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Hybrid MCDM Approaches for Sustainable Supplier Selection from the Economic and Environmental Aspects

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Abstract

Supply chain design is essential while considering environmental and economic issues in order to prevent negative environmental impacts induced by increasing levels of industrialization. A novel sustainable supply chain design strategy is offered in this research to address the trade-offs between environmental and economical concerns. One of the most important operational tasks in the construction of a green SCM is the identification of sustainable suppliers. Although many studies have considered economic criteria like cost, quality and lead time to select suppliers, just a few have taken environmental and social factors into account. This study suggests a number of integrated Multi-Criteria Decision Making (MCDM) methods for choosing and assessing environmentally and economically responsible suppliers. Various approaches of MCDM such as SAW, WASPAS, TOPSIS, and GRA are used in the suggested methodology.

Keywords: *Supplier selection, Green, MCDM, supply chain*

1.0 Introduction

Climate change and the harmful impacts of global warming have increased worldwide concern about environmental protection programmes. Firms concentrate on the creation of green products to meet client environmental needs and criteria in order to achieve and sustain competitive advantages in the global market. As a result, it is critical for organisations to build green supply chain management that incorporates environmental thinking and tactics. The environmental performance of the entire supply chain is greatly influenced by its constituent suppliers, and hence, green supplier selection is crucial. Companies must examine both environmental and economic factors when selecting a good supplier. Green suppliers must aid in reducing negative environmental impact, and at the same time, it should assure the company's expectations and objectives. Choosing the most optimal decision from a finite collection of decision alternatives based on several conflicting criteria is known as multi-criteria decision-making.it helps decision-makers choose options when dealing with discrete challenges. Especially with the help of computers, those methods have become more user-friendly, and they have found widespread acceptance in many areas of economic and management decision-making processes.

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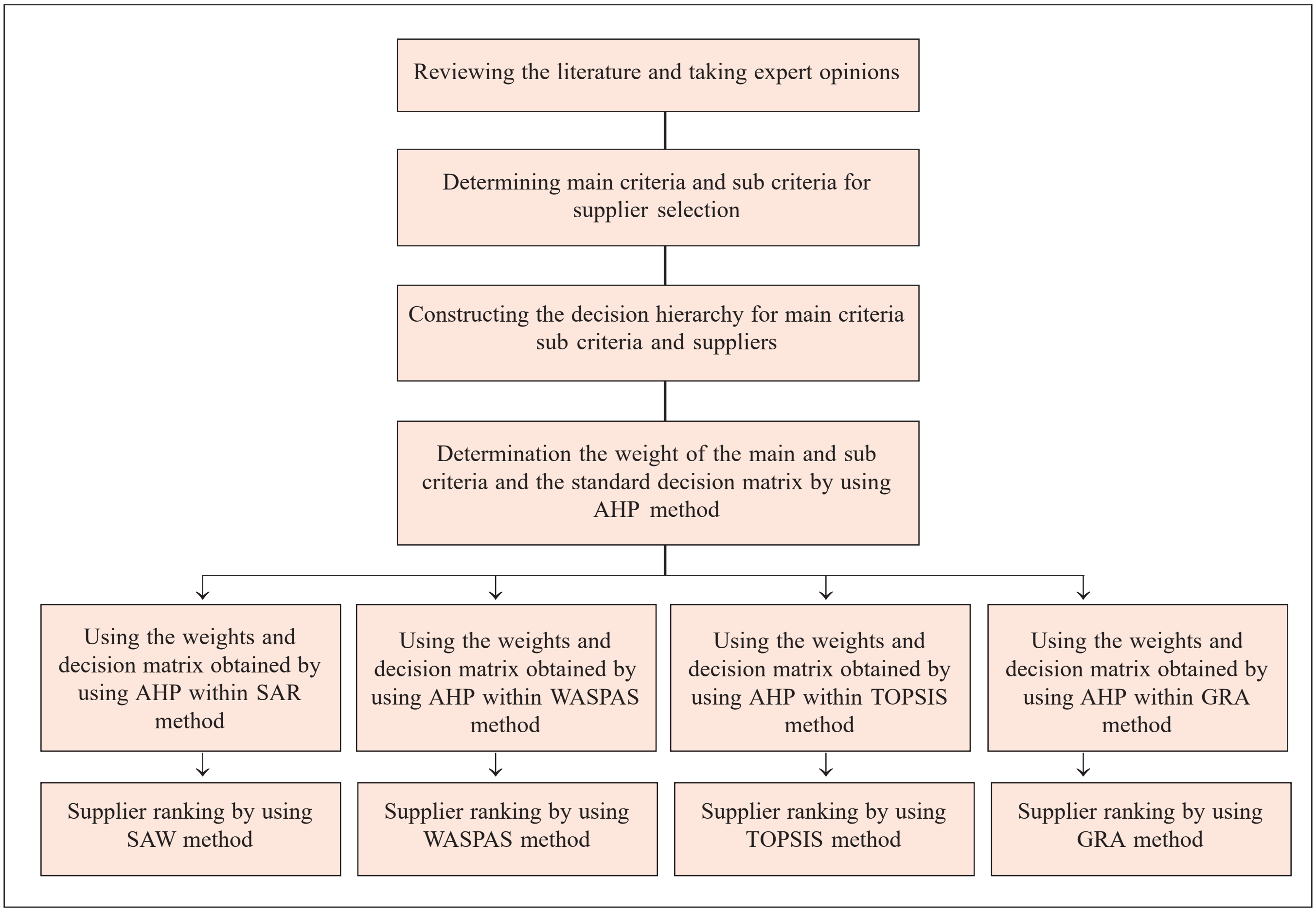

Figure 1: Proposed method Framework

2.0 Literatre Review

Here AHP is used directly in GSCM practices by providing alternatives (Ireneusz Miciua 2018: G. Karunakumar 2018). However, it is frequently combined with other techniques in works of literature, such as Electre III (Ali Alazzawi, 2020), Vikor (Ashwani Kumar, 2019), and Promethee. Weighted Aggregated Sum Product Assessment (WASPAS) has been applied for green supplier selection under a fuzzy environment (Arunodaya Raj et al, 2019). In some situations, TOPSIS is a combination of different MCDM methods such as AHP (H.W. Mie 2016, Yazdai, 2014) or ANP (Uygun & Dede, 2016, Büyüközkan & Çifçi, 2012a, Kuo et al., 2015,), TOPSIS is also used to resolve GSCM problems in the fuzzy environment (Huseylin SelcukKilic et al.2020, Ahmed Mohammed, 2019, Li & Wu, 2015, Kanan et al., 2014, Shean et al. 2013). Grey Relational Analysis (GRA) method was used in the Pythagorean Fuzzy environment (ChunxiaYu, YifanShao, 2018) and the fuzzy best-worst method (Seyed Amin Seyed Haeri, 2019). Several research studies on supplier selection may be found when the literature is reviewed.The number of research on the supplier selection problem that uses hybrid multicriteria decision-making methods is restricted, according to a survey of the literature.The studies found that introducing hybrid MCDM approaches for supplier evaluation and selection fills the gap in the manufacturing sector. Some hybrid models are utilised in supplier selection research. However, the study shows multiple ways and provides a comparative study of the developed methods. It also helps decision-makers to choose the approach that best meets their requirements

3.0 Research Problem and Objectives

The primary goal is to propose integrated multicriteria decision-making methods for selecting the best supplier in the manufacturing industry. These methods include WASPAS, Grey Relational Analysis, Analytic Hierarchical

Process, and Simple Additive Weighting. Figure 1 depicts five steps of the proposed framework.The first step is to research the literature to determine the main criteria and supporting criteria for identifying and choosing the best manufacturing supplier. Then comes the choice to create a hierarchy. The suppliers are assessed by purchasing professionals using the criterion and subcriteria in the second stage. The weights of the criterion and the decision matrix are determined in the third stage using the AHP approach. The best supplier is chosen using different hybrid MCDM models in the fourth step. In the next step, a comparative study of hybrid models is done. The MCDM approach is a subcategory of operations research models. Complex assessment and selection problems with numerous contradicting objectives or criteria are successfully solved using MCDM approaches. MCDM approaches are used to handle real-world decision-making challenges in supplier selection. Combining two or more methods with MCDM methods is the latest trend. In this analysis,the selection of suppliers in the manufacturing sectoris done with AHP, TOPSIS, WASPAS, GRA and SAW.

4.0 Mcdm Methods

4.1 Analytic Hierarchy Process (AHP).

The commonly used MCDM method is Saaty's AHP. A hierarchy is established in which the target is placed at the top of the hierarchy, with alternatives placed at the bottom. Then, using Saaty's scale, pairwise comparisons and matrices for the criteria in each level are attained. The consistency index is evaluated using "CI=(λmax–n)/(n–1)", (λmax: eigenvalue). After that, the Consistency Ratio (CR) is evaluated for each matrix using CR=CI/RI to verify if the relative estimation is valid. For each matrix, the CR values should be less than or equal to 0.10.

14.2 Simple Additive Weighting (SAW)

In this proposed research work, the SAW method is used for all criteria and all alternatives.The SAW approach assigns a weight to each property, and each alternative is determined concerning that attribute. The assessment score of every option is obtained by multiplication of the scaled value. The steps for making SAW are given below.

1. Determine matrix.
2. Get the normalized decision matrix.

$$r_{uv}\begin{cases} \dfrac{x_{uv}}{\max x_{uv}}, & u=1,\ldots,m;\ v=1,\ldots,n, \\ \dfrac{\min x_{uv}}{x_{uv}} & u=1,\ldots,m;\ v=1,\ldots,n, \end{cases} \quad \ldots (1)$$

Here, x_{uv}/max x_{uv} denotes positive criteria, min x_{uv}/x_{uv} denotes negative criteria. The criterion value is x_{uv}, the max and min value for each positive and negative criterion is max x_{uv}, minx_{uv}, and the normalised value is r_{uv}.

$$A_v = \sum\nolimits_{v=1}^{m} w_v r_{uv},\ u = 1, \cdots, \quad \ldots (2)$$

X_{uv} and w_v representthe score of alternative u to criteria v and the weight of criteria v respectively. Obtained score is ranked.

4.3 Weighted Aggregates Sum Product Assessment (WASPAS)

The WASPAS is a hybrid model that combines the weighted sum and weighted product models. It creats decision/evaluation matrix, X=[x_{ij}]pq, where x_{ij} represents performance of the i^{th} alternative in relation to the j^{th} critetarion, p shows the alternatives number, and q shows criteria number. All of the elements in the decision matrix are normalised using the two equations to make the performance measures comparable and dimensionless

$\bar{x}_{ij} = \dfrac{x_{ij}}{\max x_{ij}}$ for beneficial criteria, for non-beneficial criteria,

$$\bar{x}_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \quad \ldots (3)$$

4.4 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

"Hwang and Yoon" introduce TOPSIS, an MCDM technique. The following steps can be used to explain TOPSIS.

Decision matrix determination:

$$X_{ij} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \vdots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad \ldots (4)$$

Calculation of a normalised decision matrix (for i = 1 to n, j = 1 to m):

$$R_{ef} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \vdots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} \quad \ldots (5)$$

$$r_{ef} = \frac{x_{ef}}{\sqrt{\sum_{e=1}^{m} x_{ef}^2}} \quad \ldots (6)$$

Determining the weighted decision matrix where the sum of theweights should be 1:

$$V_{ef} = R_{ef} * W_{n \times n} = \begin{bmatrix} v_{11} & \cdots & v_{1n} \\ \vdots & \vdots & \vdots \\ v_{m1} & \cdots & v_{mn} \end{bmatrix}. \quad \ldots (7)$$

Determining values of positive (A^+) and negative ideals (A^-):

$$A^+ = \left\{v_1^+, v_2^+, \cdots, v_n^+\right\}$$
$$A^- = \left\{v_1^-, v_2^-, \cdots, v_n^-\right\} \quad \text{... (8)}$$

Determiningthe separation measures S^+ and S^-,

$$S_e^+ = \left[\sum\nolimits_{f=1}^{n}\left(v_{ef} = v_f^+\right)^2\right],$$
$$S_e^- = \left[\sum\nolimits_{f=1}^{n}\left(v_{ef} = v_f^-\right)^2\right] \quad \text{... (9)}$$

Getting the relative closeness to rank orders:

$$C_e^+ = \frac{S_e^-}{S_e^+ + S_e^-}, 0 \le C_e^+ \le 1 \quad \text{... (10)}$$

4.5 Grey Relational Analysis (GRA)

Deng was the first to come up with the concept of grey relational analysis. It is primarily used to handle problems involving decision-making based on several attributes. The results, in this case, are based on original data. Calculation simplicity, readability and utility are some advantages. The procedure is given below.

- Organize the original data to allow for comparison.
- Calculate the grey relational coefficient after determining the min and max difference.

$$\Delta_{\min} = Min\left\{\Delta_{ij}\right\}, \Delta_{\max} = Max\left\{\Delta_{ij}\right\}$$
$$\gamma(x_{0j}, x_{ij}) = \frac{\Delta_{\min} + \varsigma\Delta_{\max}}{\Delta_{ij} + \varsigma\Delta_{\max}}. \quad \text{... (11)}$$

The distinguishing coefficient is ζ, where, $\zeta \in [0, 1]$. The score of grey relation can be calculated by:

$$\Gamma(X_0, X_i) = \sum\nolimits_{j=1}^{n} w_j \gamma(x_{0j}, x_{ij}) \quad \text{... (12)}$$

Here, w_j representsthe attribute's weight.

5.0 Case Study and Discussion

Step 1: The decision hierarchy for supplier selection criteria and construction is to be determined.This study is based on data obtained from a manufacturing firm. Figure 1 depicts the supplier selection decision hierarchy.

Step 2: Construct pairwise comparison matrices.

Step 3: AHP method is used for the weights and matrix determination.

Main criteria and subcriteria weights are evaluated for the five suppliers by industry experts using a 5-point scale. After performing pairwise comparisons,weights are obtained using AHP (Table 3). In the case of traditional economical criteria, quality is most important with a priority value of 0.470. Criteria's cost is significant with a priority value of 0.060. Technology is having a priority value of .310, and delivery reliability has a priority value of 0.144. Also for green criteria, EMS has a weightage of 0.089 and pollution control criteria havethe highest weightage of 0.43. The green design criterion is an important criterion with priority.

The criterion's cost refers to the price of purchasing any product, margin, the cost for the process, a quantity discount, etc. It is the non-beneficial sub-criteria under the traditional economic criteria. ISO 9001 certifications and quality of packing show subcriteria'squality. Delivery of products as per the schedule and supplying the right product are the main dimensions for the delivery reliability. The technology criterion refers to innovative sustainable processes and products. Under the green criteria, the green design considers eco-design, reusable or biodegradable parameters in decision making. Criteria for waste management systems consider parameters such as material reuse, recycling, as well as packaging.

Step 4: Combining different MCDM methods.

Table 1: Criteria and Subcriteria

Criteria	Sub criteria	Factors/Definition
Traditional-Economical (E)	Cost (E1)	Product price, process cost, quantity discount
	Quality (E2)	Product quality, ISO 14001 Certiûcation
	Technology(E3)	Innovation, Sustainable products
	Delivery Reliability(E4)	On time delivery, right product, lead time
Green- Environmental criteria (G)	Environmental management system (G1)	Collaboration between product designers and suppliers to reduce and eliminate product environmental impacts, green image
	Green design (G2)	Eco design, Reusable, biodegradable
	Pollution control (G3)	Reducing energy consumption, Government regulation and legislation
	Waste management (G4)	Reusing and recycling materials and packaging

Table 2: Decision Matrix

Criteria	E1	E2	E3	E4	G1	G2	G3	G4
Weight	0.06024	0.4728	0.313849	0.144104	0.089396	0.275347	0.435361	0.199896
Supplier 1	0.7500	1.0000	0.8333	1.2000	1.8000	1.0000	0.7143	1.0000
Supplier 2	1.0000	0.7500	1.0000	1.2000	1.0000	0.7143	1.0000	1.4000
Supplier 3	0.8571	0.5000	0.8333	1.0000	1.2857	1.2857	0.7143	1.0000
Supplier 4	0.6667	0.7500	1.1667	1.6000	1.2857	1.0000	1.0000	1.4000
Supplier 5	0.6667	0.7500	0.8333	1.0000	1.2857	1.0000	0.7143	1.4000

Table 3: Weighted score for each supplier and ranking orders for AHP-SAW

Supplier	Weighted Score	Weighted Score	Total Score	Rank Order AHP-SAW
Supplier 1	0.84979	0.74604	1.59583	3
Supplier 2	0.77924	0.82889	1.60813	2
Supplier 3	0.69823	0.76572	1.46395	5
Supplier 4	0.853	0.89746	1.75046	1
Supplier 5	0.76481	0.79175	1.55656	4

Table 4: Weighted score for each supplier and ranking orders for AHP-WASPAS

Supplier	Weighted Score	Weighted Score	Total Score	Rank Order AHP-WASPAS
Supplier 1	0.85404	0.75351	1.60755	3
Supplier 2	0.78783	0.82388	1.61171	2
Supplier 3	0.70292	0.77135	1.47427	5
Supplier 4	0.8589	0.9035	1.7624	1
Supplier 5	0.77218	0.79742	1.5696	4

The weights received from the AHP method are combined into SAW, WASPAS, TOPSIS and GRA, and steps for best supplier selection are mentioned below.

5.1. Using AHP-SAW

Table 3 shows the weighted score and the ranking achieved by the AHP decision matrix (Table 2) and the four steps of WASPAS mentioned in the above section. Supplier 4 has the greatest weighted score; Supplier 2 has the second highest and supplier 3 has the third highest weighted score, as shown in Table 6. To conclude, the first three AHP- SAW sorting results are Supplier 4 > Supplier 2 > Supplier 1.

5.2. Using AHP-WASPAS

Table 4 shows the weighted score for every supplier and the ranking orders derived using the AHP decision matrix (Table 2) along with the different steps of WASPAS discussed in the above section. Table 4 shows that Supplier 4 has the highest weighted score, followed by Supplier 1 and then Supplier 2. As a result, the first three AHP- WASPAS sorting outcomes are Supplier 4 > Supplier 2 > Supplier 1.

5.3. Using AHP-TOPSIS

The decision matrix created from AHP (Table 2) and the six TOPSIS algorithms listed in the methods section and shown in Table 5 were combined to produce the relative closeness and rank order. The goal here is to maximise quality, technology, and reliability while lowering costs. The goal is to maximise all of the green supplier selection criteria at the same time. Supplier 4 > Supplier 1 > Supplier 2 are the first three AHP TOPSIS supplier sorting results (Table 5).

5.4. Using AHP-GRA

Results of the grey relational analysis sorting are

Table 5: Relative closeness and sorting result for AHP-TOPSIS

Supplier	C_i+	C_i+	Total	Rank Order AHP-TOPSIS
Supplier 1	0.65387	0.35621	1.01008	2
Supplier 2	0.38637	0.51298	0.89935	3
Supplier 3	0.11543	0.45401	0.56944	5
Supplier 4	0.48946	0.68478	1.17424	1
Supplier 5	0.31383	0.42744	0.74127	4

Table 6: Grey relational analysis sorting results for AHP-GRA

Criteria	E1	E2	E3	E4	G1	G2	G3	G4	GRA (E)	GRA (G)	Total	Rank
Supplier 1	0.6667	1.0000	0.3333	0.4286	1.0000	0.5000	0.3333	0.3333	0.6071	0.5417	1.1488	2
Supplier 2	0.3333	0.5000	0.5000	0.4286	0.3333	0.3333	1.0000	1.0000	0.4405	0.6667	1.1072	3
Supplier 3	0.4667	0.3333	0.3333	0.3333	0.4375	1.0000	0.3333	0.3333	0.3667	0.5260	0.8927	5
Supplier 4	1.0000	0.5000	1.0000	1.0000	0.4375	0.5000	1.0000	1.0000	0.8750	0.7344	1.6094	1
Supplier 5	1.0000	0.5000	0.3333	0.3333	0.4375	0.5000	0.3333	1.0000	0.5417	0.5677	1.1064	4

displayed in Table 6 utilising the decision matrix created from the AHP in Table 2 and the phases of GRA mentioned in the methods section. Supplier 4, Supplier 1 and Supplier 2 has the first highest, second highest, and third highest grey relational score value, as shown in Table 6. Supplier 4, followed by Supplier 1, and further, Supplier 2 are the first three AHP-GRA supplier sorting results (Table 6).

Step 5: Hybrid MCDM models

The weights of criteria and subcriteria are evaluated here using the AHP method to find the best supplier using selected MCDM methods. Tables 3 to 6 displays the results of the generated hybrid methods for supplier selection. While choosing the best supplier, we can see consistency among the methods.The researcher considers the deployment of the chosen method, which may be dependent on his or her experience. The method's ease of use is also a consideration when selecting it.

6.0 Conclusion

In the highly competitive business environment of today, market globalisation is gradually rising for each sector. Eventually, the no. of potential suppliers and selection criteria to consider when selecting a suitable sustainable supplier grows.

Recent years, the cost of production and distribution to the general public has skyrocketed. As the no. of suppliers increase, then no. of reported problems related to lack in quality has also increased significantly. Selecting an effective supplier offers a significant capacity for improving quality while lowering prices. In recent years, there has been a rise in the usage of hybrid MCDM techniques to aid decision-makers. The acceptance of the outcomes of these hybrid procedures is one of the main factors causing this increase. For bigger and more complicated situations, these techniques are also more practical to employ.

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