Chapter 1

Book Chapter

Selection of Green Supplier Using Integrated Multi-Criteria Optimization Method: A Case Study of Plastic Extrusion and Vacuum Forming Company in India

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Abstract

The manufacturer ideally should have a fair idea about the rating of its suppliers. Today's demands include cost-effectiveness, premium-quality goods, timely delivery, and superior services after the sales and engage in environmental responsibility activity. In recent years, environmental consciousness has increased significantly. Hence, while assessing a supplier, its sensitivity towards the environment must be considered along with economic factors. That is why it can be termed as "green supplier selection." The green supplier selection is considered to be a Multi criteria optimization Problem, which is more popularly known as Multi-Criterion Decision-Making (MCDM) problem. MCDM tools are required to solve such kinds of problems. A case study in India's industrial plastic component manufacturing company was carried out to address the issue. An integrated MCDM approach was deployed for green supplier assessment and selection. The research study, novel in nature, suggests how to rank suppliers as well as how low-rank suppliers incorporating environmental consciousness can

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improve their performance.

Keywords: Green supplier selection. MCDM. TOPSIS. Green supplier selection criteria. Green supply chain management.

1 Introduction

Protection of the environment is the main issue and competitive factor in the manufacturing industry nowadays. Green supply chain strategies and actions are required for every facet of Supply Chain Management (SCM), right from acquiring raw materials from suppliers to delivering finished goods to the customer. (Qureshi, Kumar, & Kumar, 2008). Environmental regulatory bodies and the government are continuously trying and forcing manufacturing industries to restrain traditional SCM practices' ill effects and adopt Green Supply Chain Management (GSCM) practices. (Zhu, Sarkis, & Geng, 2005). Being in the 21st century, deploying GSCM practices is the need of the hour. GSCM methodology is nothing but a judicial blend of traditional SCM with green environmental protection practices for sustainable development Madaan2014.Tyagi, Kumar, and Kumar's (2015) explained GSCM as incorporating environmental thinking into SCM, including product design, material sourcing and selection, manufacturing practices, delivery of the final products to the consumers, and end-of-life management of the product after its intended life. Since the beginning of the 21st century, Green Supply Chain Management has redefined business activities to build a sound economic- environment-friendly ecosystem. (Purba Rao, 2018). Nevertheless, developed countries are in a continuous engagement in adopting and successfully implementing GSCM in their organizations Whereas India is still struggling to adapt and adequately implement GSCM practices.(Chien & Shih, 2007; Dubey & Ali, 2014). In the current global scenario, there is tremendous pressure from international environmental bodies, raising the flag when GSCM practices are not implemented. They are encouraging businesses to recognize the factors that will allow them to properly and effectively follow GSCM guidelines.(Mathiyazhagan & Haq, 2013).

The green supplier selection (GSS) system is critical to the GSCM value chain. Green supplier firms have a highly environmentally sensitive image and focuses on using renewable and environment-friendly energy resources, recyclable and reusable raw materials and consumables, green designing green packaging and packaging material, etc., in their supply chain operations. (Wu et al., 2019). It is not easy to select a green supplier in compression to select a conventional supplier as stated by Aretoulis, Kalfakakou, and Striagka's (2010) and Mendoza and Ventura's (2013) as it has to consider both qualitative as well as opposing selection standards.(Cao, Wu, & Liangb, 2015; Fahimnia, Sarkis, & Davarzani, 2015). That is why GSS is acknowledged as a Multi-Criterion Decision-Making (MCDM)issue. This issue has drawn many researchers' attention in recent times.(Chatterjee, Maji, &

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Pham, 2019; Mathiyazhagan & Haq, 2013; Wu et al., 2019). Additionally, a remarkable increase in research on GSS by Govindan, Khodaverdi, and Jafarian's (2013), Malviya and Kant's (2015), and Tseng et al.'s (2019) in recent years has highlighted the significance of the issue. MCDM strategy is used in making decisions through setting up and fulfilling multiple and conflicting criteria. Its problems are common in daily routine; for instance, if anyone buys a mobile phone, it is qualified by cost, features, storage, looks, camera, etc. While in business, problems are much completed. In recent years this method has been used for better business modelling. Purchase departments of many companies use this method to select their suppliers based on a vast range of criteria such as cost of material, quality, after-sales service, financial stability, etc. (Govindan, Khodaverdi, & Jafarian, 2013; Gunasekaran & Gallear, 2012).

In the recent past, different techniques have been used for suppliers' ranking and selection. ANP, TOPSIS, AI, and integrated techniques are the most used methods for this purpose.(Akcan & Taş, 2019). The TOPSIS-based model has been put forward to score, rank, and select suppliers.(Boran et al., 2009). This model lays out the criteria of cost, quality, delivery, relationship, and closeness for evaluating suppliers. The main advantage of TOPSIS is easy to apply. The steps of the TOPSIS remain the same, whereas many attributes can be changed. TOPSIS has been applied in manufacturing systems, engineering, Supply chain management, trading, promotion-based marketing, and transportation and logistics. Further, it has also been deployed for evaluating human resources, ranking environmental factors, and assessing suppliers. (Govindan, Khodaverdi, & Jafarian, 2013; Gunasekaran & Gallear, 2012).This can further contribute to corporate sustainability.(Okr glicka, Mittal, & Navickas, 2023).

The suggested approach was applied to the industrial plastic component manufacturing company (Plastic Extrusion and Vacuum Forming Company) to select green suppliers. The products have been broadly used for home appliances, like refrigerators' inner plastic bodies and other necessities. This is a raw material usage-intensive industry, the finished product is used in the domestic market, and exported also. It is the reason why selecting the appropriate supplier plays a major role in evaluating how much the businesses accomplish. For this purpose, this paper covers studies and methods in the literature review section and later opines a multi-phase MCDM model for ineffective assessment and selection of a green supplier for a plastic sheet manufacturing company. The case design approach was carried out by selected managers and suppliers.(Chien & Shih, 2007; Tian et al., 2019). This paper meets the following objectives:

1. What are the important and applicable criteria for green suppliers' selection (GSS)
2. How to rank green suppliers using MCDM.
3. How the performance of the lowest-ranked supplier can be improved.

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2 Literature Review

Supplier selection is a crucial facet in the management of supplies and purchasing functions.(Banaeian et al., 2018). Researchers have used a variety of MCDM methods for handling the problems of green supplier selection. Various criteria for supplier selection were explored in the first section of the literature review. These criteria, including quality, timely delivery, and economic pricing, have been used by different companies to assess their suppliers.(Hlioui, Gharbi, & Hajji, 2017). The GSCM approach takes into consideration the environmental hazards, ecological balance, and climate change for all the phases of supply chain management, covering its entire cycle.(Mangla et al., 2014; Min & Galle, 1997). GSCM increases buyers' and suppliers' various opportunities because all corporate and industrial activities are environment protection-centric. (Purba Rao, 2018). The process of GSCM starts with procurement and green purchasing. It exhibits a critical impact on the supply chain environmental effect.(Günther & Scheibe, 2006; Min & Kim, 2012). As far as green supplier selection criteria are concerned, many researchers have taken different criteria based on different experts and different industry inputs across different economies. (Mathiyazhagan, Sudhakar, & Bhalotia, 2018). Lee et al.'s (2009), considered the net cost of the product through its lifecycle, quality as well as technology capabilities, along with green criteria, such as pollution control, green image, green product, environmental management, and green proficiencies.

Chen et al.'s (2010)identified green design, ISO 14001, clean production, R&D on green products, green purchasing, quality, flexibility, and delivery. Kannan, Govindan, and Rajendran's (2015) included environment protection, green image, green product, green innovation, corporate social responsibility, hazard management, and pollution control as criteria to implement GSS. A green supplier makes efforts primarily to use renewable energy sources and save, reuse, and recycle the materials. In addition, its focus remains on green designing as well as green packing while performing GSCM activities .(Wu et al., 2019). The process of selecting and verifying a green supplier is more complicated than that of a conventional supplier. (Aretoulis, Kalfakakou, & Striagka, 2010; Mendoza & Ventura, 2013; Yousefi, Jahangoshai Rezaee, & Solimanpur, 2021). This is the reason why the problem of GSS is treated as a multiple-criteria decision-making (MCDM) issue.(Cao, Wu, & Liangb, 2015). This issue had drawn many researchers' attention in recent times.(Chatterjee, Maji, & Pham, 2019; Wu et al., 2019; Yousefi, Jahangoshai Rezaee, & Solimanpur, 2021). Additionally, a remarkable increase in the research on GSS Chatterjee, Maji, and Pham's (2019), Govindan, Khodaverdi, and Jafarian's (2013), and Malviya and Kant's (2015) recently has highlighted the significance of the matter. Numerous economic and environmental facets have also been taken into consideration to verify and validate green suppliers.(Yu, Yang, & Chang, 2018).

The second part of the literature review deals with the decision-making issue of MCDM

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problems. As far as green supplies selection methods or approaches are concerned, rich literature is available. Zhang, Liu, and Zhai's (2011) classified supplier selection methods into five groups: mathematical programming models, statistical approach, linear weighting models, cost-driven models, and artificial intelligence-driven models.Kannan, De Sousa Jabbour, and Jabbour's (2014) performed a dense review of the literature, exploring MCDM techniques for selecting a green supplier. He found that Linear Programming (LP), Analytic Hierarchy Process (AHP), as well as Data Envelopment Analysis (DEA) were the most favored techniques. Similarly, in another resembling study performed by Govindan, Khodaverdi, and Jafarian's (2013), selecting a green supplier was deemed to be named problem. To solve this issue, TOPSIS, LP, DEA, network analysis, and Analytic Hierarchy Processes can be used. The name of the model was Fuzzy PIvot Pairwise Relative Criteria Importance Assessment (Fuzzy PIPRECIA) model.

Petrović et al.'s (2019) identified seven criteria for the industry: environmental image, recycling, environmentally friendly products, environmental management system, resource consumption, pollution control, and green competencies. Three MCDM methods were applied for GSS, which included fuzzy TOPSIS fuzzy ARAS methods, and fuzzy WASPS, providing a new dimension to achieve the objective.

3 Research Methodology

The study is carried out through a Case study by analyzing and observing a single company, Ambar Enterprise Ltd. The case study technique has a unique benefit in situations when the "How" "Which" and "what" kind of inquiry is being inquired. (Yin, 2013). This study's questions are intended to show "what" are the important and applicable criteria for green supplier selection, "How" should Ambar Enterprise Ltd. Rank the supplier and "how" should improve the performance of the suppliers. This study conducted a questionnaire survey to measure the important and applicable selection criteria and rank the suppliers. The research design of this study will be a combination of both the case study and the survey.

The questionnaire was designed and fabricated based on the results and crux of the literature review. The first questionnaire survey has been sent to five managers of related departments, the intended objective will be to get a list of important and applicable criteria according to their opinion. Similarly, the second survey will be sent to the purchasing manager to rank the suppliers against the identified selection criteria list. Cronbach's alpha has been deployed to ensure the statistical reliability of the collected data set. Cronbach's alpha is coming to 0.78, which shows a higher internal reliability level. Mann- Whitney U-test, TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) analysis and Parametric Analysis have been used to analyse the data.

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1. Mann–Whitney U-test H0 = statistically, there should be no difference in the importance and applicability of the criteria for GSS. H1= the importance and applicability of the criteria for GSS must be different, statistically. To assess whether the mean scores of the collected information, are significance and relevant, Mann–Whitney U-test has been applied. It is a non-parametric evaluation method used to compare two data means from the same population. It also examines whether the mean of the two data sets is equal.

2. TOPSIS Analysis Hwang and Yoon incepted the idea to design TOPSIS to solve MCDM problems. It is used for ranking the decision-making alternatives. This technique's basic philosophy states that the best alternative should have the minimum distance to the positive ideal solution and the maximum distance from the negative ideal solution. The initial step of this process is to establish a benchmark, i.e., the "Ideal Positive Solution (IPS) and Ideal Negative Solutions (INS).The second step is to form a normalized decision matrix showing these numbers. The third step is to choose the largest normalized and weighted score to obtain each criterion's positive ideal solution. Similarly, choose the least normalized and weighted score to obtain the negative ideal solution for each attribute.In the final step, one needs to calculate and figure out how far or close each alternative is from the PIS and NIS.

3. Parametric Analysis The basis of this analysis is to change only one criterion while keeping the values of all other evaluation factors constant for entire data sets.

4. List of Criteria A survey was conducted to verify and certify the proposed green supplier evaluation criteria. To evaluate, the important and applicable green supplier evaluation criteria, a questionnaire was developed. It contains two aspects, namely economic, environmental aspects.(see table 1).

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Table 1. List of Green Supplier Selection Criteria

Aspect	Main Criteria	Sub Criteria (Alternatives)
Economic Aspect	Cost	Cost of Material
		Ordering & Holding cost
		Freight cost
	Quality	Rate of Rejection
		Product Performance
		Quality Inspection Methods
	Delivery service	On-time Delivery
		After Sales Service
		Delivery Speed
		Responsiveness in solving complaints
Environment Aspect	Flexibility	Flexibility in ordering
		Flexibility in Delivery time
		Flexibility in Giving Discount
	Environmental management system	ISO14001 Certification
		Ozone-depleting Chemical used
		Eco-Labeling
		Use of environment-Friendly Raw Materials
	Green Product Image	Green certification
		Reuse
		Green packaging
		Air emissions
		Wastewater
		Hazardous wastes
	Eco-Design	Recycle of Products
		Re-Manufacturing of Products when Design
		Decrease the use of Hazard Materials in production
	Green Technology	Capability of R&D
		Process alteration to save natural resources
		Use of green raw material
	Green Transportation	Using a modern eco-efficient transportation fleet
		Use of green fuels

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4 Analysis

To analyze the first objective, a survey has been conducted. The managers (respondents)had given their preferences on a scale of 1 to 5 for each criterion. The mean value of each criterion was taken to evaluate the importance level and applicability level. The results are depicted in the following figure.(see figure 1).

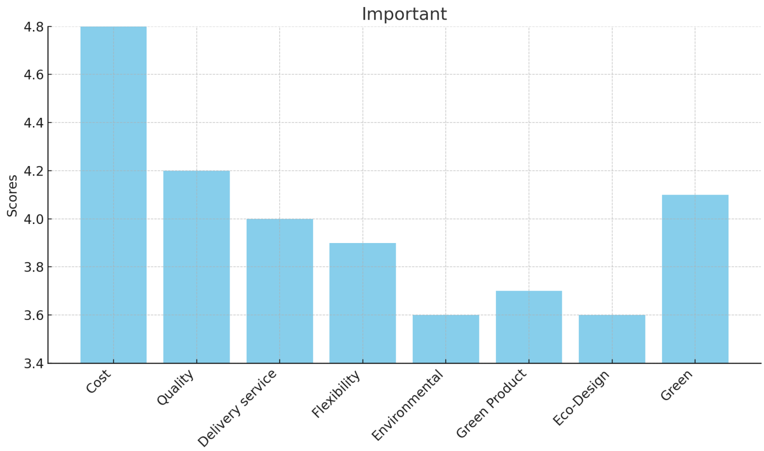

Figure 1. Important green supplier evaluation Criteria

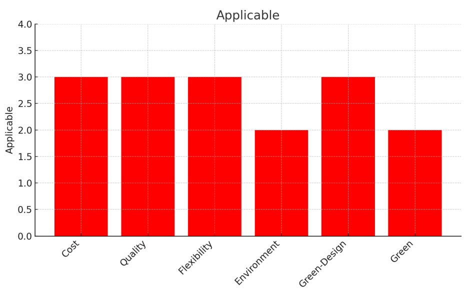

Figure 2. Applicable green supplier evaluation Criteria (analysis)

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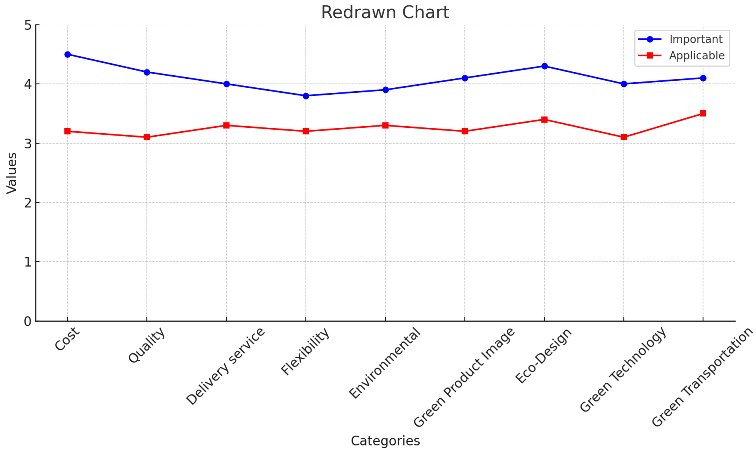

Figure 3. Important and Applicable Green Supplier Evaluation Criteria

The graph depicts important green supplier evaluation criteria. The manager gave importance to the economic aspect during supplier evaluation rather than the environmental aspect. It can be easily observed cost is at the top of the list with the highest score of 4.6; in contrast, the green product image was at the bottom of the list with a 3.9 score. Quality 4.6, flexibility 4.4, Delivery and Service 4.2, with a percentage of 92%, 88%, and 88%, followed respectively. Green transportation had more importance compared to other environmental criteria in the list. Green technology and eco-design had equal importance. Figure 2 depicts the applicable supplier evaluation criteria. As can be observed, cost is the most applicable criterion, with a score of 3.7 on the list. This was followed by Quality 3.2, flexibility; delivery service, and green product image have the same score of 3.5. It can also be observed from Figure 2 that green image had the top score of 3.5, succeeded by green transport at 3.1, Eco-design at 2.9, and green technology at 2.4.

Figure 3 shows that although all nine identified green supplier selection criteria are important and applicable cost, quality, environmental management, and green transportation are more important than the remaining criteria. So, the company should give more emphasis on these criteria for the evaluation of suppliers. Mean scores of importance and applicability have been collected and Mann–Whitney U-test has been applied by using SPSS. The test is done on ranked scores, which are not normally distributed. The p-value for all the criteria has been calculated. The p-value > 0.05 for all the attributes shows no significant difference between the importance and applicability of the attributes. It can be concluded that a good correlation between the criteria, we have taken for GSS concerning importance and applicability.

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To analyse the second object, ranking the suppliers, the multi-criteria decision-making method TOPSIS has been applied. Seven leading suppliers are known as S1, S2, S3, S4, S5, S6, and S7 have been taken. Selecting the best supplier among these seven alternatives based on nine criteria is complicated. That is why; the company's purchasing manager cannot make the right strategic decision for making long-term collaboration with the suppliers. Therefore, this section aims to evaluate and select the best suppliers for the company using TOPSIS. It is a simple mathematical equation for determining the best alternative. It has a straightforward computation process. The philosophy of this method is that the best alternative should have the minimum distance to the positive ideal solution (PIS) and the maximum distance from the negative ideal solution (NIS).‖ The closeness Coefficient (CCI) of each alternative is derived as closer to the PIS and farther from NIS and CCI approaches to 1. The steps-wise results of TOPSIS are as follows.

1. The company's purchasing manager was asked to rate the performance of the suppliers against each attribute so that the decision matrix can be formed.(see table 2).

2. Obtaining a normalized decision matrix.(see table 3).

Criteria	Cost	Quality	Delivery service	Flexibility	Environmental management system	Green Product Image	Eco-Design	Green Technology	Green Transportation
S-1	4	4	3	4	5	4	2	2	5
S-2	3	5	4	2	4	3	3	2	4
S-3	2	4	3	3	3	4	3	3	4
S-4	4	3	2	3	4	5	2	2	5
S-5	5	3	5	4	2	5	2	1	3
S-6	2	2	2	5	3	4	1	3	4
S-7	5	1	3	1	2	4	3	2	4

Table 2. A table with rotated headers

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Table 3. The normalized data set

Criteria	Cost	Quality	Delivery service	Flexibility	Environmental management system	Green Product Image	Eco-Design	Green Technology	Green Transportation
S-1	0.406	0.547	0.344	0.486	0.547	0.385	0.652	0.530	0.456
S-2	0.205	0.547	0.468	0.245	0.695	0.480	0.374	0.530	0.342
S-3	0.309	0.328	0.229	0.245	0.289	0.480	0.496	0.397	0.456
S-4	0.503	0.219	0.344	0.370	0.168	0.480	0.378	0.268	0.342
S-5	0.409	0.110	0.574	0.122	0.148	0.193	0.289	0.268	0.342
S-6	0.213	0.437	0.229	0.608	0.277	0.129	0.124	0.268	0.342
S-7	0.509	0.110	0.344	0.364	0.134	0.195	0.124	0.268	0.342
The Best	0.213	0.547	0.574	0.608	0.695	0.480	0.652	0.530	0.456
The Worst	0.503	0.110	0.229	0.122	0.148	0.193	0.124	0.268	0.342

3. Calculate the distance from PIS and NIS for each alternative. Calculate ranking and closeness coefficient (CCi).(see table 4).

Based on nine criteria, the ranking of the suppliers has been obtained. S1 is found to be the best supplier with CCI score of 0.8286, whereas supplier S7 was found to be the lowest rank supplier with CCI score of 0.0598.

To analyze, the third objective i.e.,to improve the Performance lowest-ranked supplier's performance (S7).A parametric analysis technique has been applied to determine which criterion should be focused on so the performance of the supplier can be improved. This is done by changing the weight of one criterion while keeping other criteria constant and seeing how much suppliers' performance would change.We applied parametric analysis to find out among nine main criteria have more effect on the supplier's performance (see table 5). In the table, we can see some criteria such as the cost being not alien with the performance, which means increasing the weight of Cost, Performance is decreased. Similarly, other criteria like quality, delivery service, and flexibility are alien to performance

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Table 4. Rank the supplier

Suppliers	Distance between the worst Alternatives	Distance between the best Alternatives	Distance between the worst and the best	Ranking the suppliers
S-1	1.456739	0.352071	0.828671	1
S-2	1.442791	0.698345	0.678423	2
S-3	0.972341	0.652311	0.601824	3
S-4	0.295671	0.855076	0.307531	4
S-5	0.479612	1.286531	0.287643	5
S-6	0.619571	1.270653	0.195632	6
S-7	0.092316	1.478235	0.059832	7

which meaning by increasing the weight, performance is also increased.

Table 5. Performance of S7 by changing the weight (1-5)

		Cost	Quality	Delivery service	Flexibility	Environmental management system	Green Product Image	Eco-Design	Green Technology	Green Transportation
Weight	1	0.135	0.037	0.077	0.047	0.046	0.043	0.046	0.049	0.042
	2	0.090	0.034	0.018	0.046	0.046	0.046	0.058	0.046	0.042
	3	0.076	0.042	0.045	0.054	0.098	0.054	0.087	0.058	0.047
	4	0.058	0.065	0.087	0.078	0.147	0.093	0.126	0.106	0.047
	5	0.049	0.097	0.122	0.097	0.198	0.099	0.168	0.127	0.057
	Difference	-0.091	0.681	0.119	0.148	0.072	0.120	0.076	0.029	0.056

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Figure 4 shows the performance of the lowest-ranked supplier (S7) at a different weight (1 to 5). It has been observed that cost has a reverse relation with the performance of the supplier. Whereas other green supplier evaluation criteria such as quality, delivery service, flexibility, green product image, eco-design, green technology, and green transportation directly correlate with the supplier's performance. Figure 5 shows the difference between the lowest and highest values of Performance of S7. As demonstrated in Figure 5 the difference of green Performance of S7If the performance difference is high, then any green supplier selection criteria are more effective. Flexibility has the highest performance difference, Whereas, Cost is considered a negative criterion in terms of flexibility. Flexibility is decreased by increasing the cost. Suppliers should try to decrease Table 5 calculated by changing the weight (1 to 5) of one criterion and keeping other criteria constant. Flexibility in the delivery for improvement. Delivery services and green product image have almost equal importance for performance improvement. Moreover, the remaining criteria are also helpful in S7 for performance improvement.

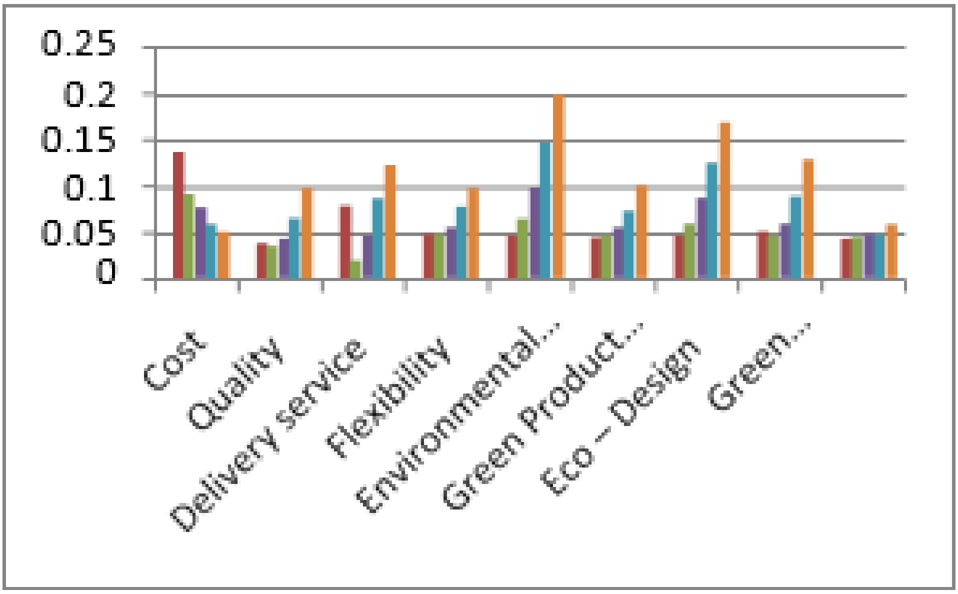

Figure 4. Performance of S7 by changing the weight (1-5)

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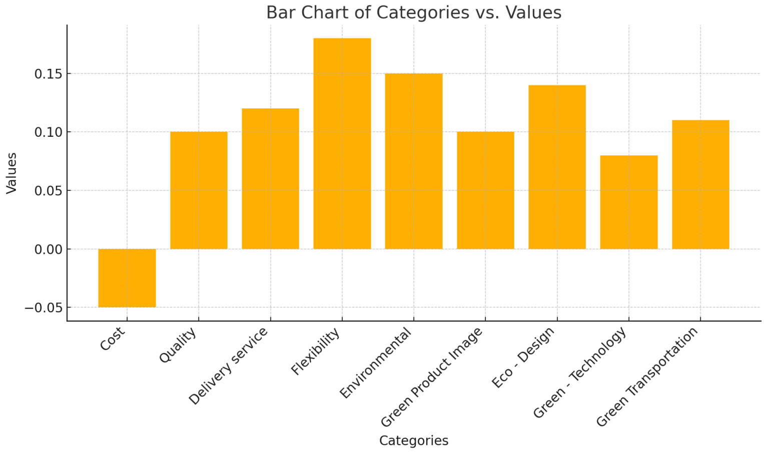

Figure 5. Difference of green Performance of S7

5 Conclusion

On the basis dense of literature reviewed, a comprehensive list consisting of nine main green supplier evaluation criteria and thirty-one sub-criteria were finalized. Based on the questionnaire-based survey, the inputs of the managers have been collected.The importance and applicability have been measured based on these inputs.

It study reveals that most effective criteria for green supplier evaluation are economic criteria, followed by environmental criteria. Mann–Whitney U-test demonstrates no significant difference between the mean scores of importance and applicability. Therefore, the developed list of the green supplier selection criteria and their corresponding sub-criteria can be used to evaluate the green supplier's performance.It is always difficult for the decision to make to decide by considering thirty-one conflicting criteria. A multi-criteria decision making method, TOPSIS, had been applied to rank the supplier as it is simple to apply,mathematical structure modeling technique. The supplies have been ranked considering all the thirty-one sub-criteria. This ranking is beneficial for various strategic decisions and long term collaboration with suitable suppliers. At the same time, the performance of the lower rank suppliers can also be measure. It has been suggested that the lowest performer supplier S7 take care of flexibility, delivery service, and green image by applying the parametric analysis. Similarly, the performance of the lower-ranked supplier can also be improved by concentrating upon specific suggested criteria.

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