Major Research Project

Green Supplier Selection Using the MCDM approach: An Analysis based on a Manufacturing Firm

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Certificate

This is to certify that **Jenith Patel, 2K21/DMBA/57,** has submitted the project report titled "Green Supplier Selection using the MCDM approach: An Analysis based on a Manufacturing Firm' in partial fulfillment of the requirements for the award of the degree of Master of Business Administration (MBA) from Delhi School of Management, Delhi Technological University, New Delhi during the academic year 2022-23.

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Declaration

I, Jenith Patel, a student of Delhi School of Management, Delhi Technological University, hereby declare that the Major Research Project on ‘Green Supplier Selection using the MCDM approach: An Analysis based on a Manufacturing Firm’ submitted in partial requirements for the award of the degree of Master of Business Administration (MBA) under the guidance of Prof. P.K. Suri is the original work conducted by me. I also confirm that neither I nor any other person has submitted this project report to any other institution or university for any other degree or diploma. I further declare that the information collected from various sources has been duly acknowledged in this project.

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ABSTRACT

With increasing government regulations and growing awareness of the harmful/hazardous effects of pollutants resulting from rapid industrialisation, organisations can no longer turn a blind eye to environmental concerns. To even compete in the global market, it is essential to prioritise environmental issues. Essentially, manufacturing industries play an instrumental role in developing a country's economy in this globalised landscape.

In this globalised scenario, the overall performance of manufacturing industries has been the backbone of developing the countries' economies. Incorporating the green criteria into the selection practices of conventional suppliers is vital for organisations promoting green supply chain management. Procurement and supplier management professionals have broadly recognised challenges associated with supplier selection.

Developing and implementing practical decision-making tools that cater to these challenges are drastically changing and evolving. MCDM approach have been applied in the literature to identify suitable GSCM practices of the selected manufacturing company. Some of the popular MCDM approaches include Analytical Hierarchy Process (AHP), the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE).

With the help of the Triangular Interval-Valued Fuzzy TOPSIS Method, it is concluded that the five demographic characteristics are majorly linked with categorising the selected industry and determines its performance in the sector of manufacturing.

This project also has implications for supply chain management managers to solve problems pertaining to Multi-Criteria Decision Making and connected to the implementation of Green Supply Chain Management practices in the selected firm. The same evaluation criteria may be applied to solve other MCDM problems, like evaluating success factors to implement GSCM practices.

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CHAPTER 1 – INTRODUCTION

1.1. Background of Manufacturing Industry

The manufacturing industry has a long history of relying on supply chain relationships and suppliers to operate efficiently and effectively. The connection between suppliers and manufacturers has evolved with time, but the basic principles have remained the same. In the past, manufacturers would often have a limited number of suppliers for raw materials and other inputs, and these suppliers were often located nearby.

However, globalization and advances in transportation and communication have made it possible for manufacturers to source materials and inputs from anywhere in the world. Today, manufacturers typically have complex supply chains that involve many different suppliers, often spread out across the globe.

These suppliers may provide everything from raw materials and components to logistics services and even research and development support. To manage these complex supply chains, manufacturers have developed a variety of strategies and tools, including just-in-time inventory management, lean manufacturing, and supply chain mapping.

They also often work closely with suppliers to build healthy relationships on the basis of collaboration, trust, and common benefit. In recent years, it has been observed that focus is growing on sustainability and ethical sourcing in the manufacturing industry, with many companies placing increased importance on working with those suppliers who have a shared commitment and value to green criteria and social responsibility. This has implications in the building of new supply chain standards and certification programs, as well as greater transparency and accountability in supply chain relationships.

1.1.1. Market Size

The market size of the manufacturing industry varies greatly depending on the country, region, and specific sector within manufacturing. However, based on Grand View Research, a report published in 2021, the manufacturing market size globally was found to be valued at USD 33.44 trillion in 2020 while compound annual growth rate (CAGR) is expected to rise at a rate of 5.1% from 2021 to 2028.

The manufacturing industry encompasses a wide range of sectors, including food and beverage, pharmaceuticals, automotive, aerospace, electronics, and more. Each of these sectors has its own market size and growth rate and can be influenced by various factors such as economic conditions, technological advancements, and government policies. Overall, in the world economy, a significant role is played by the manufacturing industry, and its market size and growth are closely monitored by analysts, investors, and policymakers.

Figure 1:Utilization of Capacity (in percentage) in manufacturing sector

Source: Indian Brand Equity Foundation

As of 2021, the manufacturing industry plays an important role in its contribution to India's economy and accounts for approximately 17-18% of India's GDP. India's manufacturing sector encompasses a wide range of industries, including textiles, chemicals, pharmaceuticals, automotive, electronics, and more.

The size of each of these sub-sectors varies, with some being larger than others. For example, the automotive industry is a major contributor to the manufacturing sector, while the electronics industry is still in its initial stages of development.

Overall, the manufacturing industry in India has significant potential for growth, with the government of India undertaking different types of initiatives to boost the growth of the sector and bag the attention in foreign investment.

1.1.2. Road Ahead

The manufacturing industry in India has immense potential for growth, and the government of India has undertaken several initiatives to boost the sector's growth. Here are some of the key developments and opportunities in the Indian manufacturing industry:

1. Make in India: Launched in 2014, the Make in India campaign aims to promote manufacturing in India and attract foreign investment. The government has introduced several policy reforms to make it easier to do business in India and has also created dedicated investment zones for manufacturing.
2. Focus on digitalization: The Government of India has recognized the significance of digitalization in driving manufacturing growth and has launched the Digital India campaign. This initiative aims to create a digitally empowered society and boost the adoption of digital technologies in manufacturing.
3. Industry 4.0: India is also focusing on adopting Industry 4.0 technologies, which include the artificial intelligence, robotics, and Internet of Things, among others. The government is encouraging the adoption of these technologies in the manufacturing sector to improve productivity, reduce costs, and enhance quality.
4. Infrastructure development: The Indian government is investing heavily in infrastructure development, which includes building new highways, ports, and airports, among other things. This infrastructure development will provide a significant boost to the manufacturing industry by improving connectivity, reducing logistics costs, and enabling better access to global markets.
5. Export promotion: The Indian government is also focusing on promoting exports from the manufacturing sector. This includes creating dedicated export promotion councils and providing incentives for export-oriented manufacturing.

Overall, the road ahead for the manufacturing industry in India looks promising. With the government's focus on promoting manufacturing and adopting new technologies, the sector is poised for significant growth in the coming years.

1.2. Problem Statement

Manufacturing companies are facing increasing pressure from stakeholders to inculcate environmental considerations into their SCM practices. Selection of environmental suppliers has emerged as an effective strategy for organizations to achieve sustainability goals while maintaining their competitiveness.

However, selecting green suppliers is a complex task that requires keeping in mind multiple criteria and the trade-offs between conflicting objectives. Therefore, the goal here is to study and develop a multi-criteria decision-making (MCDM) approach to help the selected manufacturing organization in identifying green suppliers.

The study will focus on identifying the main and significant criteria for selection of green supplier, such as performance of environment, quality, cost, and delivery, and evaluating the performance of potential suppliers based on these criteria. The MCDM approach will enable decision-makers to compare and rank the suppliers based on their overall performance and make informed decisions about supplier selection.

The case study will be conducted of the selected manufacturing firm to depict the applicability and effectiveness of the given approach. The study will provide insights into the challenges and opportunities of applying green supplier selection in this manufacturing firm and contribute to the development of sustainable supply chain management practices.

1.3. Objectives

The main objectives for conducting the study are:

- To identify the types of Green Supply Chain Management Practices along with Conventional and Social Practices.
- To assign weights of relative importance of sustainable criteria.
- To make comparative evaluation of Practices in Manufacturing firm.
- To carry out Sensitivity Analysis for examining the effect on selection of suppliers of the criteria weights.

1.4. Scope

The research has been done to study the supply chain practices of this selected manufacturing firm. Ratings have been taken from this industry's experts to assign weights to each one of the suppliers and the practices. A comprehensive study of the connected suppliers and the related practices has been carried out to analyze and draw a conclusion. TOPSIS method has been taken to measure and calculate based upon which evaluation is done and suppliers are ranked. To examine the effects of each of the weights, Sensitivity Analysis has been performed as the last step in investigation.

CHAPTER 2 – LITERATURE REVIEW

2.1. Identification of Supply Chain Practices

The objective of this sub-section is to identify the significant supply chain practices that are used by manufacturing firms and have been mentioned in past research papers. Survey of the research papers and the literature was done with the help of key words such as conventional SC practices, green supplier selection, environment responsive SC practices, social practices for sustainability and so on.

To explore the research papers that have been previously published in journals, several platforms and databases were used such as:

- Springer
- ISI (The Institute for Scientific Information)
- IEEE (The Institute of Electrical and Electronics Engineers)
- WoS (Web of Science)
- Scopus
- Google Scholar
- Science Direct
- Emerald
- DOAJ (Directory of Open Access Journals)

There were 15 parameters identified and categorized into 3 dimensions of supply chain practices to achieve overall sustainability. These three dimensions of practices are:

- Conventional Criteria
- Environmental Criteria
- Social Criteria

The details about these dimensions have been discussed in the following sections.

2.1.1. Conventional Criteria

A significant amount of research has been done considering different criteria for the activity of selection of suppliers. (Dickson, 1966) presented 23 criteria for the selection of supplier made through a survey of decision makers. The research sorted the criteria as warranties, performance, capacity, quality, cost, delivery of production facilities.

This paper was one of the earliest works on selection of suppliers. While (Ho et al., 2010) highlighted that the most successful criteria of supplier selection are drawn as delivery, price, and quality.

There was also a study performed by (Chang et al., 2011) which argued that there are top 10 criteria that received most attention. These are quality, production, service level, reduction on demand change, cost, capacity of related facilities, lead time, delivery, reliability, environmental control, flexibility, quality, and technology capability. Subsequently, the selection criteria are not similar in every research papers.

Based on these studies, five significant conventional parameters have been mapped out and taken into consideration for the ranking. These are:

- Supply Capacity
- Quality
- Technological Capability
- Price
- Service Level

2.1.2. Environmental Criteria

Though there has been much research conducted on SRM (Supplier Relationship Management) and its various concepts, it was a term coined in (Kraljic, 1983). It then evolved and the most widely recognized definition was given by the (Sanders, 2020) as “co-ordination, collaboration and information sharing between supply chain members”. When (Jones, 1995) model was introduced, the customer-supplier relationship model evolved with different approach in literatures.

These various perspectives of analysing the SRM leads to much research over different applications, but very few literatures focuses on anyone or all of the dimensions with sustainability. For instance, it was (Tidy et al., 2016) that highlighted the impact of SRM in the sustainability of environment through the decrease of greenhouse gas emissions in the application of food supply chains in United Kingdom.

While (Govindan et al., 2015) argued that for measuring supplier sustainability, an approach of fuzzy multi criteria can be taken and environmental criteria such as environmental management system, eco-design, resource consumption, and pollution production can be considered.

(Lee et al., 2009) put forward pollution control, technology capability, green competencies, quality, green products, and environment management for selection of green supplier in the high-tech industry.

(Bai & Sarkis, 2010) highlighted that grey system along with rough set methodologies can be used to integrate sustainability into supplier selection and provided a gist of environmental metrics such as pollution production, prevention, resource consumption, and environmental management system.

Based on these studies, five significant environmental parameters have been mapped out and taken into consideration for the ranking. These are:

- Environmental Management Systems
- Green Image
- Waste Level
- Pollution Production
- Environmental Competencies

2.1.3. Social Criteria

A sustainable supplier keeps in mind not only economic benefits and environmental aspects, but also different types of social issues in its operations, such as health of labour and safety in jobs, opportunities in jobs, child labour, etcetera.

More than 300 papers have been reviewed in (Seuring, 2013) after the initial research by (Seuring & Müller, 2008). Studies were reviewed on the sustainability where modelling techniques were applied on supply chain management. It was found that only 36 of these studies had a clear idea to build or use quantitative models, and so since then, a conclusion was drawn that there is a clear domination of environmental dimension, and ignorance of social dimension was seen.

To make sure that higher corporate sustainability is achieved and accomplished, companies need to work with suppliers who are co-operative with them, and/or sustainable. There have been suggestions to the companies from the researchers to try not only decreasing the costs in procurement, but also to keep in mind and develop the attitudes towards the social well-being of the suppliers for their community and the employees, along with the environmental impacts of the operations.

There have been limited studies on sustainable supplier ranking using social criteria considerations. (Maignan et al., 2002), also discussed and highlighted a procedure for companies to incorporate the criteria of social responsibility while making purchasing decisions.

Based on these studies, five main social parameters have been mapped out and taken into consideration for the ranking. These are:

- Safety, rights, and health of employees
- Staff Development
- Information Disclosure
- Forced-Child Labour
- Adherence to law and policy

2.2. <u>MCDM approaches in supplier selection.</u>

Identifying and applying the most successful procedure for evaluating the suppliers is kind of a headache for procurement and purchasing managers. Through the evaluation process, some pre-defined standards are set through which the best suppliers are selected, and any possible deviation is identified among the suppliers.

There are widely applied methods for evaluating supplier performance such as:

- Fuzzy AHP (Analytical Hierarchy Process),
- DEA (Data Envelopment Analysis),
- Fuzzy TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution)
- Fuzzy VIKOR (Multi-Criteria Optimization and Compromise Solution,
- Fuzzy DEMATEL (Decision Making Trial and Evaluation Laboratory),
- Fuzzy ANP (Analytic Network Process),

- Fuzzy PROMETHEE (Preference-Ranking-Organization-Method-for-Enrichment-of-Evaluation),
- Gray Approach,
- 2-Tuple Fuzzy Linguistic Representation Model,
- Fuzzy Sustainability Index

In this scenario, the TOPSIS methodology plays a significant role in evaluating the overall supply chain system of the organization. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision analysis method that was initially the concept of (Hwang & Yoon, 1981). Later on, some more research and surveys were done by (Yoon, 1987). Much later, (Hwang et al., 1993) made this complex method more feasible and easier to compute.

According to (Sahin & Yigider, 2016), the TOPSIS method is a process of determining the rank of the alternative concerning their distances and has also been applied in many areas relying on computer support to overcome evaluation problems under a finite number of alternatives.

(AKKOÇ & VATANSEVER, 2013) have evaluated the monetary performance of twelve commercial banks in Turkey by using two different FMCDM (Fuzzy multi-criteria decision making) approaches as well as FAHP (Fuzzy analytic hierarchy process) and FTOPSIS (Fuzzy technique for order preference by similarity to an ideal solution) methods. The authors concluded that the fuzzy AHP method measures the performance in a hierarchical structure by the use of a pairwise comparison matrix and the fuzzy TOPSIS method assesses the performance by the use of Euclidean distance to calculate fuzzy negative and positive ideal solutions.

2.3. Sensitivity Analysis: A review on the literature

Sensitivity analysis is an important technique used in decision making to determine how the results of a decision may change due to changes in the input data or assumptions. In this literature review, we will focus on studies that have used sensitivity analysis with respect to TOPSIS in supplier selection.

One study conducted by (Jia et al., 2018) used TOPSIS to evaluate and select suppliers for a company. The study also used sensitivity analysis to investigate the robustness of the results. The results showed that the selected suppliers were robust to variations in the weights of the criteria used in the TOPSIS method.

Another study by (Bai & Sarkis, 2017) used a fuzzy TOPSIS method to evaluate and select suppliers for a manufacturing company. The study performed sensitivity analysis to investigate the impact of variations in the weights of the criteria on the ranking of the suppliers. The results showed that the ranking of the suppliers was sensitive to changes in the weights of some of the criteria, but not all.

In a study by (Chang et al., 2015), the authors used TOPSIS to evaluate and select suppliers for a construction project. The study also performed sensitivity analysis to investigate the impact of variations in the weights of the criteria on the ranking of the suppliers. The results showed that the ranking of the suppliers was sensitive to changes in the weights of some of the criteria, but not all.

In another study by (Zhang et al., 2019), the authors used TOPSIS to evaluate and select suppliers for a power plant project. The study also performed sensitivity analysis to investigate the robustness of the results. The results showed that the selected suppliers were robust to variations in the weights of the criteria used in the TOPSIS method.

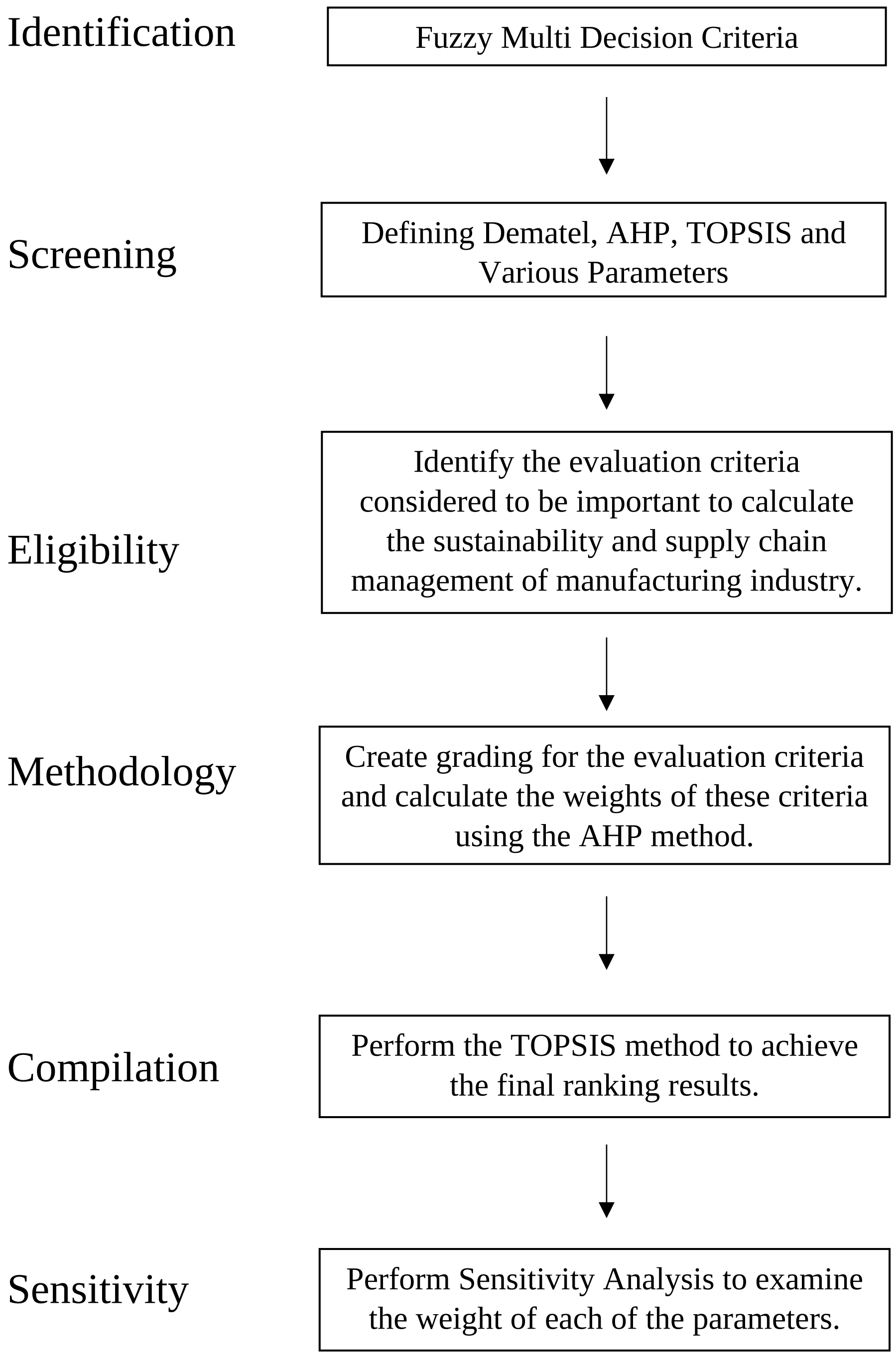
Finally, a study by (Zandi et al., 2020) used a modified version of TOPSIS to evaluate and select suppliers for a company. The study performed sensitivity analysis to investigate the impact of variations in the weights of the criteria on the ranking of the suppliers. The results showed that the ranking of the suppliers was sensitive to changes in the weights of some of the criteria, but not all.

In conclusion, the studies reviewed indicate that sensitivity analysis is an important technique for investigating the robustness of the results obtained from TOPSIS in supplier selection. The studies also suggest that the ranking of suppliers may be sensitive to changes in the weights of some criteria but not others, and that the results may be robust to some degree of variation in the weights of the criteria.

CHAPTER 3 – RESEARCH METHODOLOGY

3.1. <u>Developing MCDM approach</u>

Figure 2: Flow chart diagram of the research methodology to be followed.



Source: Own Creation

Figure 2 here depicts the flow chart of the ideal methodology that has been followed here in this study.

The aim of this section to assist decision makers in choosing the most suitable suppliers who follow sustainable practices and determining the ideal amount of products to order from each supplier based on their performance in traditional factors such as purchasing cost, delivery time, and reliability, as well as environmental and social factors.

To this end, a proper Multi Criteria Decision Making (MCDM) and Fuzzy Multi Objective Optimization approach is made as follows:

1. A comprehensive system that encompasses conventional, green, and social standards has been created, drawing from both published materials and the insights of decision-makers with expertise in the field.
2. The Fuzzy Analytic Hierarchy Process (AHP) is employed to determine the relative weights of sustainability criteria through expert assessments for selection purposes.
3. Fuzzy TOPSIS is utilized to evaluate suppliers based on their sustainability performance.
4. It will result in the establishment of a ranking order for suppliers.
5. Evaluation using Sensitivity Analysis in order to examine the weight of each of the parameters.

3.2. Ranking the Criteria: Fuzzy AHP

A case company named XYZ ltd. (fictious name) has been selected to conduct the research and analysis. It is known that:

- It is a market leader in manufacturing segment.
- The company produces a variety of products including spare parts and heavy machineries.
- It is amongst top hundred manufactures in India.
- Its annual turnover is more than 100 crores.
- XYZ ltd. has won several awards for its quality from national as well as international organizations.

This company now wants to shift its long-term goals towards environment safety and thus wants to focus on selecting green suppliers based upon their behavior. Structured questionnaire was made to evaluate the fifteen parameters by giving more priority to green practices.

Five experts have been chosen from XYZ ltd. to categorize the three dimensions and to fill out the questionnaire. The detailed questionnaire has been provided in the annexure. These experts have been then labeled as decision makers whose background consists of:

DM 1: Managing Director

DM 2: Production Manager

DM 3: Senior manufacturing engineer

DM 4: Operator

DM 5: Technician

These five experts have been chosen based on their knowledge of suppliers, experience, skillset, and their technical expertise.

3.3. <u>TOPSIS Method</u>

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method is a multiple-criteria method to ascertain a solution for a finite set of alternatives. The basic principle is that the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative ideal solution. The TOPSIS procedure can be expressed in a series of steps as follows (Kumar et al., 2018; Luthra et al., 2016; Mohammed et al., 2019; Torfi et al., 2010; Wang & Lee, 2007):

1. Sorting out the parameters as benefit or cost criteria.
2. Classify the ratings of nominated experts which are in linguistic terms using the Five-Point Likert-scale (ranging from very high to very low).
3. Fuzzify the linguistic variables of the data collected from the experts by assigning TFN (Triangular Fuzzy Number) triplets and create a fuzzy decision matrix.

4. Computing the aggregated fuzzy weight for all the parameters and acquiring the aggregated fuzzy decision matrix that integrates the opinion and preferences of the experts.

   $W_j = (W_{j1}, W_{j2}, W_{j3})$,

   Where $W_{j1} = \min(W_{jk1})$, $W_{j2} = \frac{1}{k}\sum_{k=1}^{k} W_{jk2}$, $W_{j3} = \max(W_{jk3})$ (1)

   $X_j = (X_{j1}, X_{j2}, X_{j3})$,

   Where $X_{j1} = \min(X_{jk1})$, $X_{j2} = \frac{1}{k}\sum_{k=1}^{k} X_{jk2}$, $X_{j3} = \max(X_{jk3})$ (2)

   Note: Here attribute W_j is considered to point out towards Beneficial Criteria while attribute X_j is considered for Cost Criteria.

5. In order to terminate the domination of index dimension and its differential range on evaluation results, it is necessary to normalize the original matrix to ensure that all the attributes are equivalent and of the same format. If $X_i = (a_{ij}, b_{ij}, c_{ij})$, where (i = 1, 2… n, j = 1, 2... m) are TFNs, then for benefit criteria, the normalization is carried out using the following equation:

   $$r_{ij} = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right), \quad (3)$$

   Where $c_j^+ = \max\{c_{ij}\}$.

   For cost criteria, the normalization is computed using the following equation:

   $$r_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \quad (4)$$

   Where $a_j^- = \min\{a_{ij}\}$.

6. The weighted normalized value v_{ij} is computed as:

   $$v = r_{ij} * w_j, \quad (5)$$

   Where $v = [v_{ij}]$, where i = 1,2,3,…,m. j = 1,2,3,…,n.

7. Calculate the fuzzy positive-ideal and fuzzy negative-ideal solution.

   $A^+ = (v_1^+, v_2^+, \ldots, v_n^+)$ (6)

   Where v_j^+ = max $\{v_{ij}^+\}$, i = 1,2,3,…,m. j = 1,2,3,…,n.

   $A^- = \{(v_1^-, v_2^-, \ldots, v_n^-)\}$ (7)

   Where v_j^- = max $\{v_{ij}^-\}$, i = 1,2,3,…,m. j = 1,2,3,…,n.

8. Calculate the distances, using the n-dimensional Euclidean distance. The distance of each supplier from the positive-ideal solution is given as

   $$d_i^+ = \left[\frac{1}{3}\sum_{j=1}^{n}\left(v_{ij} - v_j^+\right)^2\right]^{1/2} \text{ for i = 1, 2, 3… m.} \quad (8)$$

   Similarly, the distance from the negative-ideal solution is given as

   $$d_i^- = \left[\frac{1}{3}\sum_{i=1}^{n}\left(v_{ij} - v_j^-\right)^2\right]^{1/2} \text{ for i = 1, 2, 3… m.} \quad (9)$$

9. Calculate the Closeness coefficient to the ideal solution. The respective closeness of the supplier A_i with respect to A^+ is defined as

   $$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \text{ for i = 1, 2…m.} \quad (10)$$

   Since $d_i^+ \geq 0$ and $d_i^- \geq 0$, then understandably $CC_i \in [0,1]$.

10. Rank the order of suppliers. For ranking supplier using this index, the foremost and leading supplier is one that is distant from FNIS and nearest to the FPIS.

CHAPTER 4 – CASE STUDY

4.1. <u>Introduction</u>

Each criterion selected for investigation has been carefully explained depending upon values or percentage accomplished by suppliers. An extensive literature review was conducted, and experts' inputs were used to categorize the three criteria and the five suppliers.

The important weights of identified fifteen parameters and rating values of the selected five suppliers were assessed by experts (five in numbers).

4.2. <u>Fuzzy TOPSIS Calculations</u>

4.2.1. <u>Ratings given by Experts.</u>

Five experts or decision makers (DM1, DM2, DM3, DM4, and DM5) expressed their point of view on the important weights of fifteen parameters. The ratings are characterized by verbal terms such as very low, low, medium, high, very high.

Then, the ratings of each supplier (concerning the parameters independently) have been characterized by linguistic variables such as very low, low, medium, high, very high These linguistic variables are defined in Table 1. Initial information submitted by these five experts has been shown from Tables 2 to 4.

Table 1: Linguistic Variables Used for Definition

Symbol	Verbal Terms
VL	Very Low
L	Low
M	Medium
H	High
VH	Very High

Source: Own Analysis

Table 2: Ratings for Conventional Criteria

	Conventional				
Parameters	**Supply Capacity**	**Quality**	**Technological Capability**	**Price**	**Service Level**
	C1	**C2**	**C3**	**C4**	**C5**
DM1	**VL**	**VL**	**M**	**VH**	**VH**
S1	L	H	M	VL	VH
S2	L	M	H	VH	L
S3	VL	VH	VL	VH	VL
S4	M	L	VL	VL	VH
S5	VL	L	L	VH	VL
DM2	**VH**	**VL**	**H**	**M**	**VH**
S1	L	H	M	L	VH
S2	VL	M	L	H	VL
S3	M	VL	H	M	H
S4	VH	H	VH	VL	H
S5	VH	L	VH	M	M
DM3	**VH**	**H**	**L**	**L**	**VH**
S1	H	VH	M	VH	VL
S2	H	L	VL	L	VH
S3	M	H	VH	VL	M
S4	VL	H	H	VL	L
S5	H	VL	VH	VL	H
DM4	**H**	**VH**	**M**	**H**	**H**
S1	VL	H	VL	VL	M
S2	H	L	VH	VL	M
S3	L	M	H	VL	VH
S4	M	VL	L	VH	H
S5	L	H	VL	H	L
DM5	**VL**	**VL**	**H**	**VL**	**H**
S1	L	H	L	M	VL
S2	L	VL	VH	L	VL
S3	H	VL	VL	VH	H
S4	H	H	L	VH	H
S5	VL	L	VH	H	VH

Source: Own Analysis

Table 3: Ratings for Environmental Criteria

	Green				
Parameters	**EMS**	**Green Image**	**Waste Management**	**Pollution Production**	**Environmental Competencies**
	G1	**G2**	**G3**	**G4**	**G5**
DM1	**VH**	**VL**	**L**	**VL**	**L**
S1	H	VH	M	M	H
S2	L	VH	L	H	H
S3	L	H	L	L	H
S4	L	H	L	M	M
S5	VL	H	VL	M	VH
DM2	**M**	**H**	**L**	**VH**	**L**
S1	VH	H	VH	VL	VL
S2	VH	VH	VL	H	VL
S3	VL	VH	H	VL	M
S4	VH	M	M	VH	VH
S5	H	H	M	VL	H
DM3	**L**	**VH**	**H**	**H**	**VH**
S1	M	L	H	VH	VH
S2	H	VL	M	VH	VH
S3	VL	VL	L	M	L
S4	VH	VL	M	L	L
S5	H	H	H	H	H
DM4	**L**	**M**	**H**	**VL**	**VL**
S1	VH	VL	L	L	M
S2	L	VH	VH	VL	H
S3	L	H	M	M	VH
S4	H	M	H	H	VH
S5	H	H	VL	L	VH
DM5	**VH**	**VL**	**L**	**L**	**VH**
S1	M	M	H	M	L
S2	VH	L	L	L	H
S3	L	L	H	H	L
S4	VL	VH	L	H	M
S5	VH	L	H	L	M

Source: Own Analysis

Table 4: Ratings for Social Criteria

	Social				
Parameters	**Safety, rights, and health of employees**	**Staff Development**	**Information Disclosure**	**Forced-Child Labour**	**Adherence to law and policy**
	S1	**S2**	**S3**	**S4**	**S5**
DM1	**L**	**VH**	**M**	**M**	**L**
S1	H	H	L	VH	VL
S2	L	VL	M	VL	H
S3	H	VH	H	VL	VL
S4	M	H	M	M	M
S5	M	L	M	M	H
DM2	**L**	**VL**	**M**	**L**	**VH**
S1	H	M	M	L	M
S2	H	M	M	H	VH
S3	M	L	H	H	M
S4	L	VL	VL	VH	VH
S5	L	M	L	H	M
DM3	**H**	**H**	**VL**	**VH**	**H**
S1	H	L	VH	H	M
S2	M	M	H	M	L
S3	M	L	H	VL	L
S4	M	VH	M	L	VH
S5	VH	H	VH	VH	VL
DM4	**VL**	**VL**	**L**	**VH**	**L**
S1	L	H	VL	M	VL
S2	L	M	L	L	M
S3	VL	M	H	VH	L
S4	H	VH	M	VH	L
S5	VH	M	L	M	H
DM5	**L**	**L**	**H**	**M**	**H**
S1	VH	VH	M	VH	VL
S2	M	VH	M	H	VL
S3	L	VH	L	M	H
S4	H	L	L	M	VH
S5	L	H	H	H	L

Source: Own Analysis

4.2.2. TFNs and decision matrix

These linguistic terms in the five-point Likert scale are now transformed into Triangular fuzzy number (TFNs) in range of 1 to 9. Table 5 defines the scale corresponding to the verbal terms for both ratings. The fuzzy decision matrix made out of the thirteen parameters is shown in Table 6 to Table 8.

Table 5: Linguistic variables used in the research for TFN.

Triangular Fuzzy Number	Verbal Terms
(1, 1, 3)	Very Low (VL)
(1, 3, 5)	Low (L)
(3, 5, 7)	Medium (M)
(5, 7, 9)	High (H)
(7, 9, 9)	Very High (VH)

Source: Own Analysis

Here Very low is expressed in the form of triangular fuzzy numbers, i.e. (1,1,3). Similarly, it is done for all five expressions. The TFNs are used in order to make the results of calculations and analysis more accurate and apt.

Table 6: Representation of relative importance weights by TFN in Fuzzy decision matrix for Conventional Criteria

Criteria	Conventional														
Parameters	Supply Capacity			Quality			Technological Capability			Price			Service Level		
Criteria	Beneficial			Beneficial			Beneficial			Cost			Beneficial		
	C1			C2			C3			C4			C5		
DM1	1	1	3	1	1	3	3	5	7	7	9	9	7	9	9
S1	1	3	5	5	7	9	3	5	7	1	1	3	7	9	9
S2	1	3	5	3	5	7	5	7	9	7	9	9	1	3	5
S3	1	1	3	7	9	9	1	1	3	7	9	9	1	1	3
S4	3	5	7	1	3	5	1	1	3	1	1	3	7	9	9
S5	1	1	3	1	3	5	1	3	5	7	9	9	1	1	3
DM2	7	9	9	1	1	3	5	7	9	3	5	7	7	9	9
S1	1	3	5	5	7	9	3	5	7	1	3	5	7	9	9
S2	1	1	3	3	5	7	1	3	5	5	7	9	1	1	3
S3	3	5	7	1	1	3	5	7	9	3	5	7	5	7	9
S4	7	9	9	5	7	9	7	9	9	1	1	3	5	7	9
S5	7	9	9	1	3	5	7	9	9	3	5	7	3	5	7
DM3	7	9	9	5	7	9	1	3	5	1	3	5	7	9	9
S1	5	7	9	7	9	9	3	5	7	7	9	9	1	1	3
S2	5	7	9	1	3	5	1	1	3	1	3	5	7	9	9
S3	3	5	7	5	7	9	7	9	9	1	1	3	3	5	7
S4	1	1	3	5	7	9	5	7	9	1	1	3	1	3	5
S5	5	7	9	1	1	3	7	9	9	1	1	3	5	7	9
DM4	5	7	9	7	9	9	3	5	7	5	7	9	5	7	9
S1	1	1	3	5	7	9	1	1	3	1	1	3	3	5	7
S2	5	7	9	1	3	5	7	9	9	1	1	3	3	5	7
S3	1	3	5	3	5	7	5	7	9	1	1	3	7	9	9
S4	3	5	7	1	1	3	1	3	5	7	9	9	5	7	9
S5	1	3	5	5	7	9	1	1	3	5	7	9	1	3	5
DM5	1	1	3	1	1	3	5	7	9	1	1	3	5	7	9
S1	1	3	5	5	7	9	1	3	5	3	5	7	1	1	3
S2	1	3	5	1	1	3	7	9	9	1	3	5	1	1	3
S3	5	7	9	1	1	3	1	1	3	7	9	9	5	7	9
S4	5	7	9	5	7	9	1	3	5	7	9	9	5	7	9
S5	1	1	3	1	3	5	7	9	9	5	7	9	7	9	9

Source: Own Analysis

Table 7: Representation of relative importance weights by TFN in Fuzzy decision matrix for Green Criteria

Criteria	Green														
Parameters	EMS			Green Image			Waste Level			Pollution Production			Energy Conservation		
Criteria	Beneficial			Beneficial			Cost			Cost			Beneficial		
	G1			G2			G3			G4			G5		
DM1	7	9	9	1	1	3	1	3	5	1	1	3	1	3	5
S1	5	7	9	7	9	9	3	5	7	3	5	7	5	7	9
S2	1	3	5	7	9	9	1	3	5	5	7	9	5	7	9
S3	1	3	5	5	7	9	1	3	5	1	3	5	5	7	9
S4	1	3	5	5	7	9	1	3	5	3	5	7	3	5	7
S5	1	1	3	5	7	9	1	1	3	3	5	7	7	9	9
DM2	3	5	7	5	7	9	1	3	5	7	9	9	1	3	5
S1	7	9	9	5	7	9	7	9	9	1	1	3	1	1	3
S2	7	9	9	7	9	9	1	1	3	5	7	9	1	1	3
S3	1	1	3	7	9	9	5	7	9	1	1	3	3	5	7
S4	7	9	9	3	5	7	3	5	7	7	9	9	7	9	9
S5	5	7	9	5	7	9	3	5	7	1	1	3	5	7	9
DM3	1	3	5	7	9	9	5	7	9	5	7	9	7	9	9
S1	3	5	7	1	3	5	5	7	9	7	9	9	7	9	9
S2	5	7	9	1	1	3	3	5	7	7	9	9	7	9	9
S3	1	1	3	1	1	3	1	3	5	3	5	7	1	3	5
S4	7	9	9	1	1	3	3	5	7	1	3	5	1	3	5
S5	5	7	9	5	7	9	5	7	9	5	7	9	5	7	9
DM4	1	3	5	3	5	7	5	7	9	1	1	3	1	1	3
S1	7	9	9	1	1	3	1	3	5	1	3	5	3	5	7
S2	1	3	5	7	9	9	7	9	9	1	1	3	5	7	9
S3	1	3	5	5	7	9	3	5	7	3	5	7	7	9	9
S4	5	7	9	3	5	7	5	7	9	5	7	9	7	9	9
S5	5	7	9	5	7	9	1	1	3	1	3	5	7	9	9
DM5	7	9	9	1	1	3	1	3	5	1	3	5	7	9	9
S1	3	5	7	3	5	7	5	7	9	3	5	7	1	3	5
S2	7	9	9	1	3	5	1	3	5	1	3	5	5	7	9
S3	1	3	5	1	3	5	5	7	9	5	7	9	1	3	5
S4	1	1	3	7	9	9	1	3	5	5	7	9	3	5	7
S5	7	9	9	1	3	5	5	7	9	1	3	5	3	5	7

Source: Own Analysis

Table 8: Representation of relative importance weights by TFN in Fuzzy decision matrix for Environmental Criteria

Criteria	Social														
Parameters	Safety, rights, and health of employees			Staff Development			Information Disclosure			Forced-Child Labour			Adherence to law and policy		
Criteria	Beneficial			Beneficial			Beneficial			Cost			Beneficial		
	S1			S2			S3			S4			S5		
DM1	1	3	5	7	9	9	3	5	7	3	5	7	1	3	5
S1	5	7	9	5	7	9	1	3	5	7	9	9	1	1	3
S2	1	3	5	1	1	3	3	5	7	1	1	3	5	7	9
S3	5	7	9	7	9	9	5	7	9	1	1	3	1	1	3
S4	3	5	7	5	7	9	3	5	7	3	5	7	3	5	7
S5	3	5	7	1	3	5	3	5	7	3	5	7	5	7	9
DM2	1	3	5	1	1	3	3	5	7	1	3	5	7	9	9
S1	5	7	9	3	5	7	3	5	7	1	3	5	3	5	7
S2	5	7	9	3	5	7	3	5	7	5	7	9	7	9	9
S3	3	5	7	1	3	5	5	7	9	5	7	9	3	5	7
S4	1	3	5	1	1	3	1	1	3	7	9	9	7	9	9
S5	1	3	5	3	5	7	1	3	5	5	7	9	3	5	7
DM3	5	7	9	5	7	9	1	1	3	7	9	9	5	7	9
S1	5	7	9	1	3	5	7	9	9	5	7	9	3	5	7
S2	3	5	7	3	5	7	5	7	9	3	5	7	1	3	5
S3	3	5	7	1	3	5	5	7	9	1	1	3	1	3	5
S4	3	5	7	7	9	9	3	5	7	1	3	5	7	9	9
S5	7	9	9	5	7	9	7	9	9	7	9	9	1	1	3
DM4	1	1	3	1	1	3	1	3	5	7	9	9	1	3	5
S1	1	3	5	5	7	9	1	1	3	3	5	7	1	1	3
S2	1	3	5	3	5	7	1	3	5	1	3	5	3	5	7
S3	1	1	3	3	5	7	5	7	9	7	9	9	1	3	5
S4	5	7	9	7	9	9	3	5	7	7	9	9	1	3	5
S5	7	9	9	3	5	7	1	3	5	3	5	7	5	7	9
DM5	1	3	5	1	3	5	5	7	9	3	5	7	5	7	9
S1	7	9	9	7	9	9	3	5	7	7	9	9	1	1	3
S2	3	5	7	7	9	9	3	5	7	5	7	9	1	1	3
S3	1	3	5	7	9	9	1	3	5	3	5	7	5	7	9
S4	5	7	9	1	3	5	1	3	5	3	5	7	7	9	9
S5	1	3	5	5	7	9	5	7	9	5	7	9	1	3	5

Source: Own Analysis

4.3. **Data Analysis**

4.3.1. Fuzzy TOPSIS Results

Applying the steps from Chapter 3, the aggregated weight of the parameters are computed by applying equation (1) and for suppliers by applying equation (2). For example, for , the values for Supply Capacity, it reads (1,3,5), (1,3,5), (5,7,9), (1,1,3), (1,3,5), then the aggregated fuzzy weight is given by:

$$W_{j1} = \min(1, 1, 5, 1, 1) = 5,\ W_{j2} = \frac{1}{5}(3+3+7+1+3) = 7.8,\ W_{j3} = \max(5, 5, 9, 3, 5) = 9$$

So, the aggregated weight for criteria Supply Capacity is $W_{SC} = (1, 3.4, 9)$

Table 9: Aggregate fuzzy weights for the Conventional Criteria

Criteria	Conventional														
Parameters	Supply Capacity			Quality			Technological Capability			Price			Service Level		
Criteria	Beneficial			Beneficial			Beneficial			Cost			Beneficial		
	C1			C2			C3			C4			C5		
Weights	1	5.4	9	1	3.8	9	1	5.4	9	1	5	9	5	8.2	9
S1	1	3.4	9	5	7.4	9	1	3.8	7	1	3.8	9	1	5	9
S2	1	4.2	9	1	3.4	7	1	5.8	9	1	4.6	9	1	3.8	9
S3	1	4.2	9	1	4.6	9	1	5	9	1	5	9	1	5.8	9
S4	1	5.4	9	1	5	9	1	4.6	9	1	4.2	9	1	6.6	9
S5	1	4.2	9	1	3.4	9	1	6.2	9	1	5.8	9	1	5	9

Source: Own Calculations

Table 10: Aggregate fuzzy weights for the Environmental Criteria

Criteria	Green														
Parameters	EMS			Green Image			Waste Level			Pollution Production			Energy Conservation		
Criteria	Beneficial			Beneficial			Cost			Cost			Beneficial		
	G1			G2			G3			G4			G5		
Weights	1	5.8	9	1	4.6	9	1	4.6	9	1	4.2	9	1	5	9
S1	3	7	9	1	5	9	1	6.2	9	1	4.6	9	1	5	9
S2	1	6.2	9	1	6.2	9	1	4.2	9	1	5.4	9	1	6.2	9
S3	1	2.2	5	1	5.4	9	1	5	9	1	4.2	9	1	5.4	9
S4	1	5.8	9	1	5.4	9	1	4.6	9	1	6.2	9	1	6.2	9
S5	1	6.2	9	1	6.2	9	1	4.2	9	1	3.8	9	3	7.4	9

Source: Own Calculations

Table 11: Aggregate fuzzy weights for the Social Criteria

Criteria	Social														
Parameters	Safety, rights, and health of employees			Staff Development			Information Disclosure			Forced-Child Labour			Adherence to law and policy		
Criteria	Beneficial			Beneficial			Beneficial			Cost			Beneficial		
	S1			S2			S3			S4			S5		
Weights	1	3.4	9	1	4.2	9	1	4.2	9	1	6.2	9	1	5.8	9
S1	1	6.6	9	1	6.2	9	1	4.6	9	1	6.6	9	1	2.6	7
S2	1	4.6	9	1	5	9	1	5	9	1	4.6	9	1	5	9
S3	1	4.2	9	1	5.8	9	1	6.2	9	1	4.6	9	1	3.8	9
S4	1	5.4	9	1	5.8	9	1	3.8	7	1	6.2	9	1	7	9
S5	1	5.8	9	1	5.4	9	1	5.4	9	3	6.6	9	1	4.6	9

Source: Own Calculations

Similarly, the aggregate weights for all parameters and supplier are calculated and presented in Table 9 to Table 11.

For Beneficial Criteria, the values of these decision matrix are normalized by applying equation (3). For example, the value for Supplier 1 (S1) under Supply Capacity is obtained as:

$$c_j^+ = \max c_{ij} = 9$$

$$r_{ij} = \left(\frac{1}{9}, \frac{5.4}{9}, \frac{9}{9}\right) = (0.111, 0.378, 1)$$

For Cost Criteria, the elements of these decision matrix are normalised using equation (4). For example, the normalised rating for Supplier 1 (S1) under Price is obtained as:

$$a_j^- = \min a_{ij} = 1$$

$$r_{ij} = \left(\frac{1}{9}, \frac{1}{3.8}, \frac{1}{1}\right) = (0.111, 0.263, 1.000)$$

Similarly, the normalised values of all the suppliers for fifteen parameters are computed and are given in Table 12 to Table 14.

Table 12: Normalized fuzzy decision matrix for the Conventional Criteria

Criteria	**Conventional**														
Parameters	**Supply Capacity**			**Quality**			**Technological Capability**			**Price**			**Service Level**		
Criteria	**Beneficial**			**Beneficial**			**Beneficial**			**Cost**			**Beneficial**		
	C1			**C2**			**C3**			**C4**			**C5**		
Weights	1	5.4	9	1	3.8	9	1	5.4	9	1	5	9	5	8.2	9
S1	0.1	0.4	1.0	0.6	0.8	1.0	0.1	0.4	0.8	0.1	0.3	1.0	0.1	0.6	1.0
S2	0.1	0.5	1.0	0.1	0.4	0.8	0.1	0.6	1.0	0.1	0.2	1.0	0.1	0.4	1.0
S3	0.1	0.5	1.0	0.1	0.5	1.0	0.1	0.6	1.0	0.1	0.2	1.0	0.1	0.6	1.0
S4	0.1	0.6	1.0	0.1	0.6	1.0	0.1	0.5	1.0	0.1	0.2	1.0	0.1	0.7	1.0
S5	0.1	0.5	1.0	0.1	0.4	1.0	0.1	0.7	1.0	0.1	0.2	1.0	0.1	0.6	1.0

Source: Own Calculations

Table 13: Normalized fuzzy decision matrix for the Environmental Criteria

Criteria	**Green**														
Parameters	**EMS**			**Green Image**			**Waste Level**			**Pollution Production**			**Energy Conservation**		
Criteria	**Beneficial**			**Beneficial**			**Cost**			**Cost**			**Beneficial**		
	G1			**G2**			**G3**			**G4**			**G5**		
Weights	1	5.8	9	1	4.6	9	1	4.6	9	1	4.2	9	1	5	9
S1	0.3	0.8	1.0	0.1	0.6	1.0	0.1	0.2	1.0	0.1	0.2	1.0	0.1	0.6	1.0
S2	0.1	0.7	1.0	0.1	0.7	1.0	0.1	0.2	1.0	0.1	0.2	1.0	0.1	0.7	1.0
S3	0.1	0.2	0.6	0.1	0.6	1.0	0.1	0.2	1.0	0.1	0.2	1.0	0.1	0.6	1.0
S4	0.1	0.6	1.0	0.1	0.6	1.0	0.1	0.2	1.0	0.1	0.2	1.0	0.1	0.7	1.0
S5	0.1	0.7	1.0	0.1	0.7	1.0	0.1	0.2	1.0	0.1	0.3	1.0	0.3	0.8	1.0

Source: Own Calculations

Table 14: Normalized fuzzy decision matrix for the Social Criteria

Criteria	**Social**														
Parameters	**Safety, rights & health of employees**			**Staff Development**			**Information Disclosure**			**Forced-Child Labour**			**Adherence to law & policy**		
Criteria	**Beneficial**			**Beneficial**			**Beneficial**			**Cost**			**Beneficial**		
	S1			**S2**			**S3**			**S4**			**S5**		
Weights	1	3.4	9	1	4.2	9	1	4.2	9	1	6.2	9	1	5.8	9
S1	0.1	0.7	1.0	0.1	0.7	1.0	0.1	0.5	1.0	0.1	0.2	1.0	0.1	0.3	0.8
S2	0.1	0.5	1.0	0.1	0.6	1.0	0.1	0.6	1.0	0.1	0.2	1.0	0.1	0.6	1.0
S3	0.1	0.5	1.0	0.1	0.6	1.0	0.1	0.7	1.0	0.1	0.2	1.0	0.1	0.4	1.0
S4	0.1	0.6	1.0	0.1	0.6	1.0	0.1	0.4	0.8	0.1	0.2	1.0	0.1	0.8	1.0
S5	0.1	0.6	1.0	0.1	0.6	1.0	0.1	0.6	1.0	0.1	0.2	0.3	0.1	0.5	1.0

Source: Own Calculations

The weighted normalized fuzzy decision matrix for the suppliers under various parameters has been calculated by applying equation (5) and is displayed in Table 4.33. For example, the weighted normalized values for Supplier 1 under Supply Capacity can be calculated as:

v = [(1 * 0.111), (5.4 * 0.378), (9 * 1)]

= (0.111, 2.04, 9)

Table 15: Weighted normalized fuzzy decision matrix for the selected parameters of conventional criteria

Criteria	Conventional														
Parameters	**Supply Capacity**			**Quality**			**Technological Capability**			**Price**			**Service Level**		
Criteria	**Beneficial**			**Beneficial**			**Beneficial**			**Cost**			**Beneficial**		
	C1			**C2**			**C3**			**C4**			**C5**		
Weights	1	5.4	9	1	3.8	9	1	5.4	9	1	5	9	5	8.2	9
S1	0.1	2.0	9.0	0.6	3.1	9.0	0.1	2.3	7.0	0.1	1.3	9.0	0.6	4.6	9.0
S2	0.1	2.5	9.0	0.1	1.4	7.0	0.1	3.5	9.0	0.1	1.1	9.0	0.6	3.5	9.0
S3	0.1	2.5	9.0	0.1	1.9	9.0	0.1	3.0	9.0	0.1	1.0	9.0	0.6	5.3	9.0
S4	0.1	3.2	9.0	0.1	2.1	9.0	0.1	2.8	9.0	0.1	1.2	9.0	0.6	6.0	9.0
S5	0.1	2.5	9.0	0.1	1.4	9.0	0.1	3.7	9.0	0.1	0.9	9.0	0.6	4.6	9.0
FNIS (A-)	0.1	2.0	9.0	0.1	1.4	7.0	0.1	2.3	7.0	0.1	1.3	9.0	0.6	3.5	9.0
FPIS (A+)	0.1	3.2	9.0	0.6	3.1	9.0	0.1	3.7	9.0	0.1	0.9	9.0	0.6	6.0	9.0

Source: Own Calculations

Table 16: Weighted normalized fuzzy decision matrix for the selected parameters of environmental criteria

Criteria	Green														
Parameters	**EMS**			**Green Image**			**Waste Level**			**Pollution Production**			**Energy Conservation**		
Criteria	**Beneficial**			**Beneficial**			**Cost**			**Cost**			**Beneficial**		
	G1			**G2**			**G3**			**G4**			**G5**		
Weights	1	5.8	9	1	4.6	9	1	4.6	9	1	4.2	9	1	5	9
S1	0.3	4.5	9.0	0.1	2.6	9.0	0.1	0.7	9.0	0.1	0.9	9.0	0.1	2.8	9.0
S2	0.1	4.0	9.0	0.1	3.2	9.0	0.1	1.1	9.0	0.1	0.8	9.0	0.1	3.4	9.0
S3	0.1	1.4	5.0	0.1	2.8	9.0	0.1	0.9	9.0	0.1	1.0	9.0	0.1	3.0	9.0
S4	0.1	3.7	9.0	0.1	2.8	9.0	0.1	1.0	9.0	0.1	0.7	9.0	0.1	3.4	9.0
S5	0.1	4.0	9.0	0.1	3.2	9.0	0.1	1.1	9.0	0.1	1.1	9.0	0.3	4.1	9.0
FNIS (A-)	0.1	1.4	5.0	0.1	2.6	9.0	0.1	1.1	9.0	0.1	1.1	9.0	0.1	2.8	9.0
FPIS (A+)	0.3	4.5	9.0	0.1	3.2	9.0	0.1	0.7	9.0	0.1	0.7	9.0	0.3	4.1	9.0

Source: Own Calculations

Table 17: Weighted normalized fuzzy decision matrix for the selected parameters of social criteria

Criteria	**Social**														
Parameters	**Safety, rights & health of employees**			**Staff Development**			**Information Disclosure**			**Forced-Child Labour**			**Adherence to law & policy**		
Criteria	**Beneficial**			**Beneficial**			**Beneficial**			**Cost**			**Beneficial**		
	S1			**S2**			**S3**			**S4**			**S5**		
Weights	1	3.4	9	1	4.2	9	1	4.2	9	1	6.2	9	1	5.8	9
S1	0.1	2.5	9.0	0.1	2.9	9.0	0.1	2.1	9.0	0.1	0.9	9.0	0.1	1.7	7.0
S2	0.1	1.7	9.0	0.1	2.3	9.0	0.1	2.3	9.0	0.1	1.3	9.0	0.1	3.2	9.0
S3	0.1	1.6	9.0	0.1	2.7	9.0	0.1	2.9	9.0	0.1	1.3	9.0	0.1	2.4	9.0
S4	0.1	2.0	9.0	0.1	2.7	9.0	0.1	1.8	7.0	0.1	1.0	9.0	0.1	4.5	9.0
S5	0.1	2.2	9.0	0.1	2.5	9.0	0.1	2.5	9.0	0.1	0.9	3.0	0.1	3.0	9.0
FNIS (A-)	0.1	1.6	9.0	0.1	2.3	9.0	0.1	1.8	7.0	0.1	1.3	9.0	0.1	1.7	7.0
FPIS (A+)	0.1	2.5	9.0	0.1	2.9	9.0	0.1	2.9	9.0	0.1	0.9	3.0	0.1	4.5	9.0

Source: Own Calculations

Thereafter, Equations (6) and (7) are used to identify fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) and also are displayed in Table 15 to Table 17. They can be easily picked out.

For example, if we observe the Supply capacity, the fuzzy positive ideal solution we get is (0.111, 2.04, 9) as it's the minimum value we observe. Similarly, the fuzzy negative ideal solution we get is (0.111, 3.240, 9) as it's the maximum value we observe.

The Euclidean distance d_i^+ and d_i^- of each normalised weighted supplier from the FPIS and the FNIS is measured using equations (8) and (9), which are shown from Table 18 to Table 20 respectively.

For example, Supplier 1 under parameter supply capacity, the distances can be calculated as follows:

$$D\,(A_{i,} A_i^-) = \sqrt{\frac{1}{3}[(0.111 - 0.111)^2 + (2.040 - 2.040)^2 + (9 - 9)^2]} = 0.000$$

And

$$D\,(A_{i,} A_i^+) = \sqrt{\frac{1}{3}[(0.111 - 0.111)^2 + (2.040 - 3.240)^2 + (9 - 9)^2]} = 0.693$$

Then, the summation of distances of all the parameters for a particular bank is done so as to calculate d_i^+ and d_i^-.

Table 18: Identifying FPIS and FNIS and calculating the Euclidean distance from the ideal best and ideal worst for conventional criteria.

	Conventional											
Parameters	**Supply Capacity**		**Quality**		**Technological Capability**		**Price**		**Service Level**			
	C1		**C2**		**C3**		**C4**		**C5**			
Suppliers	d_i^-	d_i^+	d_i^-	d_i^+	d_i^-	d_i^+	d_i^-	d_i^+	d_i^-	d_i^+	$\sum d_i^-$	$\sum d_i^+$
S1	0.00	0.69	1.53	0.00	0.00	1.42	0.00	0.26	0.63	0.84	7.66	10.39
S2	0.28	0.42	0.00	1.53	1.35	0.14	0.13	0.13	0.00	1.47	8.18	9.98
S3	0.28	0.42	1.19	0.73	1.23	0.42	0.18	0.08	1.05	0.42	7.12	11.46
S4	0.69	0.00	1.22	0.64	1.19	0.55	0.07	0.19	1.47	0.00	10.80	7.80
S5	0.28	0.42	1.15	1.01	1.42	0.00	0.26	0.00	0.63	0.84	14.16	4.54

Source: Own Calculations

Table 19: Identifying FPIS and FNIS and calculating the Euclidean distance from the ideal best and ideal worst for environmental criteria.

	Green											
Parameters	**EMS**		**Green Image**		**Waste Level**		**Pollution Production**		**Environmental Competencies**			
	G1		**G2**		**G3**		**G4**		**G5**			
Suppliers	d_i^-	d_i^+	d_i^-	d_i^+	d_i^-	d_i^+	d_i^-	d_i^+	d_i^-	d_i^+	$\sum d_i^-$	$\sum d_i^+$
S1	2.92	0.00	0.00	0.35	0.20	0.00	0.11	0.14	0.00	0.78	7.66	10.39
S2	2.75	0.32	0.35	0.00	0.00	0.20	0.19	0.06	0.38	0.41	8.18	9.98
S3	0.00	2.92	0.12	0.24	0.10	0.10	0.06	0.19	0.13	0.65	7.12	11.46
S4	2.67	0.46	0.12	0.24	0.05	0.15	0.25	0.00	0.38	0.41	10.80	7.80
S5	2.75	0.32	0.35	0.00	0.00	0.20	0.00	0.25	0.78	0.00	14.16	4.54

Source: Own Calculations

Table 20: Identifying FPIS and FNIS and calculating the Euclidean distance from the ideal best and ideal worst for social criteria.

	Social											
Parameters	**Safety, rights & health of employees**		**Staff Development**		**Information Disclosure**		**Forced-Child Labour**		**Adherence to law & policy**			
	S1		**S2**		**S3**		**S4**		**S5**			
Suppliers	d_i^-	d_i^+	d_i^-	d_i^+	d_i^-	d_i^+	d_i^-	d_i^+	d_i^-	d_i^+	$\sum d_i^-$	$\sum d_i^+$
S1	0.52	0.00	0.32	0.00	1.17	0.43	0.24	3.46	0.00	2.00	7.66	10.39
S2	0.09	0.44	0.00	0.32	1.20	0.32	0.00	3.47	1.46	0.74	8.18	9.98
S3	0.00	0.52	0.22	0.11	1.32	0.00	0.00	3.47	1.24	1.19	7.12	11.46
S4	0.26	0.26	0.22	0.11	0.00	1.32	0.20	3.46	2.00	0.00	10.80	7.80
S5	0.35	0.17	0.11	0.22	1.23	0.22	3.47	0.00	1.37	0.89	14.16	4.54

Source: Own Calculations

4.3.2. Closeness Coefficient Index

Now, CC_i values are calculated using equation (10), and suppliers are then ranked subsequently. For example, the CC_i value for supplier 1 is computed as follows:

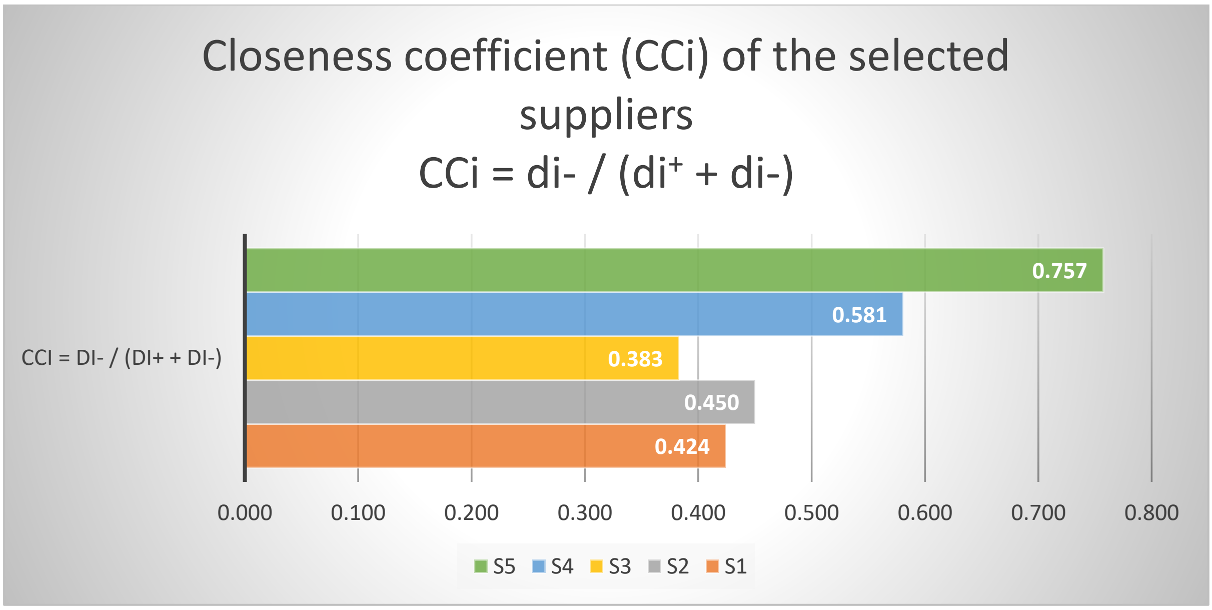
$$CC_i = \frac{7.659}{7.659 + 10.388} = 0.424$$

Table 21: Closeness coefficient (CCi) of the selected suppliers

Suppliers	d_i^-	d_i^+	$d_i^+ + d_i^-$	$CC_i = d_i^- / (d_i^+ + d_i^-)$	Rank
S1	7.659	10.388	18.047	0.424	4
S2	8.177	9.981	18.158	0.450	3
S3	7.115	11.457	18.572	0.383	5
S4	10.800	7.795	18.596	0.581	2
S5	14.165	4.539	18.704	0.757	1

Source: Own calculations

Figure 3: Graphical representation of Ranking of suppliers



Source: Own analysis

The comparison of closeness coefficient of selected eight suppliers gives the subsequent ranking order:

Supplier 5 > Supplier 4 > Supplier 2 > Supplier 1 > Supplier 3

4.4. <u>Results of Sensitivity Analysis</u>

As criteria weights have been evaluated based on individual judgements of the decision makers, it is required to perform Sensitivity Analysis to analyze the influence of criteria weights on the final ranking of suppliers considering supply chain management practices. It provides some idea about the robustness of the proposed framework. In this research, ten runs of experiments were carried out which have been tabulated in Table 22.

It may be analyzed from the results (Table 22 and Figure 4) that Supplier 5 is the best player in all of the ten experiments. There are only 2 types of results coming out here in which supplier 2 outperforms supplier 1 in 5 cases and vice-versa.

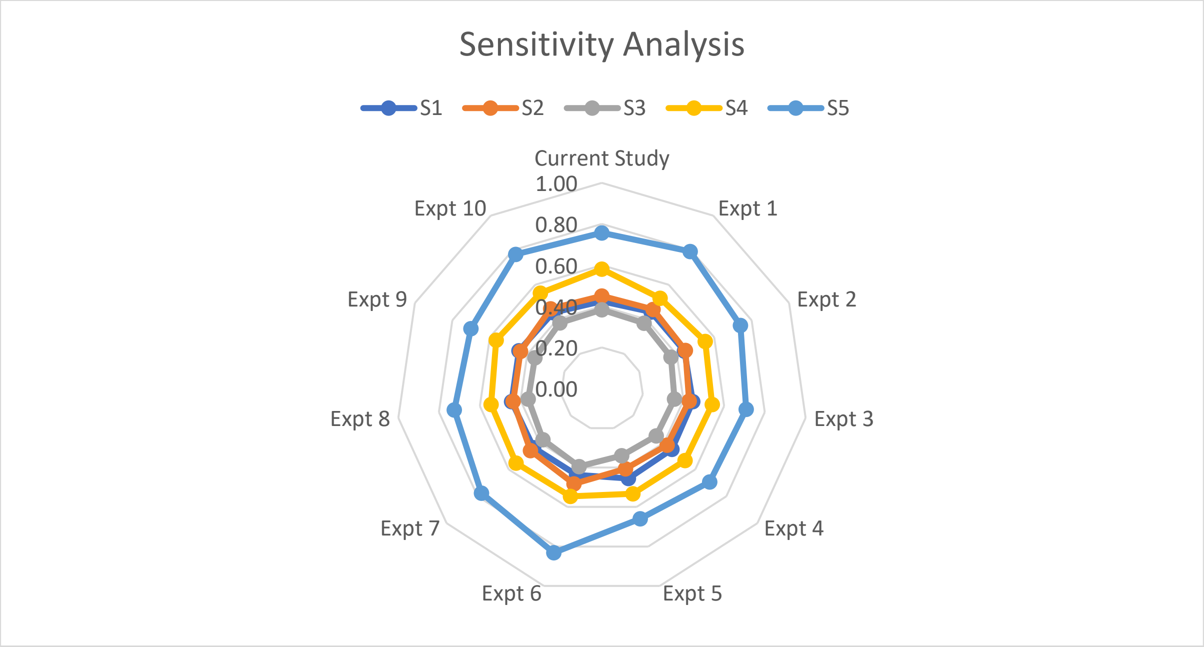
Table 22: Closeness coefficient (CCi) values for different experiments on weights

Experiment No.	Weight assignment	Overall Closeness Coefficient					Ranking
		S1	S2	S3	S4	S5	
Current Study		0.42	0.45	0.38	0.58	0.76	S5 > S4 > S2 > S1 > S3
Expt 1	W = (1, 1, 3)	0.44	0.46	0.38	0.52	0.79	S5 > S4 > S2 > S1 > S3
Expt 2	W = (1, 3, 5)	0.44	0.45	0.37	0.55	0.74	S5 > S4 > S2 > S1 > S3
Expt 3	W = (3, 5, 7)	0.45	0.43	0.36	0.54	0.71	S5 > S4 > S1 > S2 > S3
Expt 4	W = (5, 7, 9)	0.45	0.42	0.35	0.53	0.69	S5 > S4 > S1 > S2 > S3
Expt 5	W = (7, 9, 9)	0.46	0.41	0.34	0.53	0.66	S5 > S4 > S1 > S2 > S3
Expt 6	W1 = (7, 9, 9), W2-5 = (1, 1, 3)	0.44	0.48	0.39	0.55	0.83	S5 > S4 > S2 > S1 > S3
Expt 7	W1 = (7, 9, 9), W2-5 = (1, 3, 5)	0.44	0.46	0.38	0.55	0.78	S5 > S4 > S2 > S1 > S3
Expt 8	W1 = (7, 9, 9), W2-5 = (3, 5, 7)	0.44	0.44	0.36	0.54	0.72	S5 > S4 > S1 > S2 > S3
Expt 9	W1 = (1, 1, 3), W2-5 = (7, 9, 9)	0.44	0.43	0.36	0.56	0.70	S5 > S4 > S1 > S2 > S3
Expt 10	W1-4 = (1, 1, 3), W5 = (7, 9, 9)	0.44	0.46	0.38	0.55	0.78	S5 > S4 > S2 > S1 > S3

Source: Own Calculations

Therefore, this decision-making process is comparatively insensitive to criteria weight with supplier 1 emerging as best green practices and the proposed methodical framework of evaluating practices of the selected suppliers is robust.

Figure 4: Radar diagram showing the results of Sensitivity Analysis



Source: Own Analysis

This radar diagram depicts how different experiments affects ratings of the suppliers and how the Supplier 5 is clearly far ahead than the others.

CHAPTER 5 – RECOMMENDATIONS & CONCLUSION

This chapter draws certain conclusions and recommendations on the study 'Green Supplier Selection Using MCDM Approach: An Analysis based on a Manufacturing Firm' based on the literature review and analysis and its findings.

5.1. Recommendations to the company

The TOPSIS approach is a widely used method for green supplier selection in the manufacturing industry. This approach considers both environmental and economic criteria to evaluate potential suppliers and rank them based on their similarity to the ideal solution.

The recommendations to the company are:

- By selecting suppliers who can prioritize sustainability, XYZ limited can enhance its reputation, attract environmentally conscious customers, and comply with environmental regulations.
- The effectiveness of the TOPSIS approach depends on the selection of appropriate criteria and the accuracy of the data used for evaluation. Therefore, it is crucial to carefully choose the criteria that reflect the environmental and economic impact of suppliers and to ensure that the data used is reliable and accurate.
- Periodic review and modification in criteria are necessary. It is important because changes may happen in the firm's policies, culture, and its environment.
- Any misjudgment in the supplier selection process can impose enormous costs on the buying company, as changing the supplier selected or withdrawing from the strategic partnership between buyer and supplier is extremely complex and risky.
- It is likely that if more criteria were considered and at a greater level of detail, the output results (i.e., the supplier rankings) obtained from applying each method would converge, thus increasing the overall reliability of the evaluation.

Overall, the TOPSIS approach is a valuable tool for green supplier selection in the manufacturing industry, and it can help XYZ ltd. to achieve its sustainability goals while maintaining its economic performance.

5.2. Benefits to the company

Based on the analysis of the study, if this approach is implemented, then there are several benefits for XYZ ltd. such as:

- Establishment of a systematic approach for selecting and evaluating green suppliers and allocating orders to each supplier.
- Increase in product development capability and quality.
- Reduction in cost and environmentally hazardous material in the supply chain
- Increase in product market share.
- Reduced risk of purchasing i.e., through evaluating each supplier against a set of criteria and ordering from multiple suppliers.

5.3. Conclusion

The adoption of Green Supply Chain Management (GSCM) is a relatively new concept in India, but the Indian manufacturing industry has recognized its importance due to various competitive, regulatory, and community pressures. This research project proposes a fuzzy TOPSIS approach for evaluating GSCM practices in Indian manufacturing firms and effectively selecting suppliers.

The results obtained from the proposed decision making approach are similar to the findings from real life selection of suppliers by the firm, which has demonstrated the robustness of the methodology and promoted its use as a decision aid for further supplier evaluation and selection situations faced by the management of XYZ ltd.

The proposed framework is demonstrated and validated using a case study from a leading Indian manufacturer, where the results suggest that supplier 5 has effectively adopted GSCM practices and can be considered as a green supplier. The study also presents a benchmarking framework to evaluate the "greenness" of manufacturing firms, which can be used by related industries to evaluate their GSCM practices and select green suppliers in a more effective and efficient manner. These findings can help organizations streamline their operations and processes towards the adoption of green practices, in order to remain competitive.

CHAPTER 6 – LIMITATIONS & FURTHER RESEARCH

6.1. Limitations

Comparative evaluation of GSCM practices in selected firm through fuzzy TOPSIS has been done here. Adopted fuzzy TOPSIS methodology relies on experts/decision makers' opinions subjective in expression. Therefore, we need to be careful in selection of the panel of decision makers.

In this study, we have considered only three dimensions; environmental, economic, and social criteria while other dimensions like business and traditional aspects have been ignored.

These valid limitations need to be considered while integrating presented MCDM framework with economic and social dimension, i.e., towards sustainable supplier selection.

6.2. Scope for future research

Other fuzzy MCDM techniques (fuzzy AHP, fuzzy VIKOR, fuzzy DEMATEL, fuzzy PROMETHEE and fuzzy ELECTRE) may be applied in future research, and the results obtained may be compared with the results of the present study. The same evaluation criteria may be applied to solve other MCDM problems like evaluating success factors to implement all types of practices, etc. or in other sectors like manufacturing, electrical or electronic sector, etc.

Supplier selection is a critical task in manufacturing industries as it directly impacts the final product's quality, cost, and delivery. Multi-criteria decision-making (MCDM) approaches have been widely used to assist decision-makers in selecting the most suitable suppliers based on multiple criteria. Some potential areas for future research in supplier selection using the MCDM approach in the manufacturing industry include:

1. Integration of sustainability criteria: Sustainable development has become a crucial concern for many manufacturing industries. Hence, incorporating sustainability criteria, such as environmental impact, social responsibility, and economic sustainability, into the supplier selection process is a critical research area.
2. Developing dynamic MCDM models: In practice, supplier selection is a dynamic process that requires constant monitoring and evaluation. Developing dynamic MCDM models that can update the supplier ranking in real-time based on changes in criteria weights or supplier performance can be a helpful research direction.

3. Handling uncertainty and imprecision: The supplier selection process involves various sources of uncertainty and imprecision, such as incomplete information, vague criteria, and subjective judgments. Therefore, developing MCDM models that can handle uncertainty and imprecision in the decision-making process can be a valuable research area.
4. Considering risk management: Supplier selection involves risk management as suppliers' performance can be affected by various internal and external factors. Incorporating risk management criteria, such as supplier reliability, contingency planning, and risk mitigation strategies, into the MCDM approach can be an essential research area.
5. Integration of big data analytics: With the advent of big data analytics, manufacturing industries can leverage the vast amount of data available to optimise supplier selection decisions. Developing MCDM models that integrate big data analytics techniques, such as data mining, machine learning, and predictive modelling, can be a promising research direction.

Overall, supplier selection using the MCDM approach in manufacturing industry is a complex and dynamic decision-making problem that requires continuous improvement and innovation. Future research in the areas outlined above can provide valuable insights and contribute to the development of more effective supplier selection strategies.

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Annexure

Questionnaire that has been used to find the experts' ratings for the identified criteria, parameters, and the suppliers.

Please rate the importance of the practices implemented in your manufacturing firm. Where VL = very low; L = low; M = medium, H = high and VH = very high (Please tick only ONE in each row).

1. Conventional Practices

	VL	L	M	H	VH
Supply Capacity	○	○	○	○	○
Quality	○	○	○	○	○
Technological Capability	○	○	○	○	○
Price	○	○	○	○	○
Service Level	○	○	○	○	○

2. Environmental practices

	VL	L	M	H	VH
EMS	○	○	○	○	○
Green Image	○	○	○	○	○
Waste Level	○	○	○	○	○
Pollution Production	○	○	○	○	○
Environmental Competencies	○	○	○	○	○

3. Social Practices

	VL	L	M	H	VH
Safety, rights and health of employees	○	○	○	○	○
Staff Development	○	○	○	○	○
Information Disclosure	○	○	○	○	○
Forced-Child Labor	○	○	○	○	○
Adherence to law and policy	○	○	○	○	○

Please rate the status of parameters for the set of selected suppliers in your manufacturing firm. Where VL = very low; L = low; M = medium, H = high and VH = very high (Please tick only ONE in each row).

Supply Capacity

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Quality

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Technological Capability *

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Price *

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Service Level *

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Environmental Management Systems *

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Green Image *

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Waste Level *

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Pollution Production *

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Environmental Competencies *

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Safety, rights and health of employees *

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Staff Development *

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Information Disclosure *

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Forced-Child Labor *

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

Adherence to law and policy *

	VL	L	M	H	VH
S1	○	○	○	○	○
S2	○	○	○	○	○
S3	○	○	○	○	○
S4	○	○	○	○	○
S5	○	○	○	○	○

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