Sustainable supplier selection for battery manufacturing industry: A MOORA and WASPAS Based Approach

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Abstract:
The aim of present research work is to hybrid the “MOORA and WASPAS” MCDM methods in the sustainable vendor’s selection & evaluation decision. It also considers the feedback impact of the decision on strategic variables that determine the future viability of the case company in the competitive business environment. MCDM strategic decision framework is applied that considers simultaneously the influence of criteria and sub-criteria on the sustainable vendor evaluation decision. The developed framework is evaluated, and criteria weight is determined using the step-wise weight assessment ratio (SWARA) method. The MOORA & WASPAS consider the influence of criteria, sub-criteria and their interdependencies simultaneously in the system. The results of the model is the relative priorities ad ranking developed for the suppliers. The present research has been conducted in a battery manufacturing company of Punjab state of India. The influence of dimension of sustainability dimensions would be widespread due to the big market in which the case company operates. The outcome the present work can provide support to the managers who are decision makers in the industries. The framework present in the research arriving at an optimal sound decision considering all sustainability applicable dimensions. The novelty of the approach lies in the use of different MCDM model integrating the dimension of sustainability with a feedback effect for vendor selection. The industry would be benefited by showing its commitment toward social responsibility, environment management, and economic aspects leading to improved market image and profitable business with sustainability.

Keywords: Vendor selection Sustainability, Multi-criteria decision making, MOORA, SWARA, WASPAS.

1. Introduction
Sustainability is most important parameters nowadays in supply chains operating in the world. “The growing worldwide awareness of environmental aspects and sustainability dimensions, stringent government directions, and increasing community information, industries cannot neglect sustainability concerns in their business (Gaziulusoy, 2015; Govindan et al., 2016)”. To increase business performance and competitive advantage, sustainability-focused and green supplier evaluation is a crucial strategic decision in global industrial supply chains. “The sustainability-focused green supply chain is an extension of the super green supply chain in that it considers social criteria along with economic and green criteria from a supply chain context”. Notably, sustainable practices and greening aspects are becoming an integral part of the planning process of modern manufacturing organizations to improve supply chain business performance. “The integration of ecological, economic, and societal aspects to
ensure sustainable development is a foremost strategic intelligent task for business organizations in current years” Benn et al., 2014. “Vendors may play an important role in implementing sustainable/green supply chain initiatives and in achieving environmental, social, and economic gains” Shen et al., 2013. Thus, sustainable vendor selection (SVS) is a key decision in the manufacturing management of a sustainability-focused business supply chain, and “needs to be explored methodically to implement green/sustainable initiatives in competitive supply chains” Grimm et al., 2016.

2. SUSTAINABLE SUPPLY CHAIN MANAGEMENT

Supply chain management comprises of each and every stage from raw material procurement to the final delivery of products or good to the customer. Carter and Rogers provided the following definition of SSCM as “the planned combination and integration of company’s three-dimensional goals i.e. social, environmental, and economic to improvise the long-term economic performance of business and elements of its supply chains”. Similar definition proposed by Seuring and Muller where SSCM is defined as “the management of raw material, information and money flow among organizations along the complete supply chain while ensuring goals from all three dimensions are met for sustainable growth i.e., economic, environmental and social. Environmental and social criteria demand to be met by the members and stakeholders to remain within the supply chain, while it is obviously expected that competitiveness would be there and there will be an extra edge for having met customer needs and economic goals”

Three tiers of sustainability are:

Tier 1: Getting the basics right
Tier 2: Learning to think sustainably
Tier 3: The science of sustainability.

2.1 Importance of Economic Criteria

Economic criteria focus on the primary purpose of the organizations i.e. to gain higher profits. Like traditional supply chain management, the focus is on higher profitability. It can be achieved by reducing costs in different areas, reducing idle time etc. It includes criteria like ordering and logistic cost, inventory cost, Product cost, custom and insurance cost. Product quality certificates, rejection rate, and belts i.e. quality management, lean six sigma belts, capability of handling mishaps. It also includes factors like cost of environmentally friendly packaging and cost for disposal of waste for three dimensional developments. “Lead Time” and “On Time Delivery Time” between “procurement” and delivery of an order, lags in “delivery schedule”.

2.2 Importance of Social Criteria

Because of increased awareness manufacturing corporations have started concentrating on problems such as safety, working conditions, operations, wages, child labor, human rights and poverty. Pressure from management and stakeholders are forcing corporations to be socially accountable. They want companies to include social criteria like Health and Safety Practices: Occupational health and safety programs, prevention, risk-control, education, training, and counseling programs in situ to assist work force members or community members regarding serious diseases. Social Responsibility: Supporting institutional establishments, grants short term and long-term social projects, and donations. Educational Infrastructure: Programs for skills management and lifelong learning that support the continued employability of workers and assist them in managing career endings. Few more criteria that can be considered are daily recreational needs, emotional well-being life strategies, and activities to retreat against stress, sports facilities, and other community events.
2.3 Importance of Environmental Criteria

Day by day in the society awareness about environmental damage, heavy production industries and consumers both are becoming sensitive of sound environment management and control. The stakeholders of industries to ensure sound accident free practices like pollution control, reuse, recycling and recovery etc. Use of environmentally friendly “technology and materials, design capability for reduced consumption of material/energy, reuse, recycle of material, design of products to avoid or reduce use of harmful materials, green packaging” Jayant et.al., 2014. To reduce the harm to the environment, organizations should also consider parameters like strategic considerations, climatic considerations, permit requirements, compliance requirements, and government environment protection policy.

![Figure 1 Pillar of sustainability](image)

3. Literature Review

The important criteria for green vendor evaluation and selection in “Green Supply Chain” have been identified through comprehensive literature survey and expert’s inputs. A total of 14 SVS selection &evaluation criteria were identified in the present research. Further, the 14 significant vendor evaluation parameters identified were confirmed with the help of industry/academia experts’ inputs and categorized into 03 of sustainability dimensions (Social, economic and environment). The criteria selected are shown below in table 1.

4. Problem Description

Company ABC limited is the country’s largest Lead acid battery manufacturer having wide range of application in automotive power equipment, UPS etc.

| Table 1 Company profile |
|-------------------------|
| **Year of establishment** | 1982 |
| **Turnover**             | 126048 million |
| **Employees**            | 270 |
| **Production volume**    | 1 million |
| **Product manufactured** | SMF battery, Generator batteries, High powered batteries, Gel batteries, stationary batteries, Power tool battery, CNC machine battery, Thermal batteries, Quanta SMF battery |
| **Type of business**     | Manufacturer, Supplier |
ABC has set up world class manufacturing facilities in its plant situated in northern part of India. The case company has set up modern in-house research facilities with the help of nearby academia experts and experienced professionals.

| Table 2 | List of customers of the company |
|--------|---------------------------------|
| 1      | News Paper Industry             |
| 2      | Jindal steel & Power            |
| 3      | NHPC                            |
| 4      | HERO                            |
| 5      | Indian Oil                     |
| 6      | Damart                          |
| 7      | Ambuja cement                   |
| 8      | Siti network                    |
| 9      | TATA                            |
| 10     | Jaypee cement                   |
| 11     | EPC                             |

| Table 3 | List of suppliers |
|---------|-------------------|
| 1       | EMU batteries     |
| 2       | TRONTEK           |
| 3       | VNA batteries     |
| 4       | Industrial Batteries |

In the competitive business environment, the case company is facing the problem of regular supply of raw lead for production of automobile batteries in the plant. The case company wanted to procure the raw lead only from reputed suppliers that are following ISO 14000 guidelines with sustainability dimensions. A series of visits conducted in the case industry for data collection and analysis. Required data has been collected from ABC battery manufacturing industry for sustainable supplier selection to find out the weight age of the criteria selected and then the final ranking. Weightage is given according to the saaty scale.

| Table 4 | Saaty scale |
|---------|-------------|
| Intensity of Importance | Definition |
| 1       | “Equally importance” |
| 2       | “Weak”       |
| 3       | “Moderately importance” |
| 4       | “Moderate plus” |
| 5       | “Strong Importance” |
| 6       | “Strong plus” |
| 7       | “Very strong” |
| 8       | “Very Very strong” |
| 9       | “Extreme importance” |

Weightage is given on a scale of 1 to 9. Ten Alternative and fourteen criteria are under consideration. These fourteen criteria are
E1 Product cost; E2 Inventory cost; E3 Product rejection rate; E4 Quality certificates; E5 Lead time; S1 Employment stability; S2 Safety; S3 Working condition; S4 Training; S5 Human Right and Worker Interest; EN1 Recycle; EN2 Reuse; EN3 Resource consumption of raw material; EN4 Environment related certificates.

Ten alternatives that are chosen are different suppliers with which the industry deals with from which we select the best alternative. MCDM methods that are going to be applied i.e MOORA, SWARA and WASPAS are integrated with the help of MATLAB. All the manual calculation need not to be done and it make the solution of problem more structured.

| Supplier | E1 | E2 | E3 | E4 | E5 | S1 | S2 | S3 | S4 | S5 | EN1 | EN2 | EN3 | EN4 |
|----------|----|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|
| A        | 5  | 3  | 9  | 5  | 3  | 5  | 7  | 7  | 3  | 3  | 3   | 3   | 5   | 9   |
| B        | 7  | 3  | 7  | 9  | 5  | 5  | 7  | 5  | 5  | 5  | 5   | 7   | 7   | 7   |
| C        | 5  | 5  | 5  | 7  | 9  | 7  | 9  | 5  | 3  | 7  | 3   | 9   | 5   | 5   |
| D        | 3  | 3  | 7  | 3  | 7  | 3  | 5  | 5  | 7  | 7  | 9   | 3   | 3   |     |
| E        | 1  | 7  | 5  | 5  | 5  | 7  | 5  | 5  | 5  | 9  | 5   | 9   | 3   | 5   |
| F        | 9  | 3  | 3  | 3  | 5  | 9  | 3  | 9  | 7  | 5  | 7   | 3   | 7   | 7   |
| G        | 9  | 1  | 7  | 5  | 5  | 3  | 7  | 3  | 3  | 3  | 7   | 7   | 7   | 7   |
| H        | 5  | 9  | 5  | 1  | 3  | 5  | 1  | 3  | 9  | 3  | 3   | 5   | 9   | 5   |
| I        | 7  | 5  | 9  | 1  | 9  | 7  | 7  | 5  | 5  | 7  | 7   | 7   | 3   | 9   |
| J        | 3  | 7  | 3  | 7  | 7  | 5  | 5  | 3  | 5  | 1  | 5   | 9   | 3   |     |

5. Methodology

5.1 SWARA Method

The criteria weight has been calculated by using “SWARA Method” as shown in figure 2.

![Figure 2 Weights calculation based on SWARA](image)

The process of determining the relative weights of parameters using “SWARA method”
Step 1. The criteria are sorted in descending order based on their expected significances.

### Table 6 Average value of criteria

| Criteria | Average value (Sj) |
|----------|-------------------|
| E1       | 0.54              |
| E2       | 0.46              |
| E3       | 0.56              |
| E4       | 0.46              |
| E5       | 0.58              |
| S1       | 0.58              |
| S2       | 0.52              |
| S3       | 0.56              |
| S4       | 0.48              |
| S5       | 0.52              |
| EN1      | 0.44              |
| EN2      | 0.64              |
| EN3      | 0.58              |
| EN4      | 0.6               |

Step 2. Starting from the II criterion, the respondent expresses the relative importance of criterion j in relation to the previous (j-1) criterion, for each criterion. According to “Kersuliene et al. (2010)”, this ratio is called the “Comparative importance of average value, sj”

Step 3. Determine the “coefficient kj as follows”:

\[
k_j = \begin{cases} 
1 & j = 1 \\
\frac{S_j}{S_j + 1} & j > 1 
\end{cases}
\]  

(1)

### Table 7 Value of Kj for each criteria

| Criteria | Average value (Sj) | Kj= 1+ Sj |
|----------|-------------------|-----------|
| E1       | 0.54              | 1.54      |
| E2       | 0.46              | 1.46      |
| E3       | 0.56              | 1.56      |
| E4       | 0.46              | 1.46      |
| E5       | 0.58              | 1.58      |
| S1       | 0.58              | 1.58      |
| S2       | 0.52              | 1.52      |
| S3       | 0.56              | 1.56      |
| S4       | 0.48              | 1.48      |
| S5       | 0.52              | 1.52      |
| EN1      | 0.44              | 1.44      |
| EN2      | 0.64              | 1.64      |
| EN3      | 0.58              | 1.58      |
| EN4      | 0.6               | 1.60      |

Step 4. Determine the recalculated weight qjas follows:

\[
q_j = \begin{cases} 
1 & j = 1 \\
\frac{k_j}{j} & j > 1 
\end{cases}
\]  

(2)
Table 8 Value of Qj for each variable

| Criteria | Average value (Sj) | Kj = 1+ Sj | Qj = Qi-1/Kj |
|----------|-------------------|------------|--------------|
| E1       | 0.54              | 1.54       | 1            |
| E2       | 0.46              | 1.46       | 0.685        |
| E3       | 0.56              | 1.56       | 0.439        |
| E4       | 0.46              | 1.46       | 0.301        |
| E5       | 0.58              | 1.58       | 0.190        |
| S1       | 0.58              | 1.58       | 0.120        |
| S2       | 0.52              | 1.52       | 0.079        |
| S3       | 0.56              | 1.56       | 0.051        |
| S4       | 0.48              | 1.48       | 0.034        |
| S5       | 0.52              | 1.52       | 0.023        |
| EN1      | 0.44              | 1.44       | 0.016        |
| EN2      | 0.64              | 1.64       | 0.010        |
| EN3      | 0.58              | 1.58       | 0.006        |
| EN4      | 0.6               | 1.60       | 0.004        |
| Total    |                   |            | 2.958        |

Step 5. The “relative weights of the evaluation criteria are determined as follows”:

\[ w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \]  

(3)

where \( w_j \) denotes the relative weight of criterion \( j \).

Table 9 Relative weights of Evaluation criteria

| Criteria | Average value (Sj) | Kj = 1+ Sj | Qj = Qi-1/Kj | Wj = Qj/∑Qj |
|----------|-------------------|------------|--------------|-------------|
| E1       | 0.54              | 1.54       | 1            | 0.338       |
| E2       | 0.46              | 1.46       | 0.685        | 0.232       |
| E3       | 0.56              | 1.56       | 0.439        | 0.148       |
| E4       | 0.46              | 1.46       | 0.301        | 0.102       |
| E5       | 0.58              | 1.58       | 0.190        | 0.064       |
| S1       | 0.58              | 1.58       | 0.120        | 0.041       |
| S2       | 0.52              | 1.52       | 0.079        | 0.027       |
| S3       | 0.56              | 1.56       | 0.051        | 0.017       |
| S4       | 0.48              | 1.48       | 0.034        | 0.012       |
| S5       | 0.52              | 1.52       | 0.023        | 0.008       |
| EN1      | 0.44              | 1.44       | 0.016        | 0.005       |
| EN2      | 0.64              | 1.64       | 0.010        | 0.003       |
| EN3      | 0.58              | 1.58       | 0.006        | 0.002       |
| EN4      | 0.6               | 1.60       | 0.004        | 0.001       |
| Total    |                   |            | 2.958        |             |
5.2. “MOORA” Method

“Multi-objective optimization based on ratio analysis (MOORA)” is also known as multi-criteria or multi-attribute optimization. It is defined as “the process of simultaneously optimizing two or more conflicting attributes subject to some constraints” Chakraborty, 2012. This approach was introduced by “Brauers 2004”. This approach starts with “a matrix consisting of performance measures of different alternatives with respect to various criteria”.

\[ X = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} \]

Where, “Xij is the performance measure of the ith alternative on the jth attribute, m is the number of alternatives and n is the number of the attributes”. MOORA approach consists of “two parts namely ratio system approach, the reference point approach”.

To illustrate the applicability, “accuracy and potentiality of the MOORA method” in decision making the following step as given below:

**Step 1:** To find the decision matrix as given in table 10.

| Supplier | E1 | E2 | E3 | E4 | E5 | S1 | S2 | S3 | S4 | S5 | EN1 | EN2 | EN3 | EN4 |
|----------|----|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|
| EN1      | 0.338 | 0.232 | 0.148 | 0.102 | 0.064 | 0.041 | 0.027 | 0.017 | 0.012 | 0.008 | 0.005 | 0.003 | 0.002 | 0.001 | 0.000 |
| EN2      | 0.350 | 0.250 | 0.150 | 0.100 | 0.050 | 0.012 | 0.008 | 0.005 | 0.003 | 0.002 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| EN3      | 0.370 | 0.270 | 0.170 | 0.120 | 0.070 | 0.040 | 0.020 | 0.010 | 0.008 | 0.005 | 0.003 | 0.002 | 0.001 | 0.000 | 0.000 | 0.000 |
| EN4      | 0.390 | 0.290 | 0.190 | 0.140 | 0.090 | 0.050 | 0.030 | 0.015 | 0.010 | 0.008 | 0.005 | 0.003 | 0.002 | 0.001 | 0.000 | 0.000 |

**Figure 3** Result shown by SWARA method
Step 2: Normalization matrix of initial data where Xij* is equal to

\[ \frac{x_{ij}}{\sum_{j=1}^{m} x_{ij}^2} \]

where \( j = 1, 2, 3 \ldots \ldots m \)

It is obtained by dividing each element by under root of summation of square of each element in that particular column. Normalization is done without considering the beneficially of attribute.

**Table 11 Normalized Matrix**

| Supplier | E1  | E2  | E3  | E4  | E5  | S1  | S2  | S3  | S4  | S5  | EN1 | EN2 | EN3 | EN4 |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Weight   | 0.23| 0.14| 0.10| 0.06| 0.04| 0.02| 0.01| 0.01| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| A        | 0.53| 0.33| 0.26| 0.23| 0.18| 0.15| 0.12| 0.12| 0.09| 0.09| 0.05| 0.05| 0.05| 0.05|
| B        | 0.26| 0.18| 0.15| 0.26| 0.26| 0.26| 0.26| 0.26| 0.26| 0.26| 0.26| 0.26| 0.26| 0.26|
| C        | 0.37| 0.18| 0.36| 0.25| 0.25| 0.26| 0.26| 0.26| 0.26| 0.26| 0.26| 0.26| 0.26| 0.26|
| D        | 0.26| 0.18| 0.36| 0.15| 0.15| 0.15| 0.15| 0.15| 0.15| 0.15| 0.15| 0.15| 0.15| 0.15|
| E        | 0.26| 0.18| 0.18| 0.15| 0.15| 0.15| 0.15| 0.15| 0.15| 0.15| 0.15| 0.15| 0.15| 0.15|
| F        | 0.15| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18|
| G        | 0.15| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18|
| H        | 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05|
| I        | 0.47| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18|
| J        | 0.47| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18| 0.18|

**Step 3:** To find the attribute are beneficial or non-beneficial.
“Beneficial attributes are those whose higher values are required, while for non-beneficial attributes lower values are required”.

**Step 4:** To find the assessment value and ordinal ranking of assessment value.
In present research project, ten suppliers are there whose ranking depend upon the criteria selected.

Assessment value can be found by:

\[
y_i = \sum_{j=1}^{g} w_ix_{ij}^* - \sum_{j=g+1}^{m} w_ix_{ij}^*
\]  

(5)

Where,“Wi is the weight defined above of the jth attribute”.

| Suppliers | Assessment value | Rank |
|-----------|------------------|------|
| A         | 0.27547          | 7    |
| B         | 0.32916          | 2    |
| C         | 0.31329          | 3    |
| D         | 0.22097          | 9    |
| E         | 0.21055          | 10   |
| F         | 0.30550          | 4    |
| G         | 0.30501          | 5    |
| H         | 0.29763          | 6    |
| I         | 0.34346          | 1    |
| J         | 0.26987          | 8    |

The value of assessment can be positive or negative depending upon the beneficial and non-beneficial attribute. Here in this problem all the criteria are beneficial. The alternative “with highest value would be the best alternative and bear rank one”.
Figure 4: Normalized value by MOORA method

Figure 5: Assessment value by MOORA method
WASPAS Analysis

WASPAS the first time was suggested in 2012 and it is one of the robust new MCDM utility determining approaches. This approach is an integration of “Weighted Product Model (WPM)” and “Weighted Sum Model (WSM)”. “Zavadskas, Turskis, Antucieviciene, and Zakarevicius” are the innovators of this new method and, in their research, they prove “that this aggregated method gets the better accuracy compared with the accuracy of applying just one of WSM or WPM”.

“WASPAS” calculation is comprises 6 steps as given below:

**Step 1:** Decision Matrix that is to be given in Table 5.

**Step 2:** “Normalized decision-making matrix” based on

\[ X_{ij} = \frac{X_{ij}}{\max X_{ij}}, \text{ where } i=1, m; j=1, n \]  \hspace{1cm} (6)

if the “optimum value is a maximum”

\[ X_{ij} = \frac{\text{opt}X_{ij}}{X_{ij}}, \text{ where } i = 1, m; j = 1, n \]  \hspace{1cm} (7)
if the optimum value is a minimum

| Supplier | E1 | E2 | E3 | E4 | E5 | S1 | S2 | S3 | S4 | S5 | EN1 | EN2 | EN3 | EN4 |
|----------|----|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|
| **Weight** | 0.33 | 0.23 | 0.14 | 0.10 | 0.06 | 0.04 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| A | 0.55 | 0.33 | 1.00 | 0.55 | 0.55 | 0.77 | 0.77 | 0.33 | 0.33 | 0.42 | 0.33 | 0.55 | 1.00 |
| B | 0.77 | 333 | 778 | 0.55 | 0.55 | 0.77 | 0.55 | 0.33 | 0.55 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 |
| C | 0.55 | 0.55 | 0.55 | 0.77 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| D | 0.33 | 0.33 | 0.77 | 0.33 | 0.55 | 0.55 | 0.55 | 0.55 | 0.77 | 1.00 | 1.00 | 0.33 | 0.33 |
| E | 0.11 | 0.11 | 0.11 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 1.00 | 0.33 | 0.55 | 0.71 | 1.00 | 0.33 |
| F | 1.00 | 0.33 | 0.33 | 0.33 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| G | 1.00 | 0.11 | 0.77 | 0.55 | 0.55 | 0.55 | 0.55 | 0.33 | 0.77 | 0.33 | 0.77 | 0.77 | 0.77 | 0.77 |
| H | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| I | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| J | 0.33 | 0.77 | 0.33 | 0.77 | 0.77 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |

**Table 3**: Normalized Matrix

**Step 3**: Calculating “WASPAS weighted and normalized decision-making matrix” for the summarizing part

\[ X_{ij, \text{sum}} = X_{ij/qj}, \text{ where } i,m; j=1,n \]  
(8)

**Step 4**: Calculating “WASPAS weighted and normalized decision-making matrix” for the multiplication part

\[ X_{ij, \text{multi}} = X_{ij/qj}, \text{ where } i=1,m; j=1,n \]  
(9)

| Supplier | X_{ij,sum} | X_{ij,multi} |
|----------|------------|--------------|
| A | 0.560443 | 0.525262 |
| B | 0.665664 | 0.624972 |
| C | 0.627595 | 0.613161 |
| D | 0.449350 | 0.417253 |
| E | 0.405035 | 0.280106 |
| F | 0.623519 | 0.544285 |
| G | 0.630262 | 0.482522 |
| H | 0.586962 | 0.497909 |
| I | 0.702095 | 0.618678 |
| J | 0.527830 | 0.484855 |

**Step 5**: Final calculation for “evaluating and prioritizing alternatives based on”
Where $i=1,m ; j =1,n$

Table 15 Weighted Aggregated Sum Product Value

|        | $X_{ij,\text{sum}}$ | $X_{ij,\text{mult}}$ | $WAS_i$  |
|--------|---------------------|----------------------|----------|
| A      | 0.560443            | 0.522562             | 0.541502 |
| B      | 0.665664            | 0.624972             | 0.645318 |
| C      | 0.627595            | 0.613161             | 0.620378 |
| D      | 0.449350            | 0.417253             | 0.433302 |
| E      | 0.405035            | 0.280106             | 0.342570 |
| F      | 0.623519            | 0.544285             | 0.583902 |
| G      | 0.630262            | 0.482522             | 0.556392 |
| H      | 0.586962            | 0.497909             | 0.542435 |
| I      | 0.702095            | 0.618678             | 0.660386 |
| J      | 0.527830            | 0.484855             | 0.506342 |

Step 6: Final rank of alternatives

Table 16 Rank of Alternative

|        | $WAS_i$  | Rank |
|--------|----------|------|
| A      | 0.541502 | 7    |
| B      | 0.645318 | 2    |
| C      | 0.620378 | 3    |
| D      | 0.433302 | 9    |
| E      | 0.342570 | 10   |
| F      | 0.583902 | 4    |
| G      | 0.556392 | 5    |
| H      | 0.542435 | 6    |
| I      | 0.660386 | 1    |
| J      | 0.506342 | 8    |

The best alternative is for which the rank obtained is one i.e., I and the worst is for which the rank is ten i.e., E.

ASSessment VALUE OF WASPAS METHOD
6. Discussion

Comparative ranking of alternatives on the basis of MOORA and WASPAS is given in Table 13. First of all, SWARA is considered for finding the weight of criteria selected. Weight given by SWARA method is for Production cost 0.338; Inventory cost 0.232; Product rejection rate 0.148; Quality certificate 0.102; Lead time 0.064; Employment stability 0.041; safety 0.027; working condition 0.017; training 0.012; Human right and worker interest 0.008; Recycle 0.005; Reuse 0.003; Resource consumption of raw material 0.002; Environment related certificates 0.001. According to MOORA method alternatives are ranked as I>B>C>F>G>H>A>J>D>E in the decreasing order of preference and according to WASPAS method alternatives are ranked as I>B>C>F>G>H>A>J>D>E in the decreasing order of preference. It is clear from the ranking results that the multi criteria decision making approaches used i.e, MOORA and WASPAS in supplier selection in sustainability, supplier I is the best choice for the given industrial application under the given conditions and the second best choice is supplier mentioned as B while supplier mentioned as E is the worst choice.

Sustainable supplier mentioned as I is the ideal according to the criteria product cost (E1), product rejection rate (E3), lead time (E5), employment stability (S1), safety (S2), working condition (S3), reuse (EN1), recycle (EN2) and environment related certificate (EN4).

Sustainable supplier mentioned as B is the ideal according to the criteria product cost (E1), product rejection rate (E3), Quality certificates (E4), safety (S2), reuse (EN1), resource consumption of raw material (EN3) and environment related certificate (EN4).

As an alternative for a final solution, sustainable supplier mentioned as I could be considered the best compromise. A comparison of alternatives I and B is presented in Table 14 and it shows that for criteria Quality certificate and resource consumption of raw material alternative B is highly preferred over alternative I, for inventory cost, product rejection rate, employment stability, working condition, recycle and environment related certificate alternative I is slightly preferred over alternative B, for lead time alternative I is highly preferred over alternative B and for product cost, safety, training, human right and worker interest and reuse alternative B is same as alternative I. From the comparison results of sustainable supplier, I and B, it is clear that for two criteria B is highly preferred while sustainable supplier I is slightly preferred for six criteria and highly preferred for one criteria and for six criteria both are same. So, sustainable supplier I is the best choice which is also the best choice from the ranking results of MOORA and WASPAS. It may be mentioned that the ranking depends on the judgments of relative importance made by the user. The ranking may change if the user assigns different relative importance values to the criteria’s. The same is true with all these multi criteria decision making approaches.

Table 17Comparative ranking of alternatives for supplier selection

| Alternatives | MOORA | WASPAS |
|--------------|-------|--------|
| A            | 7     | 7      |
| B            | 2     | 2      |
| C            | 3     | 3      |
| D            | 9     | 9      |
| E            | 10    | 10     |
| F            | 4     | 4      |
| G            | 5     | 5      |
| H            | 6     | 6      |
| I            | 1     | 1      |
| J            | 8     | 8      |
Table 18 Comparison of alternative I and B.

| Criteria                                           | I    | B    | Preferred |
|----------------------------------------------------|------|------|-----------|
| Product cost (E1)                                  | 7    | 7    | Same      |
| Inventory cost                                     | 5    | 3    | I, slightly |
| Product rejection rate                             | 9    | 7    | I, slightly |
| Quality certificate                                | 1    | 9    | B, highly |
| Lead time                                          | 9    | 5    | I, highly |
| Employment stability                               | 7    | 5    | I, slightly |
| Safety                                             | 7    | 7    | Same      |
| Working condition                                  | 7    | 5    | I, slightly |
| Training                                           | 5    | 5    | Same      |
| Human right & worker interest                       | 5    | 5    | Same      |
| Recycle                                            | 7    | 5    | I, slightly |
| Reuse                                              | 7    | 7    | Same      |
| Resource consumption of raw material               | 3    | 7    | B, highly |
| Environment related certificate                     | 9    | 7    | I, slightly |

7. Conclusions
A framework for SSCM has been developed in the present work. The developed framework for vendor selection criteria is based on a systematic status review and a novel hybrid method based on normalizing and then find assessment value provided by MOORA, and WASPAS has been presented in the paper. The developed model has been implemented successfully in a battery manufacturer industry of Punjab state of India. The new proposed framework may not only reveal the structure of interactions among the supplier selection criteria, but also helps to find the critical criteria affecting the performance of sustainable supplier selection process. The weightage to the critical criteria was calculated by a new method named as SWARA. Ten sustainable suppliers’ alternatives were evaluated considering a set of 14 criteria in the presented case study. Ranking of alternatives has been performed by applying WSM, WPM methods, a joint criterion of weighted aggregation of the latter methods, also the ratio system as part of MOORA. Ten series of ranks were calculated respectively. It has been proved that the most preferable alternative depended on \( \lambda \) value when applying a joint weighted method WASPAS. Alternative named I was ranked as the best and alternative named B remained in the second place when \( \lambda \) value is 0.5. MOORA method consisting of the ratio system and the reference point approach in which ratio system were also applied for the developed case study. The best ranked alternative decisions coincided in the current case and supplier named I was preferred. Reliability of the joint criterion was evaluated, and validation of results was performed when comparing it to MOORA approach. It was proved that WASPAS results coincided with the ratio system form when \( \lambda \) value is 0.5. Hence the final decision that supplier named I is the best vendor for sustainable supply chain management is justified.

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