Major Project Dissertation Report on

Developing Resilient Green Supply Chain Model using AHP and Multi-objective Optimization

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C E R T I F I C A T E

This is to certify that **Ms. Aakanksha Keshari** has satisfactorily completed the project titled **"Developing Resilient Green Supply Chain Model using AHP and Multi-objective Optimization",** under the guidance of Prof. G.C. Maheshwari as a part of Master of Business Administration (MBA) curriculum of Delhi School of Management, New Delhi. This is an original piece of work and has not been submitted elsewhere.

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DECLARATION

I, **AAKANKSHA KESHARI** student of EXECUTIVE M.B.A. (DELHI SCHOOL OF MANAGEMENT, DELHI TECHNOLOGICAL UNIVERSITY, Formerly Delhi college of Engineering) hereby declare that the Project Report on "**Developing Resilient Green Supply Chain Model using AHP and Multi-objective Optimization**" has been result of my own work and has been carried out under supervision of **Prof. G. C. Maheshwari.**

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 **Aakanksha Keshari**
DATE: 18-05-2023

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Aakanksha Keshari

Developing Resilient Green Supply Chain Model using AHP and Multi-objective Optimization

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Abstract

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 customer satisfaction for the firm. However, the industries in both developing and developed nations are currently facing increasing pressure to consider environmental aspects in managing their business 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.

C O N T E N T

1.

INTRODUCTION

1.1 Background

Supply chain plays a vital role in any micro and macro-economics for continuous operation of supply and demand cycles. The main objective of supply chain management (SCM) is to maximize an organization's profitability and value to the customers through integrated planning and control decisions. However, there is an increased awareness among the people related to environmental issues and climate change. There is an increasing responsibility of all the organizations including industries, public and private sectors to minimize the environmental aspects in the society. With the increase in the awareness of environmental pollution and rising consciousness towards environmental protection, it has become imperative for business enterprises also that they must pay sincere attention to environmental measures such as pollution control, waste minimization, recyclability, energy saving, reuse, and parts interchangeability, and reducing carbon and water footprints. In general, manufacturing companies even various users purchase the same raw materials or components from several suppliers due to various economic, capacity, reliability, and risk factors. Thus, it becomes essential the manufacturers keep in view of the environmental attitudes and responsibilities of these vendors also as they are likely to affect the sustainability and environmental policies of enterprises also as the suppliers or vendors may not be sincere in these aspects as that of enterprises. These issues make the green supply chain management more relevant and critical in overall scenario.

Green supply chain management is the emerging key to address environmental aspects in operations and supply chains. The main aim of Green Supply Chain Management (GSCM) is to integrate all logistical and financial information to obtain a balance among all stages of supply chain and to increase the competitiveness of products or services. This will result in sustainable development of the organization and improved environmental and economic aspects.

Further, recent incidents around the globe have drawn worldwide interest in other dimension of the supply chain because of the huge adverse impacts of Covid-19 on the supply-demand mismatch and company's business. Supply chain systems are facing a variety of disruptions, including natural disasters such as flood, cyclone, earthquake, tsunami, climate change; human-made attacks such as Russia-Ukraine War or Suez Canal obstruction; etc.; due to growth of supply chain alternatives or strategic outsourcing. These disturbances induce instability in the supply chain and thereby in the survival, sustainability, and growth of the company. Several studies conducted recently show that supply chain disruptions can cause large damage as critical suppliers are often difficult to be replaced and may lead to significant profit loss (Simchi-Levi et al. 2015, Hosseini et al. 2019. The study conducted by Simchi-Levi et al. (2015) shows significant impact of disruptions on the profit of Ford Motor Company as shown in Fig. 1.1. They observed that the vendors whose supply chain disruptions caused greatest damage to Ford company were those from which the annual purchases by the company were relatively small (Simchi-Levi et al., 2015).

The disruption has become an inherent part of the local, regional as well as global level supply chains and the resulting consequences are most often unexpected, complex, uncertain, and challenging. Thus, the appropriate vendor selection for supplying materials has become a major key issue due to the growth of global supply chains, disruptions encountered, supplier performance, and strategic outsourcing as the disruption resulting from supplier can halt or adversely affect the business operation which may result into cascading effect that can put other components in the whole supply chain into a ripple effect of adverse consequences (Ivanov et al. 2014, Dolgui et al. 2018, Hosseini et al. 2019).

Since the vendor or supplier selection has become a complex multi-criteria decision-making problem as it may involve even some tangible and intangible criteria (Ho et al. 2010), it is important to cater environmental and economic aspects along with disruptions in supply chain. Keeping the above in views, the present study is aimed to develop a multi-criterion decision making multi-objective optimization model for resilient Green Supply Chain Management that accounts disruptions as well as environmental considerations. The use of such models will help in evolving optimal strategies for procurement and optimizing other components in the supply chain and make organizations future ready.

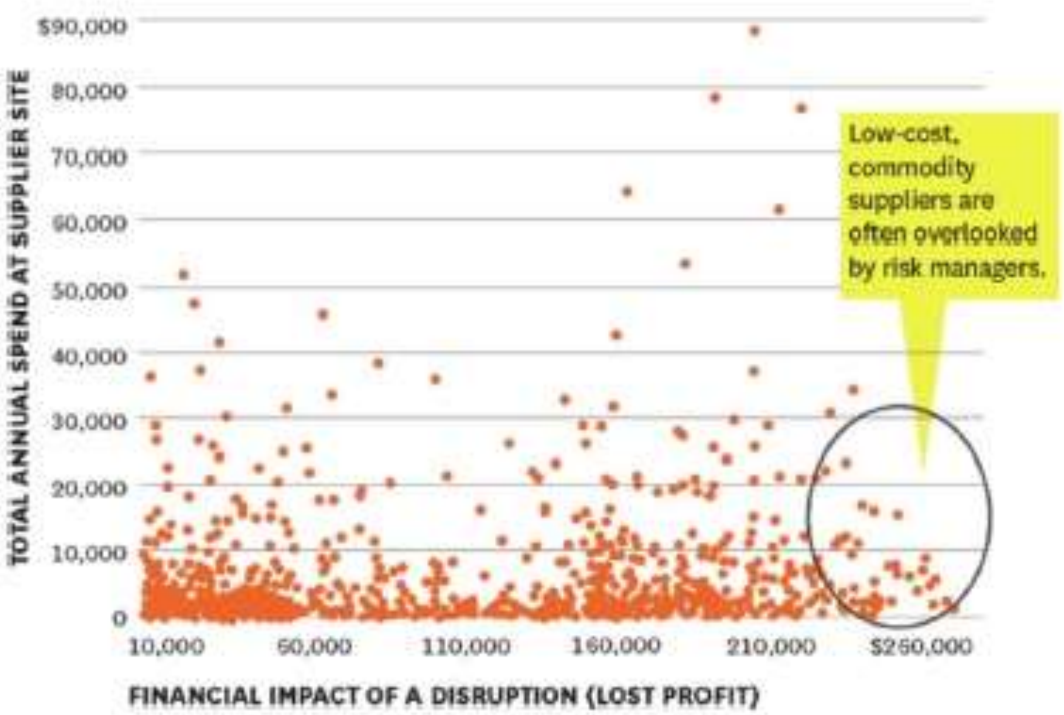

Fig. 1.1 Impact of supplier disruption on profit of Ford company (Simchi-Levi et al. 2015)

1.2 Problem Statement

The present study is focussed on addressing the environmental issues and disruptions encountered at different levels of the supply chain (buying, supplier selection, negotiation, design collaboration, procurement, sourcing analysis). Rising environmental concerns and disruptions have made an appropriate vendor selection and order allocation a challenging task as they have great potential to affect the business operation, productivity, and profitability adversely. Business enterprises need to pay sincere attention to environmental measures, disruption resilience and sustainability in the supply chain management strategies for the survival, sustainability, and growth of the company. The disruptions and environmental concerns have now become inherent part of the local, regional as well as global level supply chains and the resulting consequences are most often unexpected, complex, uncertain, and challenging. Thus, the appropriate vendor selection for supplying materials has become a major key issue due to the growth of global supply chains, disruptions encountered, supplier performance, and strategic outsourcing in the fast-changing uncertain operating environment.

1.3 Scope of Study

The aim of the present study is to develop a mathematical model which helps in finding out appropriate vendor or supplier and allocate the purchase orders keeping in view of the emerging criteria of environmental considerations and disruption resilience besides conventional criteria of minimizing the cost and timely delivery. Since it has become a complex multi-criteria decision-making problem, the present study is aimed to develop a multi-criterion decision making multi-objective optimization model for resilient Green Supply Chain Management which will enable to select the best or a set of best vendors and evolve optimal strategies for procurement and optimizing other components in the whole supply chain.

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.

1.4 Objectives

The main goal of this project study is to develop a resilient green supply chain model that accounts the aspects related to environmental concerns and disruptions situations besides the profitability and customer satisfaction in the overall business process. This will help in achieving the additional benefits in terms of environmental performance, reliability, and societal acceptance besides the conventional outcomes in terms of overall business profit and customer satisfaction. The specific objectives of the present study can be summarized as:

- To identify the components and activities of supply chain that have high risk of getting adversely affected during disruptions and potential to raise environmental concerns
- To identify the drivers and barriers pertaining to environmental concerns and disruption situations in the whole supply chain process of a business entity
- To quantify the weights and ranks of identified green and resilient parameters using AHP
- To develop a mathematical multi-objective optimization model for resilient green supply chain management that accounts environmental and disruption constraints

and objectives besides the profitability, product quality and customer satisfaction for optimal vendor selection and purchase order allocation

- To carry out a pilot case study for evolving optimal strategies for resilient green supply chain management that mitigate the uncertainty, disruptions, and environmental degradation in supply chain for sustaining economic growth.

2.

LITERATURE REVIEW

This chapter provides state-of-art on the importance of research studies in the areas of green procurement and disruptive resilience strategies, and the use of optimization techniques in supply chain management and emerging issues associated with the supply chain that have significant effect on the business operation and business growth. The literature review carried out in the present study has been grouped under two themes, namely, (i) studies focusing on environmental and disruptions in supply chain management, and (ii) use of multi-objective optimization in resources management. At the end of this chapter, concluding remarks has been presented to highlight the limitation and scope of research for the present and future studies.

2.1 Studies Focusing on Environmental and Disruptions in SCM

Walker et al. (2008) explored factors that motivate or hinder in the implementation of green supply management. Their study primarily involved surveys by interviewing people from private and public sectors. They observed that the barriers in the implementation could be internal as well as external. Shaw et al. (2012) presented an integrated approach of fuzzy theory, AHP and multi-objective linear programming for supplier selection. They illustrated the model application through a dataset of realistic situation. They observed that the model is effective in handling situations involving information vagueness related to the inputs.

Appolloni et. al. (2014) carried out extensive systematic literature review to do critical analysis of the state-of-the-art research into green procurement. They reviewed 86 research publications that appeared in literature during 1996 to 2013 and grouped them into five categories as shown in Fig. 2.1. It is evident from this figure that most literature utilized survey as the research methodology for carrying out analysis. Fig. 2.1 also shows that there is a need of dedicated research in developing mathematical models. Appolloni et al. (2014) carried out a comprehensive review on green procurement in private sector and presented a conceptual framework of green purchasing for future empirical research and identified future research directions that need sincere attention. They analysed motivation, drivers, and barriers in the implementation of green procurement. They also evaluated the performance impacts when green procurement is adopted.

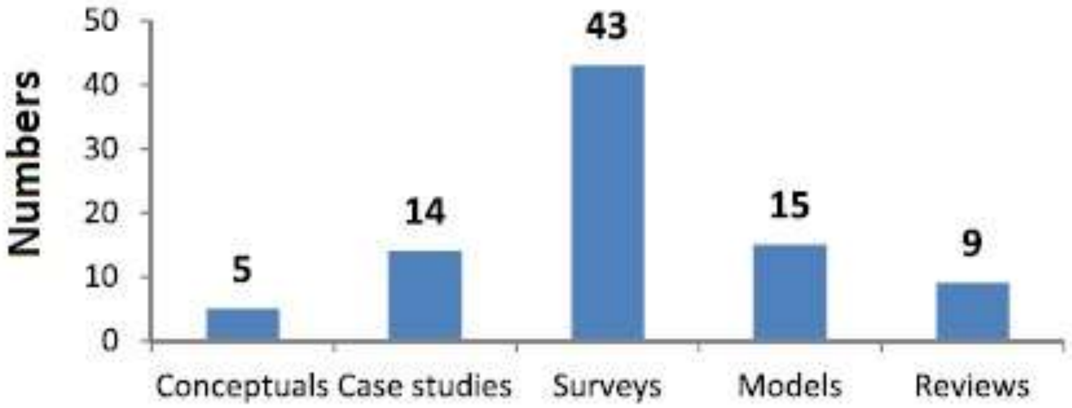

Fig. 2.1 Research methodologies utilized by various researchers in green procurement (modified from Appolloni et al. 2014)

Hamdan and Cheaitou (2017) presented a multicriteria decision making tool for supplier selection. They used fuzzy TOPSIS and AHP techniques for finding out the best supplier. The combined weights and preferences from these techniques are used in the optimization model for the supplier allocation problem. Lo et al. (2018) found that the green purchasing is a critical factor in sustainable development of enterprises and most literature focus on the use of green criteria in the supplier selection. It is observed that there are very few articles that consider both green supplier evaluation and order allocation.

Hosseini et al. (2019) presented a probabilistic model for supplier selection to deal with disruption management. They presented an approach for computing likelihood of disruption scenarios and their impact on supplier performance. A stochastic model involving mixed integer programming was utilized for the study and concluded that the results would be useful in disruption mitigation strategies.

2.2 Use of Multi-objective Optimization Techniques in Resources Management

The use of multi-objective optimization techniques is increasing to address complex problems particularly problems involving multiple objectives, viewpoints, and multiple stakeholders where decision making and arriving at the best alternative or design are complicated. To arrive at the most viable decision under multiple conflicting constraints is a challenging task. Keshari and Datta (1996) presented a generalized multi-objective optimization model that can involve multiple criteria and conflicting objectives which most often encounter in resources management projects involving environmental considerations. Such problems always require solutions under some restrictions or constraints placed upon variables that affect the decision. The decision or management policy can be tested for physical feasibility by using a model. The environmental or hydrological impact can also be derived from a model and plugged into the decision-making model as constraints. The optimal solutions may produce trade-offs among different objectives and goals. Such optimal solutions are termed as non-inferior solutions or pareto optimal solutions and the best solution is obtained as a compromised solution giving the considerations to trade-offs of one objective over the other.

Tchangani (2017) proposed a multi-objective optimization model and solved using soft computing techniques such as evolutionary computation algorithm. A distributed constraint optimization problem (DCOP) was used for modelling the management of water resource systems involving farmers' dams, economic operators, and cities. The multi criteria decision making approach was used to evaluate alternative management strategies to satisfy various societal economic and ecological needs. They studied the sustainable management of natural resources using bipolar analysis that permits to introduce some flexibility and during the recommendation phase the merit of bipolar analysis is that it allows aggregating separately incentives of the same nature.

Zhang et al. (2019) introduced a hybrid algorithm known as Multi-Objective Fireworks Algorithm with Differential Evolution (MOF-DE). This method combines the exploring capabilities of the fireworks algorithm with the exploitation capabilities of differential evolution. The MOF-DE method provides superior convergence and diversity maintenance in comparison with the standard algorithms. Sharma and Sharma (2020) introduced a hybrid strategy for tackling multi-objective optimization issues that included Genetic Algorithm (GA) and Pattern Search (PS) techniques. The study reveals that the hybrid GA-PS algorithm which combines the GA's global search capacity with the PS's local search efficiency, exhibits higher convergence and produces more diversified Pareto-optimal solutions.

Deb and Gupta (2020) presented a mathematical programming-based technique referred to as an Optimal Decomposition-based Multi-objective Optimization (ODMOO). It transforms the multi-objective optimization problem into a series of single-objective sub problems using a decomposition-based technique. It provides a diversified range of Pareto-optimal solutions by optimizing these sub problems. Chiang et al. (2021) proposed Multi-objective Optimization through Orthogonal Decomposition (MOOD) wherein the multi-objective optimization problem is divided into orthogonal sub problems and all of them are solved at once to yield the Pareto front.

2.3 Concluding Remarks

Green Supply Chain Management is considered to be environmentally and socially friendly in consideration with economically functional. The concept soared with increasing consumer concerns on how products were manufactured and delivered. In current scenario, many organizations have environmentally friendly regulations, policies, and practices. The objective of GSCM is reducing environmental and other negative impacts associated with manufacturing and movement of goods. It is also referred as sustainable supply chain management which implies that sustainable practices are adopted and ensures that decisions of present do not impact future generations. GSCM, therefore, seeks to curb the negative impact by redesigning sourcing, packaging, distribution channels, and managing reverse logistics to eliminate all the inefficiencies, dumping of packaging and unnecessary freight movements.

Green logistics aims in increasing the efficiency of transport, container, and fleet management with respect to environment friendly practices. The concept works in reducing the transport related CO_2 emissions through controlling of container and by reducing empty load travelled. Thus, logistics provider seeks to provide carbon efficient carriers. Manufacturing and transportation are the two biggest sources of CO_2 emissions. Another aspect that poses great threat is packaging which is vital for shipping and storage. The concept deals with the no. of products which can be stored, the storage method used, transportation and handling of packaged product in confined space. These packaging is used once and then is discarded. In today's scenario, packaging imposes one of the major challenges in GSCM as there is responsibility of the supplier, logistics service provider and buyer to recover, recycle and effectively dispose of packaging. Similarly, there are different drivers and barriers which are considered for affecting these cost benefits practices (Walker et al. 2008).

GSCM focuses on all the suppliers in various stages such as manufacturing, transportation of finished goods and services, packaging, and reverse logistics. It utilizes recyclable material, streamlines distribution channels, minimizing wastage to provide cost benefits to the environment, society, and economy by ensuring reduction of pollution and operational costs, streamlining different processes, and establishing stronger supplier relations. From these discussions, we can arise to the conclusion that being environment conscious is a win-win situation for both the organization and environment. Thus, the stability of supply chain to be environment friendly depends on the purchasing strategy, i.e., to have Green Procurement (Appolloni et al. 2014). Procurement strategy is therefore, directing limited resources towards projects which are showcasing environmental as well as economic performance.

The supply chain management in uncertain environment is a challenging, complex, and highly unpredictable because of the huge and diverse adverse impacts of disruptions on the supply-demand mismatch and company's business. These disturbances induce instability in the supply chain and the survival, sustainability, and growth of the company. The decision-making during pandemic like situations is very complex, multifaceted, and poorly understood as they are unpredictable and causes various uncertainties that affect the production, company growth and national and social economies. Hence, it is important to identify the vulnerable components of supply chain, anticipating and diagnosing the supply chain risks, and evolving strategic response measures for reducing the impact due to disruptions caused by pandemic situations. Every organization should have an understanding of the activities of supply chain that have high risk of getting adversely affected during these situations, by exploring the sensitivity of supply chain, quantifying the supply chain risks, assessing responses to the identified risks in time horizons of different phases from perceiving to responding or recovering, and evolving resilient strategies to mitigate the uncertainty and disruptions in supply chain for sustaining the economic growth (Hosseini et al. 2019).

To have Green Procurement and resilient method of mitigating disruptions, important decision-making process tool is required to be adopted during supplier selection and order allocation (Hamdan and Cheaitou, 2017) by considering both the objectives along with the approach of cost optimization.

Thus, we can understand from above discussions that there is very limited studies and business models that efficiently guide the supply chain process on how to respond to environmental concerns and disruptions for the success and sustainability of business. There is no integration between adopting green supply chain techniques and risk mitigation strategy in supply chain disruptions. 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. 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.

With GSCM resilient framework, analysis in terms of circular economy is also done to tackle environmental challenges such as pollution, wastage, climate change etc. The key principles for transformation of circular economy are reduction of waste and pollution in supply chain processes, keeping products in use condition and regenerating natural systems. Based on these principles; suppliers, manufacturers, transport service providers are evaluated during supplier selection and order allocation process. It helps to minimize the emissions and consumption of raw materials; and influences for innovations to adopt eco-friendly technology. It also increases the sustainability of consumption of raw materials and improves efficiency of the organization which justifies the objective of green supply chain management framework.

3.

METHODOLOGY

The methodology utilized in the present study to accomplish the intended objectives includes explorative research of the organizations among different sectors, formulation of a mathematical model using Analytical Hierarchy Process (AHP) and Multi-Objective Optimization, application of the developed model to carry out a case study, and taking computational runs using developed model for quantitative optimal solution and evolving optimal strategies to have better resilience and ensure environmental compliance.

Fig. 3.1 shows the flow chart of the methodology utilized in the present study. The various components of the methodology as shown in this figure and utilized in the present study are described in following sections.

3.1 Identifying Disruptive Parameters and Risks in Supply Chain

A structured questionnaire can be developed to carry out survey that helps in identifying the components of the supply chain where risks are expected during disruptive situations and quantifying those risks that impact the company business and financial growth. This approach can be utilized as a mathematical tool for the empirical exploration of supply chain risk and quantification of impact of various risks resulting from disruptive situation. A detailed literature review was carried out to identify attributes that should be included in framing questions for a systematized survey of supply chain risk impact of the pandemics that are likely to be encountered by the industries. Based on the various literature and the study conducted by van Hoek (2021), the questionnaire could be framed around the four categories: (i) Types of risks involved in supply chain, (ii) Drivers of supply chain risks, (iii) Risk management techniques, and (iv) Risk management responses.

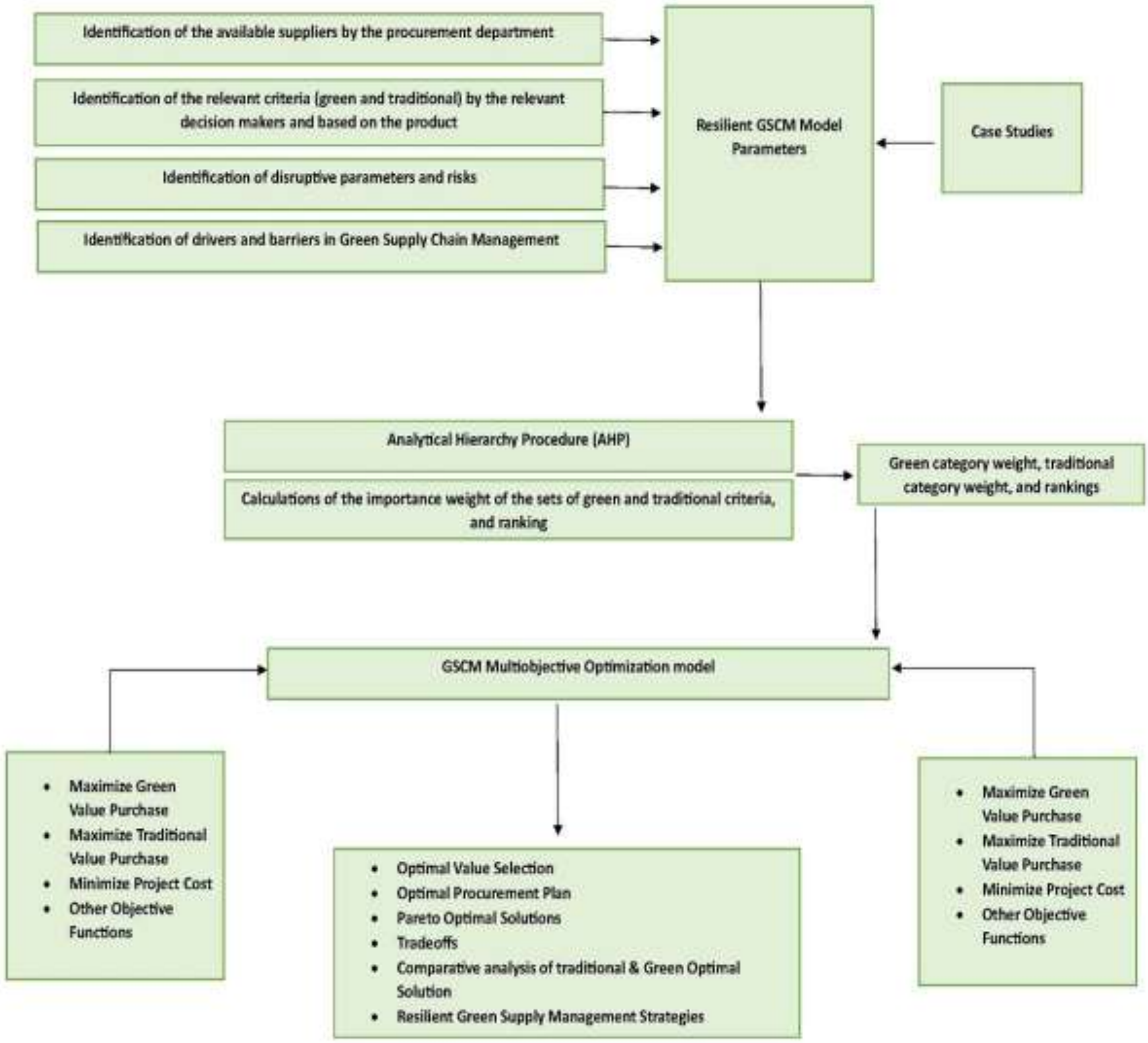

Fig. 3.1 Flow chart of the methodology utilized in the present study

The risk management responses could be generated for different time horizons, such as short-term, mid-term and long-term as discussed above. These responses would be helpful in evolving risk mitigation and recovery strategies for different time horizons and would make the strategies dynamically resilient. The survey may be conducted from a variety of supply chain managers distributed in different geographical locations and types of industries. It should engage managers representing companies in a wide range of industries including manufacturing, logistics, services, and retail. The survey should also cover different sizes of industries and the risk factors and risk responses associated with various industries vary greatly depending upon the size and scale of the industry. The idea behind the initial survey should be more focussed on the exploratory analysis, rather than in-depth statistical analysis. A typical data structure of company profile for capturing survey data while developing supply chain resilience framework is presented in Table 3.1.

Table 3.1: Data structure for company profile

Attribute	**Company N1**	**Company N2**	**Company N3 ….**	**Company Nn**
1. Type of company	X	X	X	X
2. Geography	X	X	X	X
3. Company size	X	X	X	X
4. Supply chain position	X	X	X	X
5. Transportation link	X	X	X	X

Here, the type of company indicates the nature of business of the company. It may be a manufacturing, product development, logistic services, software, pharma, beverage, or FMCG company. The geography indicated locational details of the company, whereas the company size represents whether it is a small, medium, or large sized company. The supply chain position may be manufacturer, distributor, retailer, logistics, or e-commerce. The transportation link denotes that how good transportation infrastructure is available at the company location. It gives a measure of connectivity of location by various modes of transport such as air, rail, road links. This can be expressed in qualitative terms such as low, medium, high, very high, etc. All these attributes of company play vital role in supply chain activities of the company.

Table 3.2 shows a typical set of structure of questionnaire for interviewing various officials involved in supply chain and business operations. The generated structured questionnaire can be used to seek feedback during the survey to develop a supply chain resilience framework to be utilized in response to the disruptive situations. Table 3.3 shows the categorization of company and capturing details of company profile for conducting survey. The identified risks in various components of supply chain are enumerated as supply chain risk in Table 3.4. These data are then analysed for quantifying the risks and evolving strategic measures for supply chain resilience.

Table 3.2: Typical questionnaire structure for supply chain risk assessment survey

Serial No.	Question
1	Did you observe that the supply chain of your company was impacted by disruption? If yes, how and in what manner it has impacted?
2	What challenges were faced by your company in the supply chain? Please identify risk sources in the supply chain.
3	What has driven the supply chain risks faced by your company? Please identify risk drivers in the supply chain.
4	How is your company responding to the risks being faced by you?
5	Did you consider adjusting the supply base in addressing the risks?
6	If the supply base is being adjusted, please tell in which way are you doing this?
7	What kind of measures such as multiple sourcing, local sourcing, reducing the reliance on single or few vendors, or something else were implemented?
8	Did your company increase inventory buffers? If yes, by what percentage?
9	Please state whether your company is engaging with suppliers to address supply issues?
10	In what way your company is engaging with supply vendors and what is the role of procurement?
11	Did you take measures like extending payment terms, increasing delivery time, negotiating discounts, joint mitigation efforts, segmented approaches, etc.?
12	Did your company implement some technologies to address pandemic challenges in the supply chain?

13	Identify technologies such as information sharing, technology sharing, visibility, diversification strategies, event management systems, etc.
14	Is your company planning changes in the supply chain process after the disruption? If yes, what are they?
15	Did your company make changes in lead time?
16	Did your company increase the procurement or delivery cost? If yes, what changes they offered?
17	What strategic plans were made by your company for procurement and delivery in response to disruption restrictions?
18	Did you face transportation problem for material delivery?
19	Did you encounter shortage of supply for manufacturing or product development?
20	Did you observe manpower problem in business operation?

Table 3.3: Capturing company profile

Type of Industry:	(A) Manufacturing	(B) Consulting	(C) Logistics	(D) Other
Size of Industry:	(A) Small	(B) Medium	(C) Large	(D) Very Large
Industry Operation:	(A) Local	(B) State	(C) National	(D) Global

Table 3.4: Supply chain risk 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 Drivers and Barriers in GSCM

Fig. 3.2 shows a conceptual model of Green Supply Chain Management (GSCM) indicating various drivers, controls, and performances. With increasing environmental laws, regulations, and consciousness, GSCM has received considerable attention for sustainable growth of the organization. It developed due to globalization, international trade, increased complexity & new demands for enhanced transparency & corporate citizenship. Companies, therefore, should apply GSCM strategies to respond to the market pressures and exhibit sensitiveness towards social responsibility to differentiate themselves among others in the industries. The drivers and barriers for green purchasing and supply chain activities can be categorized as Internal drivers including organizational factors and External drivers including laws & regulations, customers, suppliers, competitors, and society. The same is described in following sections.

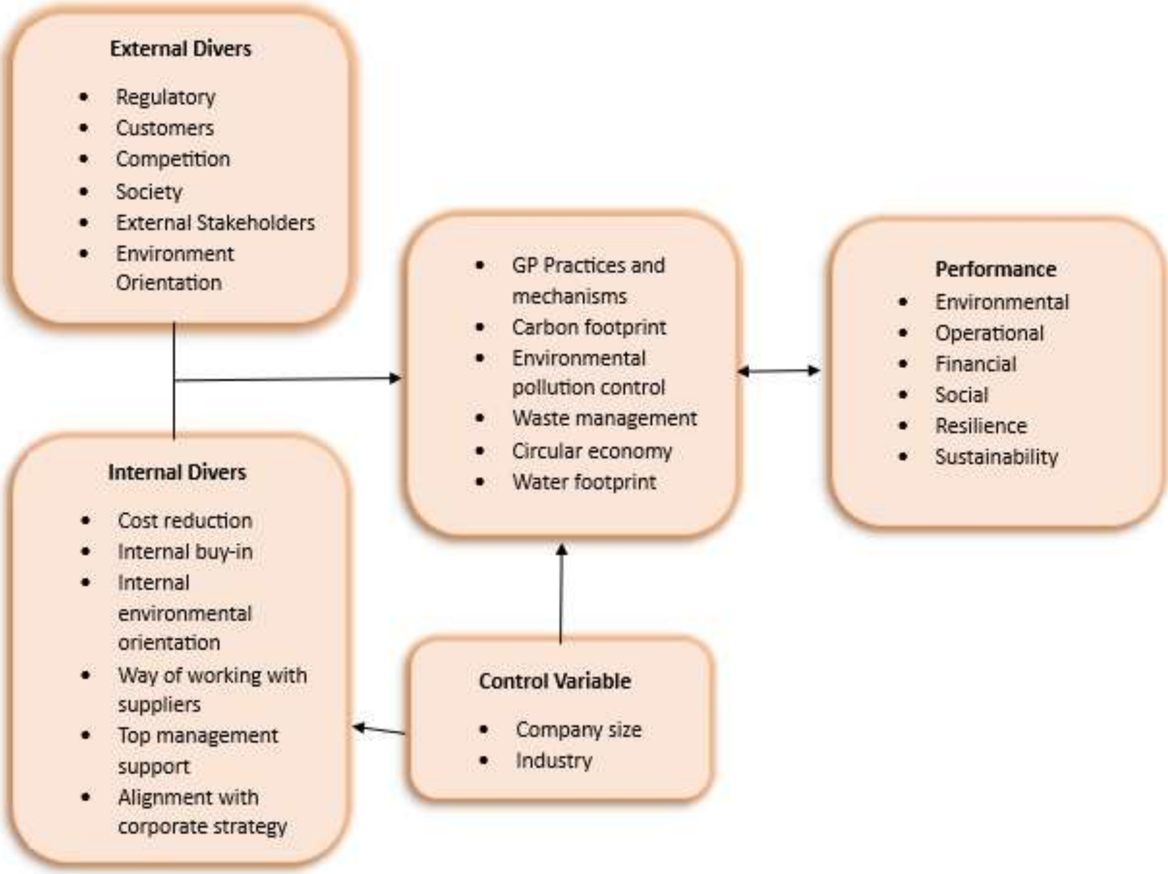

Fig. 3.2 Conceptual Model of Green Supply Chain Management (modified after Appolloni et al. 2014)

3.2.1 Drivers in GSCM

1. Internal Drivers

(i) Organizational Factors

The personal and ethical values of the leadership team of the organization embedded in the company. Middle management's support is equally important related to environmental purchasing. Operational and environmental enhancement has been observed to be related to employee involvement of the organization. Hence, middle managers personal commitment and impetus is necessary to drive successful green supply chain management.

The objective of reducing costs is the basic driving force for environmental supply chain. Pollution is associated as a hidden cost in the form of wasted resources and effort throughout a product's life cycle. Pollution prevention techniques, such as material substitution or closed-loop processes can be adopted. These initiatives are driven with the focus on cost reduction, waste elimination, and quality improvement.

2. External Drivers

(i) Laws and Regulations

Government laws, regulations and legislations are major driving factors for companies' environmental efforts. Environment compliance of the industry is also considered during green purchasing. However, it is not necessary that compliance to these environment regulations is a guarantee for improved environmental performance as it has been observed in few instances that those organizations do not have integrated environmental concerns in their value chain processes. Proactive efforts towards these regulations should be considered for GSCM as these laws motivate to innovate and reduce environmental impact.

(ii) Customers

It is witnessed that customer demands which takes long-term supply chain perspective have higher positive effect on environmental management in comparison to the customer's requests which involve unreasonable timeframe. Customers are aware of environmental conditions and therefore exert pressure on companies to improve their environmental performance by supplying green and eco-friendly products.

(iii) Competitors

To create differentiation among the competitors and to achieve the trust of societies and customers, many organizations are adopting green supply chain practices. With the enhanced technology and management approaches, industries can drive environmental innovation. A proactive strategy will also help to establish competitive advantage in that field and thus improving the financial performance of the firm.

(iv) Suppliers

Suppliers also play a crucial role in providing valuable ideas for implementation in GSCM. Integration of supply chain activities along with collaboration with the suppliers will provide more effective management of environmental issues.

(v) Society

The increasing deterioration of the environment historically, has drastically increased the public's awareness towards environmental issues. Public are now influenced by a company's reputation in the society with respect to the environment while making purchasing decisions. The demand for green and environment friendly products is rising as people are becoming more conscious of the environment issues. These are putting pressures on the marketing team and stakeholders to review their supply chain practices in line with environmental concerns. These imposed threats due to increased awareness are also creating opportunities for firms to increase their consumers base by performing exemplary in environment relates issues.

3.2.2 Barriers in GSCM

1. Internal

(i) Costs

Consumers are price sensitive and hence desire for low prices acts as a barrier for GSCM and especially SMEs who have less resources available and technology for innovation of green and eco-friendly products.

(ii) Lack of legitimacy

Some of the organization advertise or brand themselves as GSCM companies but do not practise. Top and middle management commitment is of vital importance to embed these environmental concerns within the organization.

1. External

(i) Regulations

This driver can also act as a barrier as can hinder green supply chain management practises by setting unreasonable deadlines.

(*ii) Poor supplier commitment*

Many organizations are not transparent with their suppliers and thus companies are unwilling to exchange information on GSCM because of the fear of exposing their weakness or their competitive advantage strategy.

(iii) Industry specific barriers

Organization in various industrial sectors have differing barriers based on how reactive or proactive a firm is to the environmental issues and concerns and the strategies adopted by them to gain competitive advantage among others.

3.2.3 Challenges in uncertain disruptions

Some of the pandemic like Covid-19, Russia-Ukraine War are new phenomena and supply chain is still adapting to the consequences and challenges. These long-lasting pandemics have been very disturbing and are impacting large number of industries varying in nature and dimension across the globe. Some shorter lasting pandemics, like Tsunami which effected Southern India and cyclones (YAAS, AMPHAN) severely impacted the eastern region of India. These cause disruptions in logistics and supply management for all the industries. Consequently, it becomes a vital requirement for initial exploration and findings of the challenges and uncertainty these pandemics can produce so that a resilient framework can be designed for the preparation of the pandemics to mitigate associated supply chain risks. The external forces which are likely to cause disruptions in supply chain cycle across industries in manufacturing, transportation, procurement, supply, and financial risks are as follows:

a) Increase in prices of all the raw materials
b) Disruption in logistics and transportation and increase of fuel costs
c) Shortage of inventory and critical consumables
d) Dependency on import vendors/ single sources or proprietary vendors
e) Failure in meeting timely demands of customers due to delayed delivery or transit material
f) Continuity of Warehousing process in view of COVID spread or other natural calamities
g) Employee safety who are engaged in shop floor and are on sites.
h) Deployment of Govt guideline for seamless operation
i) Inventory management and maintaining of buffer stock (taking into consideration of carrying costs
j) Mitigating human interaction in any of the warehousing operations
k) Disruption in the supply chain process of vendor partners associated with the organization

To mitigate such risks, a green supply chain resilient and agile framework must be designed based on different risk management techniques for the consideration of disruptions due to fast changing and uncertain operating environment and to have green supply chain development in the system. Some of the major decision-making categories are listed below:

- Green suppliers' selection in GSCM, through various qualitative and quantitative factors.
- Order allocation process which determines ordering quantity rapidly and allocating to vendors more effectively.

The five measures defined for evaluating the green suppliers for GSCM are namely, minimum cost, maximum quality of the product/service, delivery, technology capability of the supplier and their environmental competency (such as reduced carbon emissions in transportation/ packaging of the product/ waste generation etc.). Sustainable development of organization by reducing manufacturing and operational cost as well as enhancing environmental performance, reliability, customer satisfaction, societal acceptance, and overall profit is the key for the growth in the segment.

3.2.4 Circular Economy

Circular Economy was defined by Ellen MacArthur Foundation (EMF) as an industrial economy with a restorative or regenerative approach by value and design to consumption and production. It involves redesigning, recovering, and reusing of products and services which reduces environmental impacts. For every organization, the supply chain activities flow chart for developing a resilient framework is shown in Fig. 3.3. The circular economy for GSCM of any organization can be simply viewed as shown in Fig. 3.4.

To ensure a balance between green supply chain management, organizations should strive for achieving a balance between economic, environmental, and social objectives of the society. Every company should work to be a good corporate citizen in order to gain trust and confidence of the employees, stakeholders and shareholders. The supply chain practices which should be enrolled is summarized as follows:

- Aligning supply chain goals with vision, mission of the organization
- Evaluating supply chain process as a singly life cycle stream
- Using of green supply chain analysis during different stages as a catalyst for innovation
- Focusing on source reduction to minimize the wastage

The drivers for GSCM and importance of having circular economy analysis is illustrated as follows:

- Rising energy costs- One of the reasons for increase of raw materials in Europe recently was due to increase in energy surcharge. This indicates that due to increase in energy and fuel costs, it has led to the rise in prices of raw materials. Industries are therefore, exploring opportunities to innovate and develop green alternatives that will lead to reduction in prices significantly.

- Climate Change- People have become more aware of Global Warming impacts to the environment and biodiversity. The industries are themselves concern about the alarming effects of pollution and waste generation. Many manufacturing industries are now examining greener supply chain activities to reduce environmental impacts and to provide eco-friendly products or services to end consumers.

Fig. 3.3 Flow chart of various components of supply chain management

Fig. 3.4 Circular economy for green supply chain management

(Source: https://www.freepik.com/free-vector/flat-design-circular-economy-infographic_21095200.htm#query=circular%20economy%20infographic&position=2&from_view=keyword&track=ais)

- Changing Customer Demand- Consumers behaviour indicates that that society have become conscious about environmental impacts. They are preferring products and services which are environment friendly and are less harmful for the society and future generation. Industries are analysing this purchasing pattern and are forced to innovate and adapt to greener products.

- Regulatory compliance- Countries have also adopted regulatory compliances, policies, and laws to ban or prohibit use of products or processes which harm the environment or cause any pollution. Example is use of plastic bags. Every organization must comply to these regulations. It is one of the criteria for ESG evaluation for all the industries.

- Competitiveness- Innovations and research and development in green technologies does not only sustain the environment but also helps organizations to create differentiation among the industries and to gain a competitive advantage. Consumers are also pressurizing industries to be green in all the activities such as recycling, reducing energy consumption and wastage etc. This in return will improve the efficiency of organizations and will help to remain competitive in the market.

3.3 Ranking and Calculating Weights of Risk and Green Parameters using AHP

The Analytic Hierarchy Process (AHP) technique has been used in calculating weights and ranks of various identified parameters grouped under risk and green parameters for developing a resilient optimal green supply chain management model. AHP is a powerful and understandable methodology that allows groups or individuals to combine qualitative and quantitative factors in decision making process. It is a multi-criteria decision-making method for complicated and unstructured problems. It is an approach that uses a hierarchical model having levels of goals, criteria, possible sub-criteria, and alternatives. The hierarchical processes in AHP can be represented as shown in Fig. 3.5 and a general schematic diagram of implementation of AHP for calculating weights and ranking is shown in Fig. 3.6.

AHP captures priorities from paired comparison judgements of the elements of the decision with respect to each of their parent criteria:

- Paired comparison judgements are arranged in a matrix.

- Priorities are derived from the matrix as its principal eigenvector.
- It also allows for the measurement of inconsistency in judgement.

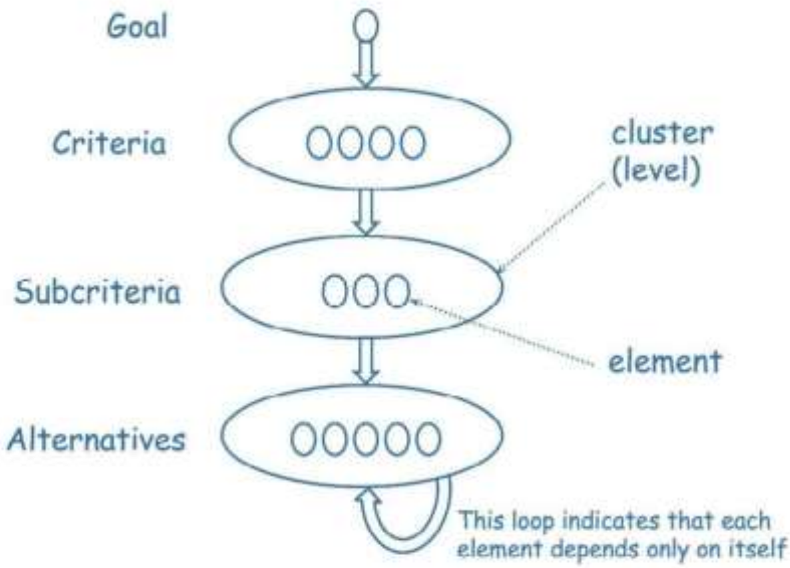

Fig. 3.5 Schematic diagram of processes in AHP

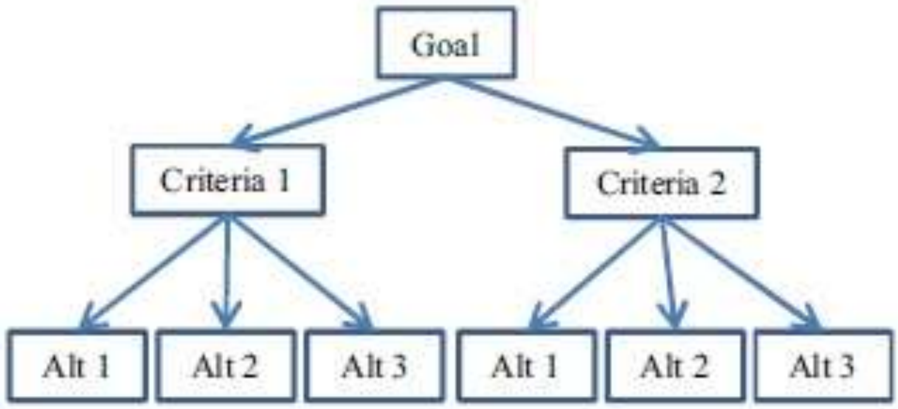

Fig. 3.6 Schematic diagram of implementation of AHP (after Hamdan and Cheaitou 2017)

Table 3.5 Satty scale

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate Importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity I has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	
1.1 1.9	If the activities are very close	Maybe difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities

The following steps are used to apply AHP technique for selection process:

1) Developing the hierarchical structure model by analysing relationships among all the factors. Here first, we define our goal. We then identify two layers, i.e., criteria layer and sub-criteria layer for analysing the options and in the third layer, we mention all the alternatives participating in the evaluation process among which selection needs to be done.

2) Construction of paired comparison matrix- Here, we start with the second layer of hierarchical structure model and use 1-9 comparison scale (Satty scale) to construct the paired comparison matrix for each element of that layer from upper layer to the bottom layer. The Saati scale is shown in Table 3.5.

   The paired comparison matrix is reflected below. It is a positive reciprocal matrix produced by pairwise comparison of each element.

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

   Here, the element r_{ij} satisfies with $r_{ij} \times r_{ji} = 1$

3) Combining of weight vectors- As this is qualitative comparison, geometric average is applied on $A_1,\ A_2 \ldots = A_k$ to obtain group evaluation matrix A. Maximum eigenvalue λ_A and its eigenvector ω. This synthesisation process can be explained following simple steps:
   a. Sum the value in each column of the pairwise comparison matrix
   b. Divide each element of the matrix by its column total. The resulting matrix is referred as normalized pairwise comparison matrix
   c. Compute the average of the elements in each row. These averages provide the priorities for the criteria.
4) Consistency test is carried out in each layer through following steps:
   a. Multiply each value in the first column of pairwise comparison matrix to the priority of the first item. Accordingly, it is carried out for each column. Sum the values across the rows to obtain vector of values or "weighted sum".
   b. Divide the elements of the weighted sum vector by the corresponding priority for each criterion
   c. Compute the average of the values which is denoted by λ_{max}
   d. Compute the consistency index from formula as expressed below:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

   where n is the no. of items being compared.

e. Compute the consistency ratio which is defined as:

$$CR = \frac{CI}{RI}$$

Here RI is the consistency index for a randomly generated pairwise comparison matrix. The value of RI depends on number of items being compared as shown below:

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 the combinational consistency rate $CR \leq 0.1$, the combinational weight vector ω could be regarded as the decision basis to choose the right alternative.

5) Ranking the combined weight vector with maximum combined weight vector as the best alternative

3.4 Formulating Multi-objective Optimization Model for GSCM

The single objective optimization problem has been commonly and widely used in decision making for various business operations. As discussed earlier, supply chain management is a critical element in business operation and is a determinative factor for business productivity and profitability. Thus, supply chain management often involves finding optimum solution that either maximizes or minimizes a single goal or objective function and most cases attempt to minimize the procurement cost. However, in most cases of the real-world settings, the decision making has become more difficult and complicated now-a-days because of the multiple stakeholders with diverse multi-viewpoints. This necessitates the development of a new multi-objective optimization model that is capable of accounting multiple diverse viewpoints as it enables us to examine many goals or objectives at once. It also helps to examine trade-offs in performance across goals or objectives as they reflect distinct criteria.

The multi-objective optimization (MOO) has emerged as a basic problem-solving approach for complicated decision-making scenarios. This technique helps in achieving the best possible trade-offs among competing goals to optimize several competing objectives at once. The multi-objective optimization gives a framework for examining and understanding the costs and benefits of alternative courses of action under different kinds of situations or circumstances. If there is no workable alternative option that can enhance at least one goal or objective without worsening any other objectives, then that solution is deemed to have Pareto optimal solution which forms the basis of multi-objective optimization. The Pareto front represents the best trade-offs among the goals and is the set of all Pareto optimal solutions. Thus, multi-objective optimization has now become an important and relevant technique that allows decision-makers to successfully address complicated situations with competing goals.

Multi-objective optimization can be defined as finding the optimal solution for two or more desired goals or objectives which may be conflicting in nature to each other. A generalized multi-objective optimization problem involving multiple criteria decision making and multiple restrictions can be mathematically expressed as follows (Keshari and Datta 1996):

Maximize or minimize $f_m(x)$ $\forall$ $m=1, 2,..M$

Subject to

$g_j(x) \geq 0$ $\forall$ $j=1, 2, ...J$

$h_k(x)=0$ $\forall$ $k=1, 2, ...K$

$x_i \geq x^{lb}$ $\forall$ $i=1, 2, ...N$

$x_i \leq x^{ub}$ $\forall$ $i=1, 2, ...N$

where x is a vector of N decision variables, functions f(x), g(x) and h(x) denote, respectively, objective function, inequality constraint, and equality constraints, m, j, and k are indices and M, J, K denote number of objective functions, inequality constraints, and equality constraints. The subscripts lb and ub denote lower and upper bounds, respectively. The decision or management policy can be tested for physical feasibility by using a model.

Multi-objective optimization is one of the emerging approaches preferred to address sustainability problems. In this project, the Epsilon constraint method has been used in multi-objective optimization where the algorithms for unconstrained problem can be converted to algorithms for constrained problems using the ε level of comparison. It compares the search points based on the pair of objective value and constraint violation of them. Using pareto-optimal solutions, trade-offs among various objectives can be obtained which helps in arriving at the best solution.

In the present study, a linear multi-objective optimal model has been formulated for the resilient green supply management by including multiple objectives keeping in views of traditional procurement and business operations as well as the aspects related to green procurement, environment, disruptive situations, and sustainability. The constraints have been also formulated by including traditional, green, and disruptive aspects so that the procurement plan must be green as well as resilient besides being optimal. The objective functions and constraints can be formulated as follows:

3.4.1 Objective Functions:

1. *Cost Objective Function:*

The first objective function has been formulated as the minimization of the total procurement cost. This is the first and traditional goal of any company for its business operation, and thus this objective function must be formulated accurately with high priority or consideration. The objective function for the minimization of procurement cost can be mathematically expressed as:

$$Minimize\ Z_1 = TCP = \sum_{i=1}^{n} \sum_{j=1}^{m} (C_{ij}\, x_{ij} + OC_{ij}\, x_{ij}) + \sum_{j=1}^{m} IC_j \sum_{i=1}^{n} x_{ij}$$

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 Control Objective Function:

The second objective function has been formulated for the quality control as it is an essential part in the supply chain as the supplied materials must pass the quality control test as it will affect the quality of the product output. Thus, the amount of quantity to be rejected through the quality control cost should be minimum. Thus, the second objective function can be formulated as the minimization of procurement cost can be mathematically 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. Timely Delivery Objective Function:

The third objective function has been formulated for the time management as the suppliers must deliver the items timely as the business operations may get affected adversely. This aspect is very important for manufacturing companies and several servicing sectors. Each vendor is expected to follow the time lead compliance. The timely delivery of materials ensures adequate inventory in the stores, avoids shortages while meeting the demand of business operations and provides reserves in disruptive situations. This is a very important and critical component of the supply chain. Thus, the third objective function has be formulated as the minimization of late delivered items by suppliers. This can be mathematically expressed as:

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

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:*

To take account of the green supply chain principles, the fourth objective function has been formulated keeping in view of environmental considerations. The environmental considerations could be reducing greenhouse gas emissions, reducing carbon footprint, reducing wastages, reducing water footprint, or reducing water and air pollution. These green considerations may result into several multiple objective functions depending upon the details of the business or company and green initiatives planned by the company management. This objective function is very important and relevant if green supply chain management strategies are required to be evolved, and thus this becomes a critical and very important component of the present study. To demonstrate the underlying concept, the fourth objective function has been formulated as the minimization of total greenhouse gas emissions for procurement. This may include the greenhouse gas emissions that may be attributed due to the type of vehicle used by vendors in supplying the material, green practices used by the vendor, carbon footprint of the product or item that is being supplied, packaging and delivery practices, etc. This objective function in simplistic form can be mathematically expressed 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 Score Objective Function:

This fifth objective function takes into account of green value score obtained for various vendors using AHP based on the green value parameters identified for the specific model application as discussed earlier. The green value score depends upon the drivers and barriers in green supply chain, disruptions and risks and other environmental considerations. While deriving green value scores for vendors, traditional aspects can be also considered to examine the cumulative effect of traditional and green aspects or initiatives associated with the supply chain management.

This objective function is very important and relevant as the main goal of the optimization for vendor selection or optimum purchase order allocation is aimed at promoting green supply chain management initiatives and thus optimal strategies are required to be evolved with these perspectives. Thus, this objective function becomes a critical and central component of the present study. The objective function is formulated by multiplying the AHP scores of vendors with the quantities supplied by them. Thus, this objective function can be mathematically expressed 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:

In addition to the objective functions described above, the developed multi-objective linear optimization model consists of several constraints for the optimal green supply chain management. These constraints are described below.

1. *Demand Constraints*

The total demand must be met in a planning horizon. Thus, the total purchased or supplied quantities should be able to fulfil the requirements of the company for running the business. This can be formulated to satisfy the demand requirement at every time level. However, to give the little flexibility in various time periods, the compliance of demand constraints has been formulated for the whole-time horizon. Thus, the demand constraints for such cases can be expressed as:

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

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

Where D is the demand and other variables and indices remain same.

2. *Supplier Capacity Constraints*

The total supply from a vendor cannot exceed its supplying capacity and thus such constraints must be put for a feasible solution. Thus, the supplier constraints can be expressed as:

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

Where SC_i is the supplying capacity of vendor i.

3. *Environmental Constraints*

To give high emphasis on environmental considerations, the environmental constraints may be constructed in several ways depending upon the environmental issues or aspects being considered in the model development or what the company management intends to support the environmental initiatives. In the present case, the environmental constraints are being expressed in terms of limitation on carbon footprint. Thus, the environmental constraints can be expressed as:

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

Where CF_{limit} is the permissible limit on greenhouse gas emissions from sourcing as these emissions result from various vendors within the planning horizon.

4. *Supplier Budget Allocation Constraints*

The company may would like to put restriction on the budget amount allocated to vendors for supplying the items. This constraint may become very effective in decision making while dealing with disruptive situations or vendors who are habitual of quoting higher cost or these constraints may even result from cost cutting by the company due to financial limitations/constraints. Thus, the supplier budget allocation constraints can be expressed as:

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

Where B_i is the budgetary limit for vendor i.

5. *Vendor Relation Constraints*

To maintain a good relationship with promising or reliable or experienced vendor, a minimum order may be required to be placed. Thus, the vendor relation constraints can be expressed as:

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

Where $S_{min\ i}$ is the minimum order for supply to be given to vendor i.

6. *Inventory Constraints*

The purchase materials should neither overflow in the store nor create any shortage for smooth functioning of business operation and without putting any additional financial burden. Thus, the inventory constraints can be expressed as:

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

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

Where I_i is the inventory in the stock for the purchase item x_{ij} at time j, and I_o is the initial inventory in stock.

These constraints keep accounting of stocks and inventory is updated. This ensures timely delivery of materials requirement and avoiding excess inventory.

7. *Non-negativity Constraints*

The optimization models based on linear programming must satisfy the non-negativity constraints. Thus, the nonnegativity constraints can be put on the decision variable x_{ij}. The zero value indicates that the associated vendor is not selected, and no quantity would be placed for purchase order for that vendor for that time or period. Thus, the non-negativity constraints can be expressed as:

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

4.

RESULTS AND DISCUSSION

4.1 Variation of Risk in SCM

A survey was conducted with the developed questionnaire set from various industries to identify and quantify the risk associated with the supply chain. The survey was distributed among different supply chain managers representing different companies to cover the various activities of supply chain management including large and small industries from India. A total of six large companies and 20 small companies were interviewed to study the nature and complexity of risks associated with the supply chain in their business. These observations and findings derived from this study are helpful in evolving strategies to mitigate the uncertainty and disruptions in supply chain for sustaining the economic growth. The set of questionnaires used for conducting the interview of representatives of all the companies have been already discussed in the previous chapter. The size of the company is reflected in terms of turnover, employee strength and business verticals. The survey data is mixed and thus the findings cannot be attributed to a single category of the industry.

Based on the survey data collected from various industries, the risks encountered by large industries were estimated and are shown in Fig. 4.1. The risk associated with the industries has been grouped under five categories. These categories are supply, demand, manufacturing, financial, and environmental. It is evident from this figure that a very high value of supply risk of 42% is associated with the large industries. It is followed by the demand and manufacturing risks of 23% and 18%, respectively. There is an environmental risk of 9%. The large value of risk associated with the supply may be also attributed to transportation particularly during disruptions. The risks associated with the small industries is shown in Fig. 4.2. It is evident from this figure that there is 25% risk associated with the supply. The largest risk is associated with the environment, being equal to 30%. The comparative analysis of Figs.

4.1 and 4.2 show that the larger industries are more vulnerable to supply risk, whereas the smaller industries are more vulnerable to environmental risk.

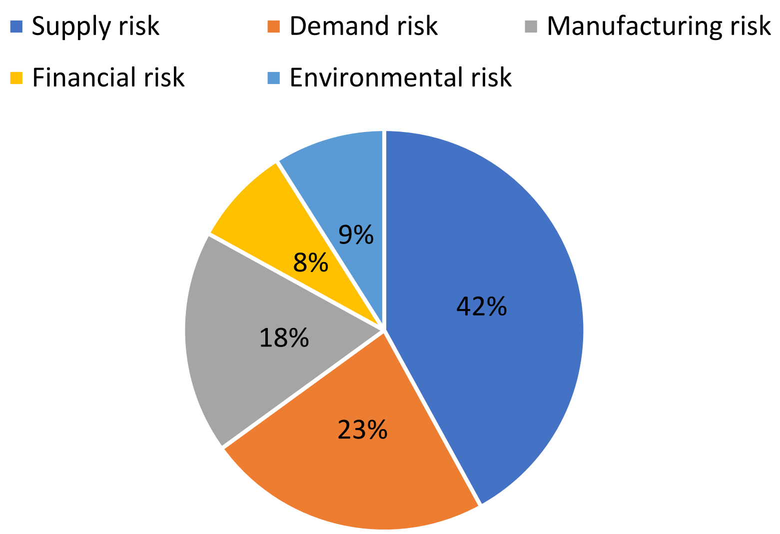

Fig. 4.1 Risk associated with large industries

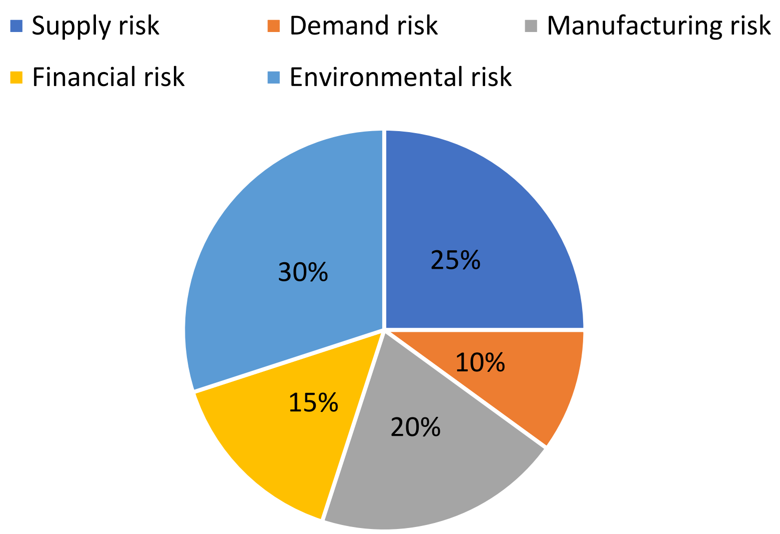

Fig. 4.2 Risk associated with small industries

4.2 Weights and Ranks of GSCM Parameters obtained from AHP

For the application of the developed model, five supplying vendors have been considered. Based on the identified risks, drivers and barriers, these factors and aspects have been grouped under five green supply chain management parameters for the numerical analysis of case study application. These GSCM parameters are being referred as (i) waste minimization initiatives, (ii) use of green fuel in transportation, (iii) greenhouse gas emission from sourcing, (iv) delivery time failure (late delivery), and (v) rejection rate (quality control test failure). The first three parameters are characterizing green procurement, the fourth parameter is characterizing disruption risk, and the fifth parameter is characterizing traditional parameter for quality control to ensure product quality. These GSCM parameters are being referred as GP1, GP2, GP3, GP4, and GP5. The supplying vendors are being represented as S1, S2, S3, S4, and S5.

Based on the values of parameter values for various vendors, the vendors given the theoretical classification rank, here they have been given ranks like 1, 2, 3, 4, and 5 as shown in Table 4.1. The value or score of 5 indicates high rank and the value of 1 shows low rank with reference to green value in this model application. These theoretical ranks were given based on the knowledge of vendors with reference to green attributes and the relationship between factors/parameters and green principles of SCM. For example, the first two parameters are directly proportional to the green value as the green value will increase as the values of these two parameters increase. On the other hand, the green values of remaining three parameters are inversely proportional to the values of these parameters as more greenhouse gas emissions, more delivery time failure, or more rejection rate will be taken as negative to the green principle and so less score or rank will be given for green value with reference to those parameters and vendors.

The pairwise matrix based Saaty scale is given in Table 4.2. The normalized matrix was computed and is shown in Table 4.3. The weight matrix obtained is shown in Table 4.4. Then after, the consistency ratio was computed for the acceptability of weights. The consistency matrix is shown in Table 4.5. The consistency index (CI) comes out to be 0.085919. The random index (RI) from Saaty table comes out to be 1.1 for 5 parameters. Thus, the consistency ratio (CR) comes out to be 0.078 which is less than 0.1, thus weights are acceptable. The factors were reclassified after re-computing the weights. Based on the weighted sum, the vendors were given green value rank and is shown in Table 4.6.

The variation of weight for green value for various vendors is shown in Fig. 4.3. It is evident from this figure that the supplier vendor 3 has scored the maximum score, followed by supplier vendor 4. The lowest score was obtained for supplier vendor 2.

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

	S1	S2	S3	S4	S5
GP1	2	1	5	4	3
GP2	2	1	5	4	3
GP3	5	4	1	3	2
GP4	5	4	1	3	2
GP5	4	5	2	3	1

Table 4.2 Pairwise matrix for 5-vendor 5-green attribute problem

Pairwise Matrix					
	GP1	**GP2**	**GP3**	**GP4**	**GP5**
GP1	**1**	2	8	9	6
GP2	0.5	**1**	9	9	3
GP3	0.125	0.111111	**1**	2	0.166667
GP4	0.111111	0.111111	0.5	**1**	0.142857
GP5	0.166667	0.333333	6	7	**1**
Column Total (CT)	1.902778	3.555555	24.5	28	10.30952

Table 4.3 Normalized matrix for 5-vendor 5-green attribute problem

Normalized Matrix						
	GP1	**GP2**	**GP3**	**GP4**	**GP5**	**Row Total (RT)**
GP1	0.525547	0.562500088	0.326531	0.321429	0.581986	2.317992788
GP2	0.262774	0.281250044	0.367347	0.321429	0.290993	1.523792312
GP3	0.065693	0.031249974	0.040816	0.071429	0.016166	0.225354608
GP4	0.058394	0.031249974	0.020408	0.035714	0.013857	0.159623317
GP5	0.087591	0.093749921	0.244898	0.25	0.096998	0.773236975

Table 4.4 Weight matrix for 5-vendor 5-green attribute problem

GP1	**0.463598558**
GP2	**0.304758462**
GP3	**0.045070922**
GP4	**0.031924663**
GP5	**0.154647395**

Table 4.5 Consistency matrix

5.713756
5.556729
5.025562
5.072113
5.350224

Table 4.6 Reclassified factors: weights and ranks for 5-vendor 5-green attribute problem

	S1	**S2**	**S3**	**S4**	**S5**
GP1	0.927197	0.463599	2.317993	1.854394	1.390796
GP2	0.609517	0.304758	1.523792	1.219034	0.914275
GP3	0.225355	0.180284	0.045071	0.135213	0.090142
GP4	0.159623	0.127699	0.031925	0.095774	0.063849
GP5	0.61859	0.773237	0.309295	0.463942	0.154647
Weighted sum	2.540282	1.849576	4.228075	3.768357	2.61371
Green Value Score (Rank: High: 5, Low: 1)	2	1	5	4	3

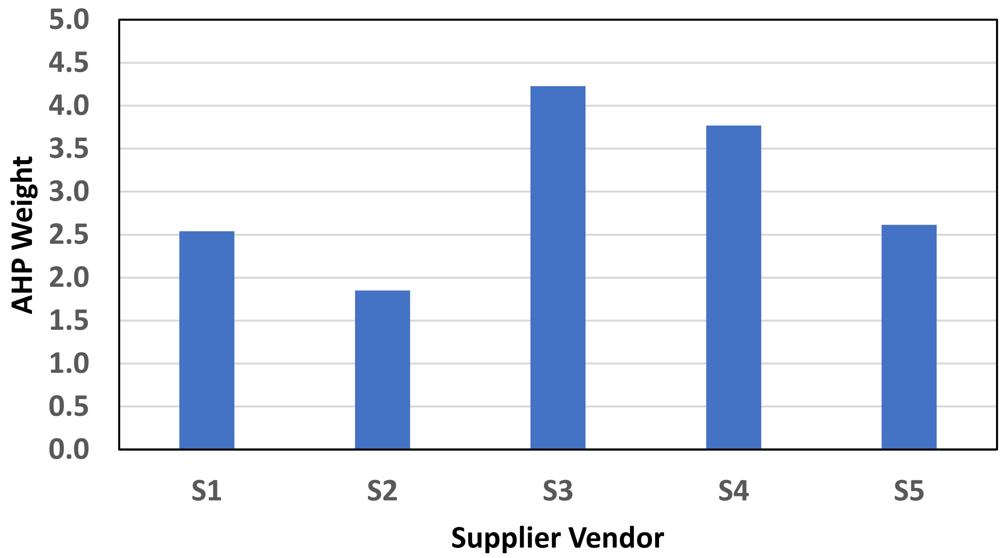

Fig. 4.3 Variation of green value score derived from AHP

4.3 Optimal Solution for Vendor Selection

The numerical solution of the optimization model was obtained for a specified data set. The data set was taken from the published literature as given in Shaw et al. (2012) as these data were not available for the companies through which surveys were collected for risk identification and quantification. The first four objective functions were considered. The unit cost of four suppliers were considered equal to 6, 7, 4, and 3 units. The percentages of rejected items from these suppliers were taken equal to 0.05, 0.03, 0.02, and 0.04, respectively, whereas the time delivery failure data for these vendors were taken equal to 0.03, 0.02, 0.08, and 0.04, respectively. The greenhouse gas emissions equivalents for these vendors were considered equal to 1.3, 1.5, 1.2, and 1.6 kg, respectively. The suppliers' capacities were taken equal to 6000, 14500, 7000, and 4000, respectively, whereas the budgetary allocation data for these four vendors were taken equal to 24000, 70,000, 60,000, and 10,000, respectively.

The optimal solution of the multi-objective optimization model was obtained through a solver by repetitively solving optimization model using the epsilon constraint method. The optimal solutions obtained for vendor selection and purchase order are shown in Figs. 4.4-4.5. Fig. 4.4 shows that all the last three vendors except the first vendor were selected for purchase ordering. The optimal values of various objective functions are shown in Fig. 4.5. It is evident from Fig. 4.4 that vendor S1 is not given any order and the vendor 2 gets maximum supply order. The rejection and delivery failure of items are very less as evident from Fig. 4.5.

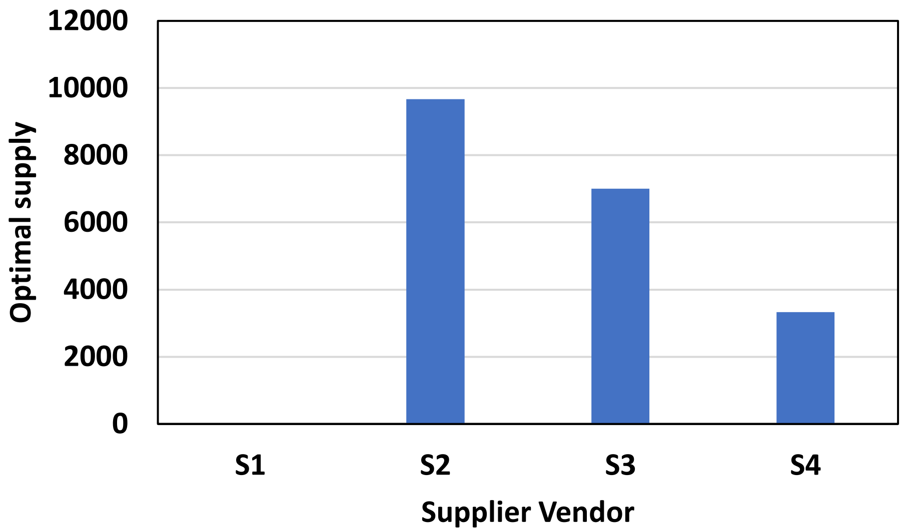

Fig. 4.4 Optimal supply from various vendors

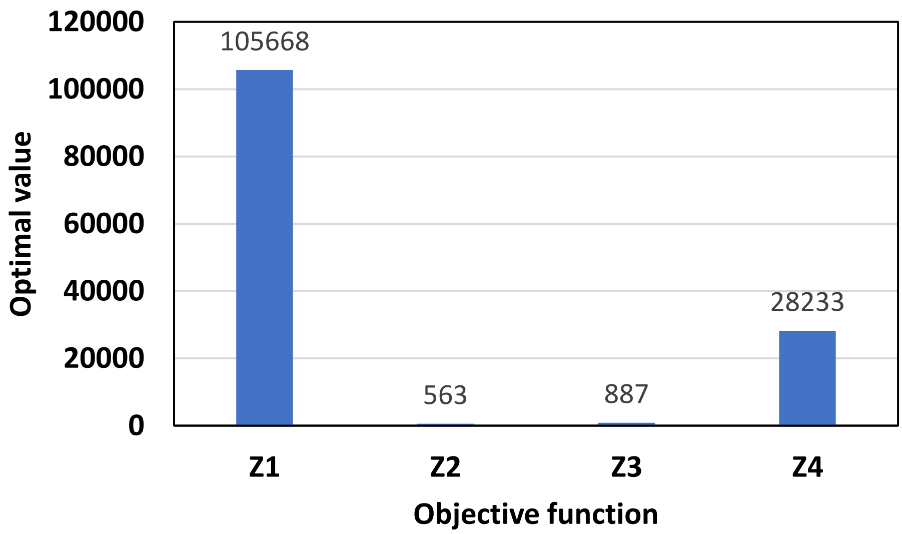

Fig. 4.5 Optimal values of objective functions

Fig. 4.6 shows that vendor 2 has large supplying capacity and it is capable of meeting demand satisfactorily. The vendors 3 and 4 are near to their saturation capabilities. The vendor S1 doesn't get any order despite having supply availability. It is also evident from Fig. 4.7 that the vendors 2 and 4 are getting optimal purchase value orders closer to their allotted budget, whereas vendors 1 and 3 are far behind to meet budgetary allocations.

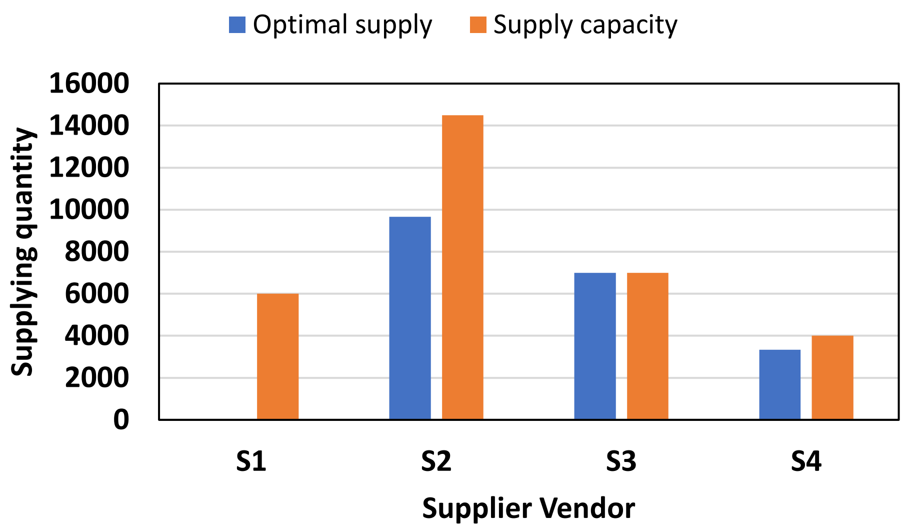

Fig. 4.6 Comparison of optimal supply and supply capacity of vendors

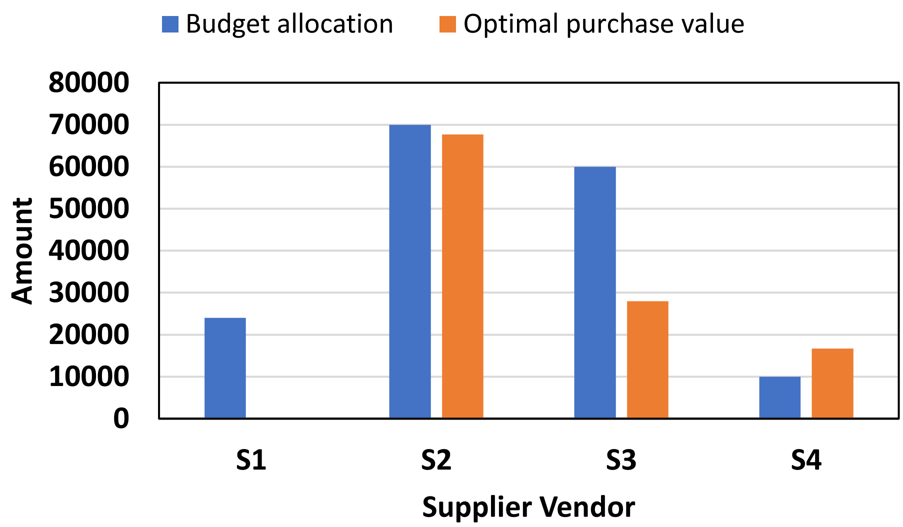

Fig. 4.7 Comparison of optimal purchase value and budgetary allocation for vendors

4.4 Supply Chain Resilience Strategies

GSCM has emerged as a key approach to have industrial growth and environmental sustainability. The notion implies insertion of environmental decisions within these supply chain activities. We can summarize it as integration of eco-friendly activities in manufacturing of products, logistics activities, delivery of products to end consumers, storage and inventory management, packaging, and end of life management of product after its useful life. These include following functions:

- Procurement activities- It includes evaluation of supplier operations in terms of raw material handling, packaging, transportation method etc.
- Distribution activities- Comprises of activities related to disposal of scrap, sale of excess stock, recycling opportunities.
- Manufacturing activities- Use of technologies for green production causing minimum pollution and wastage.

The potential areas for implementation of GSCM are as follows:

- Product design, packaging and labelling
- Transportation of hazardous material
- Manufacturing processes for waste reduction or elimination
- Suppliers selection
- Waste/scrap disposal

Several supply chain resilience strategies can be evolved after supplier selection and order allocation as per GSCM, based on the risks involved in the company operations, particularly supply chain of the business operation. The supply chain resilience strategies could be evolved based on the factors that have potential to affect the whole supply chain, or a particular segment in supply chain such as supply, production, or transportation component. Fig. 9 shows the various supply chain strategies that can be implemented during various phases of disruptions. These strategies could be expressed as:

- Developing collaborative relationships among supply chain partners
- Diversification strategies
- Establishing business continuity management systems for supply chain
- Distributed power
- Information sharing

- Developing unbreakable relationships with key suppliers
- Flexible supply base and multiple sourcing
- Suppliers' risk awareness
- Identical plant design/process facility
- Reduced recovery time by anticipation and preparedness
- Mapping multiple transportation routes
- Identifying multi-modal transportation

Operational Challenges:

a) Increase in prices of all raw material:

- Bulk Procurement- It provides benefit of less orders, low prices. It also results in lesser machine setups and other associated costs.
- Negotiating Savings and Payment terms with vendor partners to obtain credit benefit. Strengthening vendor panel, conducting reverse auctions, cost-break up analysis, price trend forecast.

b) Disruption in logistics and transportation:

- Prioritization of urgent material as per defined priority level/ syndication with user (short term)
- Country wise mapping to be done for all import orders and region wise mapping for local vendors.
- Regions to be mapped as “Hot Zones” while identifying the regions which are adversely affected, and which have minimal impact.
- De-routing of consignments based on above analysis to ensure timely delivery of material
- Continuous discussion with vendor partners for information sharing and collaborating with strategic suppliers for risk mitigation during urgency.

c) Shortage of Inventory and Critical Consumables:

- Critical operational consumable material list compilation along with urgent indigenous materials as per MSD planned

- Dedicated workforce for delivery follow-up with all the suppliers for orders with potential risk of non-delivery and streamlining the process
- Maintaining buffer stock of critical consumables
- Tracking of transit material and monitoring hot zones for alternate route planning of flagged orders
- Alternate vehicle arrangements through Transportation team for critical spares delivery stuck in Hot Zones

d) Dependency on import vendors/ single sources or proprietary vendors:

- Shift orders between suppliers, plants, and geographies to meet the urgency (Short terms)
- With the help of end-users, developing new vendors (de-prioritization, Localization and Indigenization) for risk mitigation and dependency on single sources vendors (Mid- term)
- Identifying alternate material with the help of end-users and having a mix orders to keep a balance and continuity of the production (long term)

e) Space Constraint for inventory monitoring (due to increased stock):

- Storage space to be optimized and alternate storage space to be identified (short term)
- Storage location wise capacity planning to be carried out for key process consumables (short term)
- Visualization tool to be created for end-to-end inventory visibility (mid-term)
- Vendor Managed Inventory implementation for critical consumables and inventory reduction

f) Disruption in Operation due to unavailability/ shortage of workforce:

- Pool of skill resource to be created for replacing manpower at covid impacted areas (or cyclone/tsunami prone areas)
- End to End process visibility through Digital implementation

- Develop new capability by selecting, designing and implementing new (information) technology such as blockchain applications, machine learning capability for event management
- Transparency of the inventory and demands within the team as well as with vendor partners using IT tools for monitoring of stock and planning of timely execution of orders

g) Process adequacy:

- Labour intense process to be identified and possibility of mechanization should be investigated to mitigate the risk
- Digitalization of the complete Procure to Pay process in Supply Chain for enhancing and streamlining the process of supply chain

<u>Human Resource Challenges:</u>

- Identification & development of alternate resources for multi-tasking should be planned and training to be imparted
- Skill workforce pool to be created and temporary shelter to be arranged for employee working on extended hours on shop floors and warehouses
- Arrangement of transportation as per the job requirement for the workforce involved in different activities of supply chain (taking consideration of lockdown during Covid and blocked roadways during cyclone/tsunami)

<u>Communication:</u>

- Dissemination of early warning signals for speedy response to adverse indicators
- Communication to suppliers/ stakeholders for critical consumable supplies for better preparedness in case of pandemic situation
- Data Storage and visualisation of preservation of Tacit, Implicit and Explicit knowledge

5.

CONCLUSION

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 disruptions in the supply chain are highly unpredictable and cause large uncertainties and affect the business and economy severely. Supply chain management in uncertain environment is a challenging, complex, and highly unpredictable because of the huge and diverse adverse impacts of disruptions on the supply-demand mismatch and company's business. These disturbances induce instability in the supply chain and the survival, sustainability, and growth of the company.

A multi-criterion decision making multi-objective optimization model has been developed for resilient Green Supply Chain Management which accounts disruptions as well as environmental considerations to arrive at the optimal vendor selection and optimal placing or allocation of purchase orders. A linear multi-objective optimization model has been formulated with green weights derived from AHP. The developed optimization model consists of five objective functions and seven different categories of constraints. The objective functions include cost, quality control, timely delivery, environmental, and green value score functions. The constraints include limitations on demand, supplying capacity, environmental, budgetary allocation, vendor relation, inventory, and non-negativity. The study identifies and quantifies risks associated with the supply chain. The identification and quantification of risks were carried out through an empirical approach by interviewing the candidates with a structured questionnaire. The survey was carried out with six large industries and 20 small industries. The drivers and barriers in the supply chain were identified. Based on these aspects including disruptions, various traditional and green parameters affecting supply chain were screened out for obtaining the weights, ranks, and green value scores for these parameters using Analytic Hierarchy Procedure (AHP). The obtained AHP weights were used in the developed multi-objective optimization for determining optimal vendor selection and optimal order placement.

The study reveals that there is a high supply risk associated with the large industries, whereas the environmental risk is high with small industries. The numerical analysis for calculating weights and ranks using AHP was carried out for 5 vendors and 5 green parameters. The model can examine traditional and green approaches for optimal solutions. Optimal solutions can also be obtained for a combination of traditional and green approaches in supply chain management. The use of such models will help in evolving optimal strategies for procurement and optimizing other components in the supply chain. The developed 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.

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