An F-PROMETHEE technique for analysing the risk factors in green manufacturing

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Abstract. In the contemporary globalization, green manufacturing have achieved the more significance. Recently, many firms know about the importance of green because of the environmental and social concerns involved. Green manufacturing implementation is vital one for environment as well as improving the business. The goal of the green manufacturing is to protect the environment, prevent the pollution and also for waste reduction. But the adoption of green manufacturing is challenging for industrial managers because of the several risk factors involved in the firm. For the green manufacturing implementation, this paper aims to recognize and analyse the risk factors of green manufacturing and also to identify the critical alternative in Indian medical equipment manufacturing firm by using MCDM (Multi-Criteria decision making method) like F-PROMETHEE (Fuzzy Preference Ranking Organization method for Enrichment Evaluations). The outcomes of the paper will be surely useful for industrial managers for the implementation of green manufacturing in their firms.

1. Introduction
Pollution from environment, resource allocation and growth of population are the three key issues in global world environment. Environmental pollution plays a major role for affecting both industrial and society development and also in manufacturing firms. Therefore, all the firms are looking for reducing the environmental impact. ISO has suggested some international standards for the environmental management system as well as management system for quality products. The highlight of the paper is to lessen the environment impact. They need to implement the process of Green manufacturing with sustainable development. For future point of view, they consider the characteristics of sustainable consumption and production [1]. For the past decade, manufacturers should manufacture the product with consumption of resource and also low environmental impact during the process such as quality, transport, packaging, production and design. Manufacturers who manufacturing the product with mass production, they should focus only on the green manufacturing. Lot of waste and energy are used on the routine basis, it affects the health and well-being of employees. Development of firm is affected by several risk factors in the firm. This paper mainly focuses on increasing sustainable energy, waste reduction and environmental pollution. To solve this issue, we analysed the risk factors of green manufacturing in medical equipment manufacturing firms and to identify the critical alternative by using MCDM methods like Fuzzy PROMETHEE. This paper outcome will definitely assist the industrial managers for the implementation of green manufacturing. Green manufacturing implementation is not only for the environment and also for increasing the business profit [2]. In the process of manufacturing, material intensiveness and reducing energy is mainly achieved by green manufacturing implementation.
The remainder section of the paper is discussed below. Section 2 represents relevant literature about risk factors in the process of green manufacturing and gap of literature. Flow chart of the paper is demonstrated in Section 3. Section 4 defines the procedure of Fuzzy PROMETHEE method. Case study of the paper is described in Section 5. Conclusion and scope for future research is discussed in Section 6.

2. Relevant Literature

This paper has classified the relevant literature into two sub-segments namely a) Risk factors involved in green manufacturing b) Literature gap

2.1. Risk factors involved in green manufacturing

Paul et al. [3] conducted a review in manufacturing industry related to the significance of green manufacturing, techniques and its application. The findings of the paper showed that implementation of green manufacturing are essential for reducing the waste from products and prevent the pollution from environment. Digalwar et al. [4] evaluated the performance measures for execution of green manufacturing and also case study is conducted in nine different manufacturing firms. This study gives useful tips to improve the business as well as achieving the practices of green manufacturing. Deif [5] created a framework for green manufacturing for the efficiency of production in the department of paint in wood products manufacturing firm. The outcomes of the paper is mainly for accomplishing the green manufacturing implementation as well as level of greenness in the paint dept. Govindan et al. [6] assessed the green manufacturing risk factors and also identify the most influential risks in the Indian industry by using Fuzzy Analytic Hierarchy Process. The consequence depicts that regulation compliance is the most influential factor in the industry and they need to implement some set of standards related to environment. Liu et al. [7] created a replica for green manufacturing risks in various projects and also performed a case study in refrigerator manufacturing firm by using MADM (multi-attribute decision making) with fuzzy approach. This paper shows project 3 has the critical green manufacturing risks and this model is useful for partial data and different elements in decision making of green manufacturing. Mittal et al. [8] evaluated the green manufacturing barriers and drivers in both emerging and developing nations like Germany and India and also to compare the both drivers and barriers. For the successful green manufacturing implementation, this paper surely helps the managers and decision makers from industries in both nations. Sangwan [9] analysed the green manufacturing benefits of both qualitative and quantitative in Indian enterprises by using SPSS software. The outcomes of the paper identified that most important benefits are reducing treatment, handling and disposal cost as well as packaging and transport cost. Seth et al. [10] recognized the most influencing performance measures and risk factors of green manufacturing in cement industry. Commitment from top management, culture in organizations, supply chain management and human resources are the key factors in implementation of green manufacturing.

2.2. Literature gap

As of now, there are only limited papers related to risk factors of green manufacturing by using MCDM methods. But there are no papers related to risk factors of green manufacturing in Indian medical equipment manufacturing firms by using Fuzzy PROMETHEE method. In order to fulfil this gap, we analysed the risk factors in this paper. Table 1 shows the risk factors in green manufacturing process.
Table 1. Risk factors in green manufacturing.

| S. No. | Risk Factors                          | Notation |
|-------|--------------------------------------|----------|
| 1     | Requirements in supply chain          | F1       |
| 2     | Demand by employees & customers       | F2       |
| 3     | Benefits in Finance                   | F3       |
| 4     | Status of the firm                    | F4       |
| 5     | Shareholders                          | F5       |
| 6     | Environmental conservations           | F6       |
| 7     | Organizational resources              | F7       |
| 8     | Consumers                             | F8       |
| 9     | Challengers                           | F9       |
| 10    | Commitment from top management        | F10      |

3. Flow chart of the paper

![Flowchart of the paper](image)

**Figure 1.** Flowchart of the paper.

The above figure 1 shows the flowchart of this paper work for better clarity and understanding.
4. Fuzzy PROMETHEE method

Brans et al. [11] was first initiated the PROMETHEE method for ranking the number of alternatives. PROMETHEE method is used for understanding the concept very easily and it has more applications in routine life and also it is technique of outranking. Ulengin et al. [12] said that both incomplete and final rankings are provided by PROMETHEE I and II. For processing the fuzzy data in problems of decision making, this method has lack of ability. Fuzzy set theory was initiated to manage the ambiguity of individual decision. To develop the problem with both solution and formulation by fuzzy set theory, which are complicated for the analysis by traditional methods. For this purpose, we integrate both PROMETHEE method and fuzzy set theory and it is termed as Fuzzy PROMETHEE method and this method was first initiated by [13] and they implemented in the steel industry. Many researchers recently used Fuzzy PROMETHEE method for solving the problems [14-16].

The procedure for fuzzy PROMETHEE method is discussed below:

Phase 1: In the first step, to find the decision makers, risk factors and alternatives and they are denoted as m, f and a.

Phase 2: Describe the related fuzzy no’s and linguistic values
This paper used the five point linguistic scales suggested by Chen et al., (2011) and they are stated in TFN (Triangular fuzzy no’s) and to evaluate the significance weight of risk factors.

Phase 3: Collect the opinion of decision makers
For every risk factor, the average weight is

\[
We_j = \frac{1}{m} \left[ \sum_{f=1}^{m} We_f \right] = \frac{1}{n} \left[ We_j^1 + We_j^2 + ... We_j^n \right] \quad (1)
\]

Under every risk factor i (f_i), the assessed value of the alternative j (A_j) is

\[
y_{ij} = \frac{1}{m} \left[ \sum_{f=1}^{m} y_{ij}^m \right] = \frac{1}{m} \left[ y_{ij}^1 + y_{ij}^2 + ... y_{ij}^n \right] \quad (2)
\]

Phase 4: Constructing the fuzzy decision matrix and calculate the average fuzzy weight

\[
S = \left[ y_{ij} \right]_{a \times f} = \begin{bmatrix}
  y_{11} & y_{12} & \cdots & y_{1k} \\
  y_{21} & y_{22} & \cdots & y_{2k} \\
  \vdots & \vdots & \ddots & \vdots \\
  y_{a1} & y_{a2} & \cdots & y_{ak}
\end{bmatrix} \quad (3)
\]

Under every risk factor i (f_i), y_{ij} denotes the assessed value of the alternative j (A_j)

\[
We = [we_1, we_2, ..., we_k] \quad j = 1,2,..., f \quad (4)
\]

We_j indicates the weight of the risk factor i.

For the triangular fuzzy number, We_j and y_{ij} are the linguistic variable.

Phase 5: Build the function of fuzzy preference
There are two set of alternatives (A) are p and q, the function of preference Pr (p, q) is described below:

\[
Pr(p, q) = 0, \quad y_{bj} \leq y_{aj} \quad j = 1,2,..., f \quad (5)
\]

Pr(p, q) preference function signifies the intensity of outranking that p is larger to q. From the pairwise comparison alternatives, the outranking relation is constructed. y_{ij} > y_{aj} \iff pPr q (p outranks q)
\( y_{b_j} = y_{a_j} \iff p \Pr q \) (p is dissimilar to q) \hspace{1cm} (6)

Phase 6: For describing the relation of valued outranking, firstly to define the function of multi-criteria preference \( \pi(p, q) \) and it can define below.

\[
\pi(p, q) = \frac{1}{f} \sum_{i=1}^{f} \text{Pr}_i(p, q)
\]

\[
\pi(p, q) = \sum_{i=1}^{f} [\text{We}_i \cdot \text{Pr}_i(p, q)] / \sum_{i=1}^{f} \text{Wr}_i
\]

Phase 7: For the alternatives preordering to calculate the flows

Fuzzy PROMETHEE I: Partial disorder is used to show alternatives and it is difficult to contrast each other.

Outgoing flow
\[
\phi^+(p) = \sum_{x \in p} \pi(q, x), \forall p, x \in A
\]

Here \( \phi^+(p) \) is the summation of preference that p is larger to various alternatives. For the better alternatives, \( \phi^+(p) \) will be higher.

Incoming flow
\[
\phi^-(p) = \sum_{x \in p} \pi(q, x), \forall p, x \in A
\]

Here \( \phi^-(p) \) is the summation of preference that various alternatives are larger to p. For the better alternatives, \( \phi^-(p) \) will be smaller.

Next one is defuzzify the maximizing and minimizing sets.

\[
C (\text{Maximizing sets}) = \{y, e_y(y)\} \vert y \in C
\]

\[
e_y(y) = (y - y_1) / (y_2 - y_1), y_1 \leq y \leq y_2
\]

0, otherwise

\[
N (\text{Minimizing sets}) = \{y, e_y(y)\} \vert y \in N
\]

\[
e_y(y) = (y - y_2) / (y_1 - y_2), y_1 \leq y \leq y_2
\]

0, otherwise

Fuzzy PROMETHEE I is the incomplete preorder of \((A_1, J_1, C)\) acquired by deliberating the connection of two preorders, and is affirmed by the incomplete preorder which is denoted in eq (13). Outgoing and incoming flows will be recognized in PROMETHEE.

\[
pA_1q \ (p \text{ outranks } q) \iff \begin{cases} pA^+q \text{ and } pA^-q, & \text{if } \text{pA}^+q \text{ and } pA^-q, \\ pA^+q \text{ and } pA^-q, & \text{Or } pA^+q \text{ and } pA^-q, \end{cases}
\]

\[
pJ_1q \ (p \text{ is dissimilar to } q) \iff \begin{cases} pJ^+q \text{ and } pJ^-q; & \text{if } pJ^+q \text{ and } pJ^-q; \\ \text{Or } pA^+q \text{ and } pA^-q, & \text{Or } pA^+q \text{ and } pA^-q; \end{cases}
\]

\[
pCq \ (p \text{ and } q \text{ are unequalled}) \iff \begin{cases} \text{if } pJ^+q \text{ and } pJ^-q; & \end{cases}
\]

\[
\text{Else.}
\]

Fuzzy PROMETHEE II: It gives the impartial preorder and is persuaded by the total flow and in the equation 14. The impartial preorder appears in eq (20):

Hence, Total stream is
\[
\phi(p) = \phi^+(p) - \phi^-(p)
\]

(14)
\[ pA_{ij}b \quad (p \text{ outranks } q) \quad \text{if } \phi(p) > \phi(q) \]
\[ pJ_{ij}q \quad (p \text{ is similar to } q) \quad \text{if } \phi(p) = \phi(q) \]

From the outgoing and incoming flows, the incomplete preorder is obtained by using Fuzzy PROMETHEE I and the final ranking is based on total flows by using Fuzzy PROMETHEE II.

Phase 8: Building the outranking graph for evaluates the ranking of every alternative.

5. Case study

In the modern day business scenario, green manufacturing is the key one for improving the production as well as turnover. Regarding this scenario, this paper conducted the case study in leading medical equipment manufacturing firm with more than 500 workers employed. It is located in southern part of India. Current case firm has a problem for not protecting the environment from the pollution as well as producing the product with more waste. To overcome this issue, they need implementation of green manufacturing. But there are more no of risk factors in the process of green manufacturing. Therefore risk assessment is needed for controlling the risk factors. The main aim of the paper is to examine the risk factors and to select the critical alternative in the firm by using F-PROMETHEE method. A team of decision makers like \((DM1, DM2, DM3)\) is framed to select the most preferable alternative for the firm related to green manufacturing such as Environmental standards (A1), Innovation in green technologies (A2) and Trend in external markets (A3). The findings of the paper will definitely assist the industrial managers for the green manufacturing implementation. The scope diagram of the paper is presented in Figure 2.

![Figure 2. Scope diagram of the paper.](image)

5.1. Analyzing the risk factors in green manufacturing

Step 1: Decision makers provide the ratings for risk factors and alternatives by using Table 2 in the form of questionnaire.
Table 2. Linguistic scales and their related fuzzy no’s.

| Fuzzy No     | Alternatives rating | Risk Factor weights |
|--------------|---------------------|---------------------|
| (0.75,1.1)   | Best (B)            | Very High (VH)      |
| (0.5,0.75,1) | Good (G)            | High (H)            |
| (0.25,0.5,0.75) | Fair (F)          | Medium (M)          |
| (0.0,0.25,0.5) | Poor (P)           | Low (L)             |
| (0.0,0.0,0.25) | Worst (W)          | Very Low (VL)       |

Step 2: Decision makers given the rating of both risk factors and alternatives are given in Table 3 and table 4.

Table 3. Weight of every risk factor given by decision makers.

| DM1 | DM2 | DM3 | DM4 | Weights of Fuzzy (Wej) |
|-----|-----|-----|-----|------------------------|
| F1  | M   | H   | H   | M                       | (0.375,0.625,0.875) |
| F2  | H   | H   | M   | VH                      | (0.5,0.75,0.9375)  |
| F3  | M   | M   | L   | M                       | (0.75,1.75,2.75)   |
| F4  | H   | H   | H   | M                       | (1.75,2.75,3.75)   |
| F5  | M   | H   | H   | H                       | (1.75,2.75,3.75)   |
| F6  | L   | M   | M   | L                       | (0.5,1.5,2.5)      |
| F7  | H   | M   | VH  | H                       | (2.3,3.75)         |
| F8  | M   | M   | M   | L                       | (0.75,1.75,2.75)   |
| F9  | H   | M   | H   | M                       | (1.5,2.5,3.5)      |
| F10 | M   | M   | L   | M                       | (0.75,1.75,2.75)   |

Table 4. For every alternative rating given by decision makers.

|       | A1 | A2 | A3 |
|-------|----|----|----|
| F1    | F  | P  | F  |
| F2    | P  | P  | G  |
| F3    | F  | F  | F  |
| F4    | F  | P  | P  |
| F5    | G  | W  | P  |
| F6    | P  | W  | P  |
| F7    | P  | P  | F  |
| F8    | F  | P  | F  |
| F9    | W  | F  | P  |
| F10   | F  | P  | P  |

Step 3: Next step is to convert the linguistic evaluation into TRFN (Trapezoidal fuzzy numbers) for generating the fuzzy decision matrix and to find fuzzy weight of every risk factor. Table 5 and table 6 shows the normalized and weighted normalized Fuzzy decision matrix.
Step 4: Hamming distance technique is used for calculating the distance among two alternatives 1 and 2 regarding every risk factors. For instance, to compare the first and second alternative A1 and A2 is (0.094, 0.156, and 0.219). Therefore the alternative 1 is ideal than the alternative 2.

Step 5: By using the weight of risk factors and preference function value to calculate the function of fuzzy preference and it is depicted in table 7. By using equation (9) and (10), the fuzzy flows for every alternative are found and listed in the below table 8.

**Table 5.** Normalized fuzzy decision matrix.

|   | A1 | A2 | A3 |
|---|----|----|----|
| F1 | (0.25,0.5,0.75) | (0,0.25,0.5) | (0.25,0.5,0.75) |
| F2 | (0,0.25,0.5) | (0,0.25,0.5) | (0.5,0.75,1) |
| F3 | (0.25,0.5,0.75) | (0.25,0.5,0.75) | (0.25,0.5,0.75) |
| F4 | (0.25,0.5,0.75) | (0,0.25,0.5) | (0,0.25,0.5) |
| F5 | (0.5,0.75,1) | (0,0,0.25) | (0,0.25,0.5) |
| F6 | (0,0.25,0.5) | (0,0,0.25) | (0,0.25,0.5) |
| F7 | (0,0.25,0.5) | (0,0.25,0.5) | (0.25,0.5,0.75) |
| F8 | (0.25,0.5,0.75) | (0.25,0.5,0.75) | (0.25,0.5,0.75) |
| F9 | (0,0,0.25) | (0.25,0.5,0.75) | (0,0.25,0.5) |
| F10 | (0.25,0.5,0.75) | (0,0.25,0.5) | (0,0.25,0.5) |

**Table 6.** Weighted normalized fuzzy decision matrix.

|   | A1 | A2 | A3 |
|---|----|----|----|
| F1 | (0.094,0.313,0.656) | (0.0156,0.438) | (0.094,0.313,0.656) |
| F2 | (0.0188,0.469) | (0.0188,0.469) | (0.25,0.563,0.938) |
| F3 | (0.047,0.219,0.516) | (0.047,0.219,0.516) | (0.047,0.219,0.516) |
| F4 | (0.109,0.344,0.703) | (0.172,0.469) | (0.172,0.469) |
| F5 | (0.219,0.516,0.938) | (0,0,0.234) | (0,0.156,0.438) |
| F6 | (0,0.094,0.313) | (0,0.0156) | (0,0.094,0.313) |
| F7 | (0.0188,0.469) | (0,0.0156) | (0.125,0.375,0.703) |
| F8 | (0.047,0.219,0.516) | (0.109,0.344) | (0.047,0.219,0.516) |
| F9 | (0,0.0219) | (0.094,0.313,0.656) | (0,0.094,0.313,0.656) |
| F10 | (0.047,0.219,0.516) | (0.109,0.344) | (0.109,0.344) |

Step 6: By using equation (1), defuzzifying the value of fuzzy outgoing and incoming flows. Table 9 shows the crisp values of both outgoing and incoming flows and also final rankings are based on the total flows.
Table 9. Crisp flows.

|        | Outgoing flow | Incoming flow | Total flow | Final Ranking |
|--------|---------------|---------------|------------|---------------|
| A1     | 1.364         | 0.421         | 0.9434     | 1             |
| A2     | 0.463         | 1.028         | -0.5651    | 3             |
| A3     | 1.302         | 1.681         | -0.3783    | 2             |

Incomplete and final rankings are provided by Fuzzy PROMETHEE I and II and it is shown in Figure 3 and figure 4.

![Diagram Diagram Diagram Diagram](image)

**Figure 3.** PROMETHEE I - incomplete ranking.

![Diagram Diagram Diagram Diagram](image)

**Figure 4.** PROMETHEE II – final ranking.
6. Conclusions and scope for future work

This paper used the multi criteria decision making method like F-PROMETHEE for analyzing the risk factors of Green manufacturing in medical equipment manufacturing firms and for choosing the critical alternative in the firm. For the production managers as well as officials in the firm, implementation of environmental management system (EMS) and green manufacturing is a key issue. This paper recognizes ten risk factors and three alternatives from industrial experts as well as gathered from relevant literature. From these alternatives, environmental standards (Alternative 1) with a total flow of 0.9434 are the critical alternative in the firm. The outcomes showed that lack of rules and regulations related to the environment for the green manufacturing implementation. In the strategic manufacturing decisions, environmental standards act as a major role. Therefore the firm should implement the environmental management system with ISO 14001 standards for lessening the environmental impact. For fulfilling the regulations of government, implementation of green manufacturing is the vital one. Currently based on the report from Indian government in 2019, nearly 30,000 organizations are certified with ISO 14001. Green manufacturing implementation is mainly for protecting the environment from pollution, controlling risk, producing the product with less waste and low cost of the product regarding the needs of customer. Green manufacturing is very useful for increasing the performance of the firm. For the importance of green practices, every month to conduct the audit from both internal and external officers related to ISO certification and adoption.

Managers from industries will use our outcomes for the implementation of green manufacturing and also to know and understand about what are the risks in green manufacturing. Final outcomes will also help third parties such as stakeholders, customers, suppliers, advocacy groups related to an environment, politicians, governments and regarding the concerns of employees. Based on the results, production managers conduct the program for employees regarding the importance of green.

This paper has several limitations and it can be explored later on. First one, there are only ten risk factors and three alternatives are identified in this paper, for the future point of view, more no of risk factors and alternatives will be identified. Second one, this paper examining the risk factors by using F-PROMETHEE method. Therefore to analyse the risk factors by using different MCDM ranking methods like TOPSIS, VIKOR, and ANP. Finally, this paper identifies the factors from medical equipment manufacturing firm only. For the future perspective, you will do the research in other firms also.

7. Appendices

Appendix A: Questionnaire

Note:

For a review, a questionnaire was framed and it is provided to the experts in the field to evaluate risk factors in lean implementation of three medical equipment manufacturing firms in the southern region of India. Gathered data will be used only for the purposes of research. Comments from you will not share to third party or any social media and it will be kept secret. Your input will help in bringing about positive outcomes in this research and it is very important.

For providing a rating, our heartfelt thanks for spending your time and effort.
Table A1. Linguistic scales and their related fuzzy no’s.

| Fuzzy No     | Alternatives rating | Risk Factor weights |
|--------------|---------------------|---------------------|
| (0.75,1,1)   | Best (B)            | Very High (VH)      |
| (0.5,0.75,1) | Good (G)            | High (H)            |
| (0.25,0.5,0.75) | Fair (F)          | Medium (M)          |
| (0.0,0.25,0.5) | Poor (P)           | Low (L)             |
| (0,0,0.25)   | Worst (W)           | Very Low (VL)       |

Please tick [✓] in any one of rating that you feel suitable for each item. (Refer to Table A1)

|       | DM1 | DM2 | DM3 | DM4 |
|-------|-----|-----|-----|-----|
| F1    |     |     |     |     |
| F2    |     |     |     |     |
| F3    |     |     |     |     |
| F4    |     |     |     |     |
| F5    |     |     |     |     |
| F6    |     |     |     |     |
| F7    |     |     |     |     |
| F8    |     |     |     |     |
| F9    |     |     |     |     |
| F10   |     |     |     |     |

|       | A1  | A2  | A3  |
|-------|-----|-----|-----|
| F1    |     |     |     |
| F2    |     |     |     |
| F3    |     |     |     |
| F4    |     |     |     |
| F5    |     |     |     |
| F6    |     |     |     |
| F7    |     |     |     |
| F8    |     |     |     |
| F9    |     |     |     |
| F10   |     |     |     |

Please tick [✓] in any one of rating that you feel suitable for each item. (Refer to Table A1)

Profile of the expert:

1. Name: ……………………………………..
2. Experience in Medical equipment manufacturing firms (in years): …………
3. Name of organization: ………………………..
4. Current position in the organization: ………………………
5. Mobile No. & Email: ………………………….
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