environmental factors to optimize vendor selection and order allocation. This includes green weights derived from the Analytical Hierarchy Process (AHP) using a linear multi-objective optimization framework. The model is derived from isolated metrics by considering five main objective functions: cost, quality control, on-time delivery, environmental impact, and green score. However, to achieve optimal performance, model factors in the system wide effects. These include:

This study takes an empirical approach and conducts a structured questionnaire to representatives of 6 large companies and 20 small and medium-sized companies to identify and quantify supply chain risks and identify drivers and barriers. Common green parameters affecting the supply chain were evaluated using AHP to derive green value weights, ranks, and scores. These AHP weights are integrated into a multi-objective optimization model to facilitate optimal vendor selection and ordering.

Quantitative analysis was performed using AHP for five vendors and five green parameters to determine weights and ranks. This model makes it possible to consider traditional and environmentally friendly approaches and provides optimal solutions that combine these strategies in supply chain management. The implementation of such a model helps to develop effective research strategies and optimize various aspects of the supply chain, resulting in reduced production and operational costs, improved environmental efficiency, reliability and customer satisfaction. Increase overall profitability.

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