CIRCULAR 'SUPPLIER EVALUATION AND SELECTION' USING HYBRID MCDM METHODS: CASE OF THE STEEL MANUFACTURING INDUSTRY

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ABSTRACT

Supplier evaluation is a prominent multi-criteria problem encountered in supply chain management (SCM). The steel industry has prioritized quality, cost and delivery in most of its decision-making for choosing suppliers. However, corporations are adopting circular economy (CE) principles more frequently due to the current focus on attaining sustainability and minimizing environmental damage. An integrated multiple-criteria decision-making (MCDM) method is proposed in this study to evaluate circular suppliers (CS) in the steel manufacturing sector from a developing country's standpoint, which includes Best-Worst Method (BWM) and Comprehensive Distance-Based Ranking (COBRA). In this proposed method, optimum weights of all criteria were determined by BWM, and then suppliers were ranked using COBRA. Results revealed that the top three factors for choosing a supplier are on-time supply, meeting specifications, and rejection rate. The resultant ranking from the proposed methodology was compared with another MCDM method and presented its result.

Keywords: Supplier evaluation, MCDM, Best-Worst Method (BWM), COBRA.

1. Introduction

Due to the competitive global business environment and increased environmental concerns, manufacturers are constantly looking for new approaches to increase their operations' effectiveness, environmental friendliness, and materials procurement. On average, about 70% of commercial organizations' costs relate to acquiring materials [1, 2]. Therefore, suppliers of raw materials, who are at the top of any supply chain, are crucial to improving the competitiveness of any organization and minimizing its impact on the environment [1]. Selecting the right supplier helps an organization's profitability and capacity to meet consumer demands by lowering costs as well as performance improvement of the supply chain [3]. When selecting a supplier, several factors are taken into account [4]. Due to its intricacy, supplier selection is seen as a multiple-criteria decision-making (MCDM) issue.

Along with cost-cutting, environmental protection and minimizing the environmental impact of business operations are two other growing concerns [5, 6]. This motivates numerous sectors to employ sustainable business methods while interacting with the supply chain. For example, the general economic model (take-make-use-dispose) has served as the foundation for supply chain management (SCM) concepts for the past 150 years [7, 8]. However, after their life cycles, items are viewed in this economic model as unusable [9]. Therefore, this economic model significantly adds to the increasing degradation of the environment and exhaustion of natural resources, along with the conventional ways of SCM [10].

Current estimates place the world's population at over 9 billion by 2050 and over 10.1 billion by 2100 [8]. The demand for natural resources will rise due to this population growth, increasing environmental pressure [11, 8]. The amount of waste produced annually is growing quickly; by 2025, 2.2 billion tons are expected to have been produced [12]. Today's businesses are shifting toward sustainable operating strategies to combat the increasing wastage of natural resources and materials. Circular economy (CE) is a key efficiency concept for minimizing adverse environmental effects [13]. Pearce and Turner introduced the circular economy in 1989 using an experimental framework, building on the concepts of Kenneth Boulding [8]. The CE model is viewed as a commercial tactic that considers socioeconomic and environmental concerns [14]. They recycle trash and resources and create durable and reusable products [15, 16, 17]. A CE can provide suggestions on reducing trash production, landfill upkeep expenses, transportation expenses, and more, offering a holistic plan for sustainable development [18]. The CE model has recently attracted much interest from researchers due to its advantage over traditional economic systems while conserving the environment and social well-being [19].

CE-based SCM, or circular SCM (CSCM), can also boost firms' competitiveness and lessen their environmental effect [20]. Currently, numerous recently enacted laws and regulations across the globe are driving businesses to incorporate CE criteria in their decision-making [21]. The steel industry is among the highest energy, water and raw material consumers and produces high solid waste and pollutants [22, 23, 24]. Additionally, steel is one of the essential building elements and is utilized in many facets of our daily life. But the sector must contend with demand to lessen its carbon footprint from both an environmental and an economic standpoint. Since only a few locations currently contribute most of the carbon dioxide emissions produced by the steel sector, steel facilities are an excellent choice for decarbonization. Industries must adapt to these new situations to prevail in the long run.

Around 8% of the world's CO2 was emitted from the steel industry in 2018 [25]. The Paris Agreement set a goal for the global steel industry to decarbonize by 2050 to reduce these environmental effects [25]. One strategy to assist the industry in achieving this goal is applying circular SCM methods [26, 27]. Although the electrical equipment, furniture, and textiles industries have already demonstrated the effectiveness of basic CE concepts, the steel sector is nascent in adopting this strategy [17, 28, 29].

1.1. Research questions and objectives

Recently, supplier selection has been conducted using many MCDM techniques in different industries. However, more research needs to be done on CSCM and supplier evaluation [30, 31, 32]. Moreover, only a few studies consider the context of the circular supplier (CS) for the steel industry in growing economies.

Therefore, we propose this study to address this gap by answering the following research questions (RQs):

RQ1: Which criteria are significant in supplier evaluation from a CE standpoint for the steel production industry?
RQ2: How can the identified supplier evaluation criteria most effectively incorporate into the supplier selection procedure in growing economies?

The BWM-COBRA hybrid MCDM approach is constructed to handle the CS evaluation for the steel industry of India to respond to the RQs mentioned above. The study, therefore, aims to accomplish the research objectives (ROs) as follows:

RO1: Determine the criteria for supplier evaluation that apply to the steel sector in emerging economies.
RO2: Using the BWM approach, determine the weights of the indicated supplier evaluation criterion.
RO3: From a CE standpoint, order the available suppliers using the COBRA technique.
RO4: Discuss how the planned research will have an impact on management.

The existing literature on the CE model and supplier evaluation criteria are briefly reviewed in section 2. Section 3 discusses the suggested technique for CS selection in the context of the steel sector. The computational results are summarised in section 4, and section 5 encapsulates the findings, their implications, and the study's limitations. Finally, section 6 traces the scope of further research and concludes the study.

2. Literature Review

Multi-criteria decision-making (MCDM) is choosing an optimal option from a group of possibilities. Several factors are considered [33]. For the problem's solution space, MCDM problems are typically categorized as either discrete or continuous. MCDM methods manage discrete issues, and multi-objective decision-making drives ongoing difficulties [34]. The two components of MCDM in real problems are selecting criteria, their weights, and values and gathering data using a specific strategy to evaluate the options [33]. There are two methods for weighting the choice criteria now in use, namely, subjective and objective. Data from the decision matrix of the attributes for each choice are utilized as weighting variables in the objective weighing approach. DMs' subjective preferences are considered when using subjective weighting methods. As a result, a unique evaluation matrix known as a pairwise comparison matrix is created to assess the variations in the DM's preferences on the qualities [35]. However, in pairwise comparison matrices, discrepancies arise frequently due to various factors, such as experts' lack of concentration, which forces them to revise the comparison so that the comparison matrix is consistent. This typical strategy has yet to be proven effective, and the inconsistencies stem from the way pairwise comparison-based approaches conduct unstructured comparisons [34].

As a result, Razaei created the Best Worst Method (BWM) approach, which differs from other methods like Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) in calculating weights from pairwise comparisons. Varying the conventional AHP, the BWM does not require pairwise comparisons between all criteria by the DMs. They only need to choose the two criteria that are the most and least desirable and then compare them side by side with the other criteria using pairwise comparisons [36]. In contrast to AHP and ANP, BWM can provide more reliable results and use fewer pairwise comparisons, making it better suited for problems where the number of criteria rises [37].

3. Methodology

3.1. Research design

This section presents our BWM-COBRA hybrid MCDM approach for evaluating and ranking available CS in the steel manufacturing industry.

As in **Table 1,** all the criteria for CS evaluation were established first from the literature study and expert opinions. Next, BWM determines the weights for criteria and sub-criteria for CS. Finally, all available CS were ranked using COBRA. **Figure 1** describes the proposed research methodology.

Table 1: Criteria for CS evaluation

Criteria	Sub-Criteria	Sub-Sub-Criteria	Benefit/ Cost	Source
Sustainability (C1**)**	Social (**SC1**)	Health & Safety of People **(SSC1)**	B	Expert Feedback
		Managing Resources (**SSC2**)	B	Expert Feedback
		Inequality & Poverty (**SSC3**)	B	[38]
		Information Disclosure (**SSC4**)	B	[38]
		Employee Training & Development (**SSC5**)	B	Expert Feedback
		CSR (**SSC6**)	B	Expert Feedback
		Public awareness (**SSC7**)	B	Expert Feedback
	Economic (**SC2**)	Cost (**SSC8**)	C	Expert Feedback
		Quality(**SSC9**)	B	Expert Feedback
		Lead Time(**SSC10**)	B	Expert Feedback
		Financial Stability (**SSC11**)	B	Expert Feedback
		Delivery (**SSC12**)	B	[39], [40]
Environmental and Circular (C2**)**	Using eco-friendly and recyclable raw material (**SC3**)		B	[40], [41]
	Use of green technology (**SC4**)		B	[42], [43], [44]
	Green packaging (**SC5**)		B	[1], [39]
	Designing Environment-friendly Product (**SC6**)		B	Expert Feedback
	Cross-industry cooperation (**SC7**)		B	Expert Feedback
	Environmental Product Declarative of Specific Product (**SC8**)		B	Expert Feedback

Criteria are defined as benefit criteria (B) and cost criteria (C).

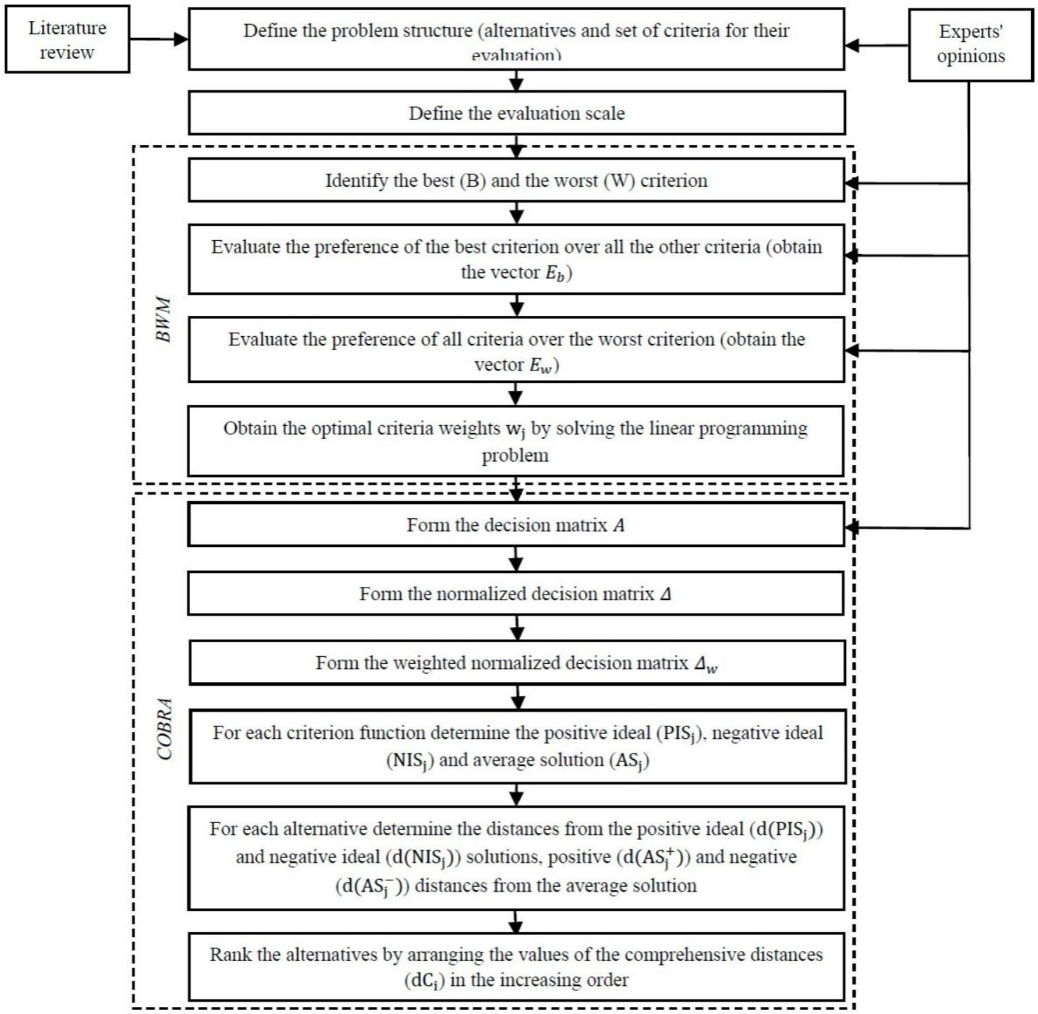

Figure 1: Methodology adopted [45]

3.2. Data collection

For our study, we have used two sources, i.e., a literature study and an expert response, for data collection. Firstly, the study of literature and opinion collected from experts were used to determine all the criteria and sub-criteria for CS evaluation. Provided the initial importance of criteria as a BEST and WORST to create comparisons between the BEST to other criteria and other criteria to WORST to obtain the global weights of the criterion using BWM methods. Finally, suppliers were ranked from expert opinion data. Responses from 20 industrial experts were collected and used for this study. Industry experts were shortlisted with at least a bachelor's degree in mechanical engineering, working experience of five years in stainless steel operations and supply chain, and an understanding of sustainability, environmental and CE model.

3.3. Data analysis

The BWM-COBRA hybrid approach used to conduct the analysis has been discussed in the below sections:

a) **Best-Worst Method (BWM):** In place of employing a complete pairwise comparison matrix, we can compare the BEST over other criteria and every other criterion over Worst in BWM [46] through the following steps:

Step 1: Define criteria set for decisions $\{C_1, C_2, \dots, C_n\}$.
Step 2: Decide BEST and WORST from the criteria set $\{C_B$ and $C_W\}$.
Step 3: Using a 9-point scale, indicate how much the best criterion is preferred above the other criterion.

$$A_B = \left(a_{B_1}, a_{B_2}, \dots, a_{B_n}\right), \quad (1)$$

Step 1: Using a number between 1 and 9 indicates how much the other criterion is preferred over the worst.

$$A_W = (a_{1w}, a_{2w}, \dots, a_{nw}), \quad (2)$$

Step 2: Determining ideal weights to ensure the greatest absolute differences are minimized $(W_1^*, W_2^*, \dots, W_n^*)$.

$$\min \max\left\{\left|\frac{W_B}{W_j} - a_{B_i}\right|, \left|\frac{W_j}{W_W} - a_{jW}\right|\right\},$$
$$\text{s.t,} \quad \sum_j W_j = 1 \quad (3)$$
$$W_j \geq 0 \; for \; all \; j$$

The above model could be resolved by reconstructing it as the subsequent nonlinear issue:

$$\min \lambda \left|\frac{W_B}{W_j} - a_{B_i}\right| \leq \lambda \; for \; all \; j$$
$$\text{s.t,} \quad \left|\frac{W_j}{W_W} - a_{jW}\right| \leq \lambda \; for \; all \; j,$$
$$\sum_j W_j = 1 \quad (4)$$
$$W_j \geq 0 \; for \; all \; j$$

On solving the above equation, we obtain the optimal weights $(W_1^*, W_2^*, \dots, W_n^*)$ and λ^*.

b) Comprehensive Distance-Based Ranking (COBRA) is an MCDM method that measures the distance from the ideal rating for each alternative among criteria and ranks based on the closeness of the ranking from the ideal solution [46].

This latest method is carried out by following a series of steps:

Step 1: Generate a decision matrix A by rating each criterion (i) in relation to each alternative (j).

$$A = \left[\begin{pmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nm} \end{pmatrix}\right], \tag{5}$$

here, n and m are the number of criteria and the number of alternatives, respectively.

Step 2: Establish a weighted normalized decision matrix Δw,

$$\Delta_w = \left[\alpha_{ji}\right]_{n\times m}, \tag{6}$$

where,

$$\alpha_{ji} = \frac{w_i \times a_{ji}}{\max_j a_{ji}} \tag{7}$$

Step 3: Calculate the average rating (AS_i), positive ideal (PIS_i) and negative ideal (NIS_i) for each criterion, as follows:

$$PIS_i = \max_j \alpha_{ji}, \forall i \in 1, \cdots, n \; za \; i \in J^B \tag{8}$$

$$PIS_i = \min_j \alpha_{ji}, \forall i \in 1, \cdots, n \; za \; i \in J^c \tag{9}$$

$$NIS_i = \max_j \alpha_{ji}, \forall i \in 1, \cdots, n \; za \; i \in J^B \tag{10}$$

$$NIS_i = \min_j \alpha_{ji}, \forall i \in 1, \cdots, n \; za \; i \in J^c \tag{11}$$

$$AS_i = \frac{\sum_{j=1}^{m} \alpha_{ji}}{n}, \forall i \in 1, \cdots, n \; za \; i \in J^B, J^c \tag{12}$$

where J^B is the benefit criteria and J^c is the cost criteria.

Step 4: Determine the distance for each alternatives from positive (d(PIS_i)), negative (d(NIS_i)) and average rating average (d(AS_i+)) and (d(AS_i-)) respectively) as follows:

$$d(S_j) = d(S_j) + \sigma \times d(S_j) \times d(S_j), \forall i = 1, \dots, m \tag{13}$$

Where (S_j) represents any solution (PIS_j, NIS_j and AS_j), σ is the correlation coefficient,

$$\sigma = \max_j dE(Y_i)_j - \min_j dE(Y_i)_j, \tag{14}$$

dE(Y_j) is the Euclidian distance, and dT(Y_j) is the Chebyshev distance. These are calculated as follows:

$$dE(Y_i)_j = \sqrt{\sum_{i=1}^{n} (Y_i - \alpha_{ji})^2}, \forall j = 1, \dots, m, \tag{15}$$

$$dT(Y_i)_j = \sum_{i=1}^{n} \left|Y_i - \alpha_{ji}\right|, \forall j = 1, \dots, m, \tag{16}$$

For negative and positive distances from an average score, use the following equations:

$$dE(AS_i)_j^{+/-} = \sqrt{\sum_{i=1}^{n} \tau^{+/-}(AS_i - \alpha_{ji})^2}, \forall j = 1, \dots, m, \tag{17}$$

$$dT(AS_i)_j^{+/-} = \sum_{i=1}^{n} \tau^{+/-}\left|AS_i - \alpha_{ji}\right|, \forall j = 1, \dots, m, \tag{18}$$

where,

$$\tau^{+} = \begin{cases} 1, if AS_i > \alpha_{ji} \\ 0, otherwise \end{cases} \text{ and } \tau^{-} = \begin{cases} 1, if AS_i > \alpha_{ji} \\ 0, otherwise \end{cases}$$

Step 5: Order the alternatives by the increasing order of a comprehensive distance (dCi) that is calculated as:

$$dC_i = \frac{d(PIS_i)_j - d(NIS_i)_j - d(AS_i)_j^{+} + d(AS_i)_j^{-}}{4}, \forall \text{i} \tag{19}$$

4. Description of the case model and analysis

The steel plant where the experiment was conducted is among the world's top fifteen stainless steel conglomerates. The group deals with 2 MTA crude steel capacities annually. The company is backed by its excellent people, business operations, customer centricity, safety practices and social responsibility. Betterment of production procedures and environmental protection are the most important goals in the development plans at the plant. Hence, improving the selection procedure for CS is vital. The research provides an alternative model for selecting suppliers and rating them. These ratings were given to the thirteen raw material suppliers at the steel plant, for which data was collected from January 2022 to March 2022.

Initially, the criteria and sub-criteria were defined for evaluating CS by reviewing literature and collecting expert opinions for suppliers with a minimum experience of 10 years [47]. Then, the criteria weights were estimated by the BWM method. Next, the best and worst criteria **(Table 2)** and pairwise comparisons were collected from twenty managers and experts in the steel industry and tabulated. Finally, criteria and sub-criteria weights were calculated using eq. (2). **Table 3** presents the global weights for all the criteria. Once the criteria weights are estimated by BWM, by applying the COBRA subsequently, the alternatives' ranks are obtained.

As in **Table 4**, a nine-point linguistic scale [45] is used to evaluate the alternatives. Firstly, the evaluation of four suppliers is carried out through the COBRA questionnaire, and then the corresponding values are calculated. Also, **Table 5** presents the options evaluated using the decision matrix generated from expert responses.

Table 2: The BEST and WORST CE Criteria

Criteria	Best/Worst	Sub-Criteria	Best/ Worst	Sub-Sub Criteria	Best/ Worst
C1	BEST	SC1	WORST	SSC1	BEST
				SSC2	
				SSC3	WORST
				SSC4	
				SSC5	
				SSC6	
				SSC7	
		SC2	BEST	SSC8	
				SSC9	BEST
				SSC10	
				SSC11	WORST
				SSC12	
C2	WORST	SC3	BEST		
		SC4			
		SC5	WORST		
		SC6			

Table 3: Calculated Weights for each criterion using BWM

Criteria	Weight	Sub-Criteria	Weight	Global Weight	Sub-Sub Criteria	Weight	Global Weight
C1	0.533	**SC1**	0.467	0.248911	**SSC1**	0.384	0.096
	0.533		0.467	0.248911	**SSC2**	0.15	0.037
	0.533		0.467	0.248911	**SSC3**	0.033	0.008
	0.533		0.467	0.248911	**SSC4**	0.067	0.017
	0.533		0.467	0.248911	**SSC5**	0.156	0.039
	0.533		0.467	0.248911	**SSC6**	0.093	0.023
	0.533		0.467	0.248911	**SSC7**	0.117	0.029
	0.533	**SC2**	0.533	0.284089	**SSC8**	0.258	0.073
	0.533		0.533	0.284089	**SSC9**	0.488	0.139
	0.533		0.533	0.284089	**SSC10**	0.129	0.037
	0.533		0.533	0.284089	**SSC11**	0.051	0.014
	0.533		0.533	0.284089	**SSC12**	0.074	0.021
C2	0.467	**SC3**	0.509	-	-	-	0.238
	0.467	**SC4**	0.261	-	-	-	0.122
	0.467	**SC5**	0.055	-	-	-	0.026
	0.467	**SC6**	0.174	-	-	-	0.081

Table 4: Linguistic Scale for CS Evaluation [45]

Linguistic Evaluation	Numerical Value	Abbreviation
None	1	N
Very Low	2	VL
Low	3	L
Fairly Low	4	FL
Medium	5	M
Fairly High	6	FH
High	7	H
Very High	8	VH
Extremely High	9	EH

Table 5: Decision matrix of each alternative w.r.t criterion

CRITERIA	CS1	CS2	CS3	CS4	CS5	CS6	CS7	CS8	CS9	CS10	CS11	CS12	CS13
SSC1	2	2	3	1	9	8	2	6	2	3	8	5	8
SSC2	4	4	8	9	3	5	3	6	9	6	7	3	8
SSC3	9	2	2	9	8	7	7	9	2	3	9	3	4
SSC4	9	5	1	5	6	3	7	5	6	3	7	8	1
SSC5	3	1	5	4	1	4	4	1	6	9	8	4	7
SSC6	3	6	8	2	5	1	8	4	1	1	5	6	4
SSC7	6	3	7	3	4	1	5	9	2	7	2	5	4
SSC8	5	2	1	5	2	6	1	2	7	1	9	6	8
SSC9	8	4	8	2	2	3	1	6	6	1	3	9	1
SSC10	9	5	9	3	4	1	4	5	8	9	5	2	9
SSC11	2	2	4	3	5	3	1	7	4	3	1	7	6
SSC12	1	6	2	4	6	6	7	1	7	4	4	7	7
SC3	5	9	6	8	5	4	1	6	9	6	7	1	7
SC4	5	7	5	6	5	9	9	7	7	4	9	6	5
SC5	1	3	3	6	3	6	6	6	9	2	1	5	1
SC6	4	5	9	5	1	2	4	4	9	3	3	1	7

Table 6 shows the positive and negative ideals, and an average alternative rating is calculated as described earlier (section 3.3.b). Finally, the increasing order of a total distance (dCi) is calculated using Eq. (19). Lower the comprehensive distance (dCi) better the supplier. From **Table 6**, it can be concluded that Supplier-9 is most preferred.

Table 6: Distance and corresponding ranking of alternatives

Supplier	d(PIS)	d(NIS)	d(AS+)	d(AS-)	dC	Rank
S1	0.18751927	0.1272344	0.06245651	0.06434991	0.01554457	8
S2	0.16130160	0.12000599	0.01724234	0.03980476	0.01596451	9
S3	0.15757967	0.14966031	0.06499667	0.05278830	-0.0010722	7
S4	0.18238223	0.10295775	0.03160832	0.05382326	0.02540986	11
S5	0.19061512	0.11631565	0.04804132	0.06060255	0.02171517	10
S6	0.12975016	0.17776862	0.08345295	0.03113154	-0.0250850	2
S7	0.16431573	0.17134328	0.07396334	0.06467976	-0.0040778	6
S8	0.10309496	0.16213147	0.04773907	0.02512960	-0.0204115	4
S9	0.12240805	0.17191580	0.08297772	0.02961751	-0.0257170	1
S10	0.22951794	0.09060668	0.02580732	0.09294263	0.05151164	13
S11	0.16860195	0.16617409	0.08867515	0.04581847	-0.0101072	5
S12	0.13061311	0.16109211	0.07897979	0.02701084	-0.0206120	3
S13	0.21716375	0.09921348	0.05346726	0.07541960	0.03497565	12

The comparison of ranking derived through the proposed method with the Analytic Hierarchy Process (AHP) (**Table 7**) shows that the ranking obtained is valid.

Table 7: Comparison of results from AHP and Proposed Method

Supplier	AHP	COBRA
S1	7	8
S2	5	9
S3	1	7
S4	10	11
S5	6	10
S6	11	2
S7	3	6
S8	4	4
S9	9	1
S10	2	13
S11	13	5
S12	8	3
S13	12	12

The rank from AHP is different from the developed method for two reasons. First, at the weighing level, AHP, unlike BWM, does not follow an approach that weighs based on the preference from best and worst criteria. Secondly, the COBRA method adopts a distance-based evaluation that comprehensively calculates the ranking based on the distance from the ideal average rating. For example, AHP suggests picking supplier 3, while the proposed methodology suggests supplier 9.

5. Managerial Insights

Managers and decision-makers in the steel industry must choose between potential suppliers in regular cycles, especially as the goals of the steel industry keep adopting improvements in CE methods and requirements. Therefore, the tool developed in the study will help prioritize the important criteria for the time and identify the optimal supplier. This method is especially better than sole AHP as the BWM-COBRA hybrid method provides several advantages. First, the BWM techniques offer the benefit of reducing the number of comparisons, therefore significantly reducing the size of the questionnaire to be filled by experts. Hence, data collection becomes simpler and easier for the responders to fill out. Second, BWM also determines the best and worst criteria in advance; this way, it is easier to fill the preferences of best over other criteria and other criteria over worst. Finally, by combining the COBRA method to determine the optimal alternative, we eliminate the simpler averaging method of ranking, hence providing more reliable results.

6. Limitations

Like most real problem studies, this study is not perfect. The study had the limitation of collecting responses from experts only from one company, which restricts the viewpoint from being shared. Different companies may have varying goals and respective criteria. Even for the same criteria, different experts from other companies might have different preferences. Therefore, further study with experts from different companies may offer various agreements on best and worst criteria and consequent comparative ratings. Thus, changing the weights. The rating of suppliers concerning the criteria is unlikely to vary as experts from any company are most likely to agree on the rating of suppliers for CE criteria.

7. Conclusions

Supplier selection is a prominent problem faced by all industries. The scale and criticality of the problem rise as the goals for selection get critical, and prospect suppliers get higher. As the steel industry is noted for producing high amounts of CO2, they need to move to circular economy practices to achieve its sustainability goals. In this study, a hybrid MCDM method is developed to identify and select the most appropriate supplier regarding CE goals. The proposed three-phase methodology supports the steel manufacturing industry rank its multiple suppliers and choosing the best regarding sustainability, environment and circular advancements. In the initial stage, the criteria and sub-criteria for CS were defined based on the abilities of each supplier. Then, BMW estimated the weights for all CE criteria and sub-criteria. Finally, the CS for the steel manufacturing industry is ranked and selected based on the circular abilities of suppliers using COBRA. Based on the results obtained from this proposed methodology, Supplier 2 was the best CS among all the four major suppliers. Furthermore, this method provides a distance-based ranking, unlike the simple average process in AHP.

Therefore, for future research, hybrid algorithms using AHP weighing and other distance-based ranking method is possible. Also, a response for weighing and rating alternatives from a set of experts from different companies would provide interesting results.

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