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Prioritizing Barriers to Green Manufacturing: Environmental, Social and Economic Perspectives

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Abstract

Manufacturing firms consume energy and natural resources in highly unsustainable manner and release large amounts of green house gases leading to many economic, environmental and social problems from climate change to local waste disposal. A growing number of organizations have begun working towards implementation of Green Manufacturing (GM) because of increased concerns about the pollution increase, natural resources depletion and global warming. However, there are barriers which hinder the implementation of GM. In order to mitigate these barriers, the prioritization of barriers is essential as high-priority barriers can be taken up first to address the issue more effectively within the available resources. The prioritization becomes more vital for the emerging countries because of the limited recourses. This paper aims at identifying and prioritizing barriers to GM implementation. A fuzzy TOPSIS multi-criteria decision model has been developed to prioritize these barriers from environmental, social and economic perspectives. The study concluded that lack of awareness/information, technological risk and weak legislation are three most important barriers to GM. The prioritization of the barriers from different perspectives is expected to help the decision/policy makers in government and industry to mitigate these barriers in an effective manner.

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"Keywords: Green Manufacturing (GM); Barriers; Sustainable Manufacturing; Prioritizing"

1. Introduction

Manufacturing sector is vital for the emerging and developing economies to improve the quality of life of their citizen. The limited natural resources and growing energy demand is slowing down the pace of development in developed countries, meanwhile, the manufacturing sector of emerging countries is attracting global attention because of untapped potential for growth in terms of natural resources and human resources, in addition to relatively less stringent environmental legislation [1]. At the same time, the growth of manufacturing sector brings in some challenges like fast depleting natural resources; soil, water and air pollution; and severe health hazards to humanity. These challenges are posing risk to sustainable development of the planet.

The need of achieving higher economic prosperity with least environmental impact has led to a new manufacturing paradigm of Green Manufacturing (GM). GM means designing, manufacturing, delivering, and disposing products that produce minimum negative effect on environment and society and are economically viable. However, the implementation of GM in the industry is hindered by barriers. The implementation of GM is possible only with collaborated efforts of government and industry in a strategic way by mitigating the GM barriers. This paper aims at prioritization of the barriers to GM using fuzzy TOPSIS based on environmental, social and economic perspectives. The

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prioritization of GM barriers will help government and industry to focus on few vital barriers to mitigate within limited resources.

The remainder of this paper is organized as follows: next section provides the background of the study followed by methodology in section 3. Section 4 presents the results and discussion. Finally, section 5 provides the conclusions of the study.

2. Background

Various studies in the past have identified the barriers to green manufacturing [2-5], environmentally conscious manufacturing [6-9], sustainable manufacturing [10-13], cleaner production [14-19], cleaner technology adoption [20-22], environmentally sound technology [23], environmental strategy in manufacturing [24], environmental management system [25], environmental sustainability [26], environmentally conscious technology adoption [27], environmentally responsible practices [28], and environmentally benign manufacturing [29], etc. The 12 barriers identified by Mittal et al. [4] shown in table 1 have been adopted for this study. Table 1 also provides the description of each barrier for more clarity.

Table 1: List of GM barriers and their description (Adapted from Mittal et al. 2013)

Code	Barrier	Description
B_1	Weak Legislation	Ineffective and/or complex legislation; absence of environmental laws
B_2	Low Enforcement	Ineffective and/or non enforcement of laws; corruption; inadequate monitoring mechanism
B_3	Uncertain Future Legislation	Immature developments in legislation; possibility of completely new regulations in future
B_4	Low Public Pressure	Ineffective pressure of local communities, media, NGOs or politicians
B_5	High Short-Term Costs	Higher capital and implementation costs
B_6	Uncertain Benefits	Uncertain and/or insignificant economic advantage; slow return on investment; paying back of older investments is prior
B_7	Low Customer Demand	Price sensitive customers; curiosity for cheaper products; no environmental concern in the market
B_8	Trade-Offs	Outsourcing of environmental problems to off-shore countries where environmental laws are not stringent; short product life cycles
B_9	Low Top Management Commitment	Green issues are not a concern for top management
B_{10}	Lack of Organizational Resources	Lack of skilled/experienced staff; no financial resources or capital access
B_{11}	Technological Risk	Threat of implementing newer/ complex technology; fear of problems; compatibility issues with existing systems
B_{12}	Lack of Awareness/ Information	Limited awareness of green trends; limited access to green literature; scarcity of adequate information

There are three distinct aspects which should be taken care of in order to implement newer manufacturing strategies like green manufacturing – planet, people, and prosperity [30]. This provided the motivation to prioritize the GM barriers using environmental (planet), social (people) and economic (prosperity) perspectives. Moreover, the review of literature suggests that there is hardly any paper prioritizing the barriers to GM implementation except Shi et al. [18] using analytical hierarch process (AHP) to rank barriers to cleaner production for China. Fuzzy TOPSIS multi-criteria decision making (MCDM) technique is used to prioritize the barriers as it is better equipped to deal with two major kinds of uncertainties, i.e. ambiguity and vagueness, which exist in the real life. Also, TOPSIS is easy to compute and understand [31].

3. Methodology

Fuzzy TOPSIS, developed by Chen, is a practical method and fits human thinking under actual environment [32]. Fuzzy theory is applied to model parameters for decision making to prioritize GM barriers. In fuzzy set theory, a triangular fuzzy number can be defined by a triplet and the conversion scales are applied to transform the linguistic terms into fuzzy numbers. Table 2 provide the selection and assessment criteria and alternatives for prioritizing GM barriers.

Table 2: Linguistic variables and fuzzy ratings for criteria and alternatives

Linguistic terms for criteria	Linguistic terms for alternatives	Membership Function
Very Low Importance (VL)	Not Important (NI)	(1,1,3)
Low Importance (L)	Less Important (LI)	(1,3,5)
Medium Importance (M)	Fairly Important (FI)	(3,5,7)
High Importance (H)	Important (I)	(5,7,9)
Very High Importance (VH)	Very Important (VI)	(7,9,9)

The steps of fuzzy TOPSIS algorithm can be expressed as follows [33,34]:

Step 1: Assignment of ratings

The linguistic ratings are assigned to various criteria and alternatives with the help of three decision maker groups named as DM1, DM2, and DM3 from people of environmental, social and economic expertise respectively (Table 3 and 4). These decision makers were experts from government, industry and industry associations working in the field of green/sustainable manufacturing, pollution control, etc. for at least five years. Each decision maker group comprises of three experts leading to a total of nine experts for the study.

Table 3: Linguistic assessment of criteria

Criteria	DM1	DM2	DM3
Environmental perspective (C1)	VH	H	H
Social perspective (C2)	H	H	L
Economic perspective (C3)	M	H	VH

Step 2: Compute aggregate fuzzy ratings for the criteria

The linguistic ratings of the criteria are transformed into aggregate fuzzy ratings using the table 2 as shown in table 5.

Table 4: Linguistic assessment of alternatives

Barriers	Environmental	Social	Economic
B_1	I	VI	FI
B_2	VI	VI	LI
B_3	FI	FI	I
B_4	I	I	LI
B_5	FI	LI	VI
B_6	LI	NI	I
B_7	FI	FI	I
B_8	I	FI	FI
B_9	I	VI	NI
B_{10}	LI	LI	VI
B_{11}	I	I	I
B_{12}	VI	VI	I

If the fuzzy ratings of all decision makers are described as triangular fuzzy numbers $\tilde{R}_k = (a_k, b_k, c_k)$, k = 1, 2. . . K, then the aggregated fuzzy rating is given by

$$\tilde{R} = (a, b, c), k = 1, 2... K,$$

where

$$a = \min_k \{a_k\}, \quad b = \frac{1}{K}\sum_{k=1}^{K} b_k \quad \text{and} \quad c = \max_k \{c_k\}$$

Table 5: Aggregate fuzzy weights for the criteria

Criteria	DM1	DM2	DM3	Aggregate Fuzzy Weight
C1	(7,9,9)	(5,7,9)	(5,7,9)	(5,7.66,9)
C2	(5,7,9)	(5,7,9)	(1,3,5)	(1,5.66,9)
C3	(3,5,7)	(5,7,9)	(7,9,9)	(3,7,9)

Step 3: Compute the fuzzy decision matrix

The linguistic ratings of the alternatives are transformed into fuzzy ratings, using the table 2, as shown in table 6.

The fuzzy decision matrix for the alternatives $(\tilde{D})$ is constructed using the following relation:

$$\tilde{D} = \begin{array}{c} \\ B_1 \\ B_2 \\ \ldots \\ B_m \end{array} \begin{array}{c} \begin{matrix} c_1 & c_2 & \ldots & c_n \end{matrix} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \ldots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \ldots & \tilde{x}_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \ldots & \tilde{x}_{mn} \end{bmatrix} \end{array}$$

Table 6: Aggregate fuzzy weights for alternatives

S. No.	Environmental	Social	Economic
B_1	(5,7,9)	(7,9,9)	(3,5,7)
B_2	(7,9,9)	(7,9,9)	(1,3,5)
B_3	(3,5,7)	(3,5,7)	(5,7,9)
B_4	(5,7,9)	(5,7,9)	(1,3,5)
B_5	(3,5,7)	(1,3,5)	(7,9,9)
B_6	(1,3,5)	(1,1,3)	(5,7,9)
B_7	(3,5,7)	(3,5,7)	(5,7,9)
B_8	(5,7,9)	(3,5,7)	(3,5,7)
B_9	(5,7,9)	(7,9,9)	(1,1,3)
B_{10}	(1,3,5)	(1,3,5)	(7,9,9)
B_{11}	(5,7,9)	(5,7,9)	(5,7,9)
B_{12}	(7,9,9)	(7,9,9)	(5,7,9)

Step 4: Normalize the fuzzy decision matrix

The raw fuzzy weights presented in table 6 are normalised using a linear scale transformation to bring the various criteria scales onto a comparable scale.

The normalized fuzzy decision matrix $\tilde{R}$ shown in table 7 is computed as:

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n}, \quad i = 1, 2, \ldots, m; \quad j = 1, 2, \ldots, n$$

Where $\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right)$ and

$$c_j^* = \max_i \{c_{ij}\} \text{ .... (Benefit or Importance Criteria)}$$

Table 7: Normalised alternatives

S. No.	Environmental	Social	Economic
c_j^*	9	9	9
B_1	(0.56,0.78,1)	(0.78,1,1)	(0.33,0.56,0.78)
B_2	(0.78,1,1)	(0.78,1,1)	(0.11,0.33,0.56)
B_3	(0.33,0.56,0.78)	(0.33,0.56,0.78)	(0.56,0.78,1)
B_4	(0.56,0.78,1)	(0.56,0.78,1)	(0.11,0.33,0.56)
B_5	(0.33,0.56,0.78)	(0.11,0.33,0.56)	(0.78,1,1)
B_6	(0.11,0.33,0.56)	(0.11,0.11,0.33)	(0.56,0.78,1)
B_7	(0.33,0.56,0.78)	(0.33,0.56,0.78)	(0.56,0.78,1)
B_8	(0.56,0.78,1)	(0.33,0.56,0.78)	(0.33,0.56,0.78)
B_9	(0.56,0.78,1)	(0.78,1,1)	(0.11,0.11,0.33)
B_{10}	(0.11,0.33,0.56)	(0.11,0.33,0.56)	(0.78,1,1)
B_{11}	(0.56,0.78,1)	(0.56,0.78,1)	(0.56,0.78,1)
B_{12}	(0.78,1,1)	(0.78,1,1)	(0.56,0.78,1)

Step 5: Compute the weighted normalized matrix

The weighted normalized matrix $\tilde{V}$ for criteria is computed by multiplying the weights $(\tilde{w}_j)$ of evaluation criteria with the normalized fuzzy decision matrix $\tilde{r}_{ij}$ (Table 8) as:

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n}, \quad i = 1, 2... m; \quad j = 1, 2... n$$

where $\tilde{v}_{ij} = \tilde{r}_{ij}(.)\tilde{w}_j$

Table 8: Weighted normalised alternatives

S. No.	Environmental	Social	Economic
B_1	(2.78,5.96,9)	(0.78,5.66,9)	(1,3.89,7)
B_2	(3.89,7.66,9)	(0.78,5.66,9)	(0.33,2.33,5)
B_3	(1.67,4.26,7)	(0.33,3.14,7)	(1.67,5.44,9)
B_4	(2.78,5.96,9)	(0.56,4.40,9)	(0.33,2.33,5)
B_5	(1.67,4.26,7)	(0.11,1.89,5)	(2.33,7,9)
B_6	(0.56,2.55,5)	(0.11,0.63,3)	(1.67,5.44,9)
B_7	(1.67,4.26,7)	(0.33,3.14,7)	(1.67,5.44,9)
B_8	(2.78,5.96,9)	(0.33,3.14,7)	(1,3.89,7)
B_9	(2.78,5.96,9)	(0.78,5.66,9)	(0.33,0.78,3)
B_{10}	(0.56,2.55,5)	(0.11,1.89,5)	(2.33,7,9)
B_{11}	(2.78,5.96,9)	(0.56,4.40,9)	(1.67,5.44,9)
B_{12}	(3.89,7.66,9)	(0.78,5.66,9)	(1.67,5.44,9)
FPIS(B+)	(9,9,9)	(9,9,9)	(9,9,9)
FNIS(B-)	(0.56,0.56,0.56)	(0.11,0.11,0.11)	(0.33,0.33,0.33)

Step 6: Compute the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS)

FPIS and FNIS of alternatives are computed in the last two rows of the table 8 as follow:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, ...\tilde{v}_n^*), \quad \text{where } \tilde{v}_j^* = \max_i \{v_{ij3}\}$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, ...\tilde{v}_n^-), \quad \text{where } \tilde{v}_j^- = \min_i \{v_{ij3}\},$$

i = 1, 2. . . m; j = 1, 2, . . . , n

Step 7: Compute the distance of each alternative from FPIS and FNIS

The distance of each weighted alternative from the FPIS and the FNIS is computed as shown in tables 9 and table 10 respectively. The distance between them is given by following relation using vertex method

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2]}$$

$$d_i^* = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^*) \qquad d_i^- = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^-) \qquad i = 1, 2 . . . m$$

Table 9: Distance for GM barriers (from FPIS)

Distance	C1	C2	C3
d(B1,B+)	3.999	5.124	5.601
d(B2,B+)	3.051	5.124	6.722
d(B3,B+)	5.173	6.148	4.705
d(B4,B+)	3.999	5.551	6.722
d(B5,B+)	5.173	6.967	4.018
d(B6,B+)	6.554	7.855	4.705
d(B7,B+)	5.173	6.148	4.705
d(B8,B+)	3.999	6.148	5.601
d(B9,B+)	3.999	5.124	7.718
d(B10,B+)	6.554	6.967	4.018
d(B11,B+)	3.999	5.551	4.705
d(B12,B+)	3.051	5.124	4.705

Table 10: Distance for GM barriers (from FNIS)

Distance	C1	C2	C3
d(B1,B-)	5.924	6.063	4.382
d(B2,B-)	6.651	6.063	2.934
d(B3,B-)	4.334	4.349	5.863
d(B4,B-)	5.924	5.705	2.934
d(B5,B-)	4.334	3.004	6.421
d(B6,B-)	2.810	1.695	5.863
d(B7,B-)	4.334	4.349	5.863
d(B8,B-)	5.924	4.349	4.382
d(B9,B-)	5.924	6.063	1.563
d(B10,B-)	2.810	3.004	6.421
d(B11,B-)	5.924	5.705	5.863
d(B12,B-)	6.651	6.063	5.863

Step 8: Compute the closeness coefficient (CC_i) of each alternative

The closeness coefficient (CC_i) represents the distances to the FPIS and the FNIS simultaneously. The aggregate closeness coefficient of each alternative is shown in table 11. Also, the individual perspective closeness coefficients are shown in table 12.

Table 11: Closeness coefficient for alternatives (aggregate)

Barrier	d_i^*	d_i^-	CC_i
B_1	14.724	16.369	0.526
B_2	14.896	15.648	0.512
B_3	16.027	14.545	0.476
B_4	16.272	14.563	0.472
B_5	16.159	13.759	0.460
B_6	19.114	10.368	0.352
B_7	16.027	14.545	0.476
B_8	15.748	14.655	0.482
B_9	16.841	13.550	0.446
B_{10}	17.539	12.234	0.411
B_{11}	14.255	17.492	0.551
B_{12}	12.880	18.577	0.591

Table 12: Closeness coefficient for alternatives (individual perspective)

Code	CC_i (Environmental Perspective)	CC_i (Social Perspective)	CC_i (Economic perspective)
B_1	0.597	0.542	0.439
B_2	0.686	0.542	0.304
B_3	0.456	0.414	0.555
B_4	0.597	0.507	0.304
B_5	0.456	0.301	0.615
B_6	0.300	0.178	0.555
B_7	0.456	0.414	0.555
B_8	0.597	0.414	0.439
B_9	0.597	0.542	0.168
B_{10}	0.300	0.301	0.615
B_{11}	0.597	0.507	0.555
B_{12}	0.686	0.542	0.555

Step 9: Rank the alternatives (i.e. barriers)

Prioritization of GM barriers according to the CC_i in decreasing order and the alternative with the highest closeness coefficient for final implementation is presented in table 13. The best alternative is closest to the FPIS and farthest from the FNIS.

Table 13: Closeness coefficient for alternatives (aggregate)

Code	Barrier	CC_i	Priority
B_{12}	Lack of awareness/information	0.591	1
B_{11}	Technological risk	0.551	2
B_1	Weak legislation	0.526	3
B_2	Low enforcement	0.512	4
B_8	Trade-offs	0.482	5
B_7	Low customer demand	0.476	6
B_3	Uncertain future legislation	0.476	6
B_4	Low public pressure	0.472	8
B_5	High short-term costs	0.460	9
B_9	Low top management commitment	0.446	10
B_{10}	Lack of organizational resources	0.411	11
B_6	Uncertain benefits	0.352	12

4. Results and Discussion

The graphical representation of importance of GM barriers obtained through fuzzy TOPSIS MCDM is shown in figure 1.

The study reveals that 'lack of awareness/information' in terms of insufficient information about the available technology choices and limited access to green literature or the information diffusion is the top ranked (1/12) barrier which hinder the implementation of GM in the industry. The study further reveals that 'technological risk' of the immature and unproven technology in terms of state-of-the-art technologies, materials, operations and industrial processes are often not easily and cheaply available to the company is second (2/12) most important barrier followed by 'weak legislation' in terms of complete absence of environmental laws or complex and ineffective environmental legislations at third position (3/12).

'Low enforcement' in terms of ineffective enforcement of environmental laws because of lack of organizational infrastructure, lack of trained human resources, cost of monitoring and dishonest officials, etc. has been ranked at fourth position (4/12) followed by 'trade-offs' in terms of outsourcing of dirty manufacturing work to developing or emerging markets where environmental laws are less stringent which reduces company’s share of emissions at fifth position (5/12). These barriers are not most important barriers, but are important as the legislation is not fully enforced and the manufacturing is shifted to countries with less stringent legislations.

The results further reveals that 'low customer demand', 'uncertain future legislation', 'low public pressure', and 'high short term costs' are at number 6,7,8, and 9 respectively. These four barriers have moderate importance in emerging countries like India.

'Lack of top management commitment', 'lack of organizational resources', and 'uncertain benefits' are among the least impact/important barriers to GM implementation. Companies particularly SMEs or MSMEs in emerging and developing countries show resistance to change even for the adoption of better manufacturing and management systems.

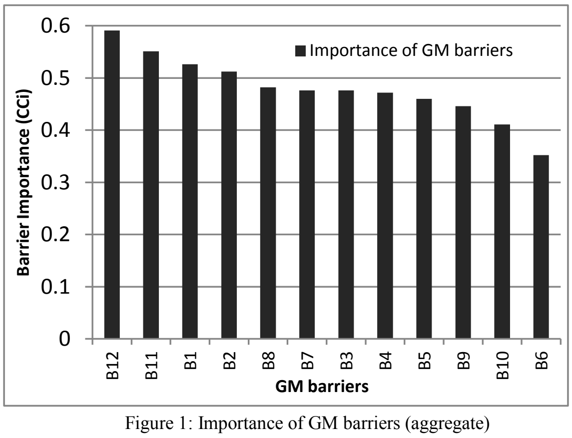

Figure 1: Importance of GM barriers (aggregate)

Figure 2 provides the comparison of the importance of GM barriers among all the three perspectives individually i.e. environmental, social and economic.

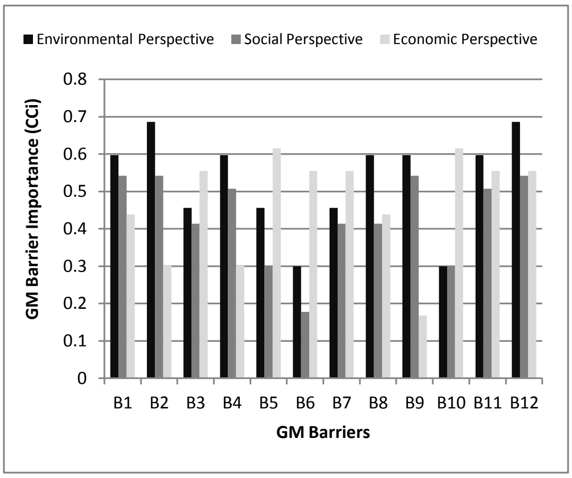

Figure 2: Importance of GM barriers (individual perspectives)

5. Conclusions and Recommendations

The prioritization of twelve barriers to green manufacturing based on environmental, social and economic perspectives using inputs from experts in environmental, social and economic background respectively.

Fuzzy TOPSIS methodology yielded interesting results in terms of importance of GM barriers. The following suggestions and recommendations are proposed, based on the study, as an action plan for the decision/policy makers in government and industry to implement GM:

- The government should also include the awareness/ information campaigns as a obligatory activity for NGOs funded by government. To educate the community as a whole about the importance of environment friendlier products and processes, which can further generate more customer demand of green products.
- The government should invest more in science and technology to promote the development of indigenous green technologies in association with technical institutions of the country. The government should also facilitate the industry to import and implement proven technologies.
- The government should also put in place required environmental legislation at par with technologically developed countries to force the industry to invest in green technologies.
- The government should build and upgrade necessary infrastructure to enforce the environmental legislation effectively.
- The Government should also ensure the uniform environmental legislation in all states/regions of the country to stop companies from shifting the dirty manufacturing to places with lax environmental legislation.

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