Vol. XIV & Issue No.03 March - 2021
INDUSTRIAL ENGINEERING JOURNAL

ANALYSING THE BARRIERS AND SOLUTIONS TO PROMOTE ENVIRONMENTALLY CONSCIOUS MANUFACTURING USING AHP-PROMETHEE HYBRID FRAMEWORK

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Abstract:

Conventional manufacturing system focuses only on economic growth but with the increase in pollution and rapid depletion of natural resources, there is a need of adopting Environmentally Conscious Manufacturing (ECM), which gives the utmost importance to environment along with and economy and society comes. Adopting ECM may act as solution of the problem of increasing pollution level and scarcity of natural resources. But for adopting ECM, there is a requirement of full understanding of various barriers in attaining the goal of ECM and their solutions to remove or to lower the impacts of barriers otherwise it may lead to heavy losses. In this research study efforts have been made to identify and analyse various solutions to adopt ECM with respect to various barriers. With the help of literature and inputs from experts', total eleven solutions and ten barriers have been identified and analysed using AHP-PROMETHEE hybrid framework. Results revealed that strong and clear policies formation along with its execution, firm focused producer towards environment issues, designing the products for remanufacturing, training for skill enhancement of the workforce and financial support for technological up gradation are the top rated solutions to be adopted to promote the concept of ECM. The final results will be very helpful in adopting ECM.

Keywords: Environmentally Conscious Manufacturing; Barriers; Solutions; AHP; PROMETHEE.

1. INTRODUCTION

With the increase in industrialization, natural resources have been utilized with very fast rate in the name of productivity and competitiveness (Tilwankar et al., 2019). This problem can be overcome by adopting Environmentally Conscious Manufacturing (ECM) (Ülkü and Hsuan; 2017). ECM differs from conventional production system in many ways as ECM focus on producing products that are economic, environment friendly and beneficial for society while conventional production system is focused only on economic aspect (Thongplew et al., 2017; Cohen, 2020).

Tseng et al. (2017) suggested that ECM should be considered in business decision-making models. For solving the problems of Indian manufacturing industries, techniques with minimum energy consumption and minimum wastage, should be adopted (Singh et al., 2018). These goals can be achieved by adopting ECM but adopting ECM is not an easy task for any organisation as it may result in heavy losses, if not adopted properly (Orji, 2019). Proper knowledge of various barriers in adoption of ECM along with their solutions is required for successful implementation of ECM (Jayaram and Avittathur, 2015). Therefore there is a need of identifying and analyse the various challenges related to adoption of ECM and their solutions for attaining the goal of ECM (Mangla et al., 2017; Caldera et al., 2019). So in the present study efforts have been made to identify and analyse the various barriers and solutions to be adopted for ensuring ECM. All the solutions are prioritized on the basis of experts' input to help policy makers and managers in decision making and promoting ECM. The objectives of this research study are:

- To identify various barriers in adoption of ECM.
- To calculate the weights of various identified barriers, which are treated as criteria over which alternatives are ranked; and
- To identify and analyse various solutions to be adopted for ensuring ECM.

To identify the various barriers for attaining the goal of ECM is the first objective of the present work. As a result of literature survey and inputs from experts', ten barriers have been identified. The second objective of calculating the weights of barriers is achieved by using AHP methodology. The next objective is to identify and analyse the various solutions to be adopted for ensuring ECM. This goal is achieved by using PROMETHEE methodology. The final result gives the prioritised list of all the barriers and solutions. The knowledge of the barriers and solutions will help governments and managers in making decisions to attain ECM.

2. FINDINGS FROM LITERATURE AND EXPERTS' INPUT

This section presents the various findings from literature and experts' input. In this research work various barriers in adopting ECM and various solutions to remove the barriers or to lower the impact of the barriers have been identified. All these solutions have been analysed by using PROMETHEE MCDM methodology by taking barriers as criterion. The weights of criteria (barriers) have been calculated by using AHP MCDM methodology.

2.1 Barriers in adopting Environmentally Conscious Manufacturing

For smooth adoption of ECM, it is significant to understand the various barriers in adopting ECM. In order to identify the various barriers from literature, an exhaustive survey was conducted and finally ten barriers have been identified. All the ten barriers are given in the Table 1.

Table 1: Barriers in adopting ECM

S. No.	Specific Barrier	Notation	References
1	Poor adoption of remanufacturing and reusing	B1	Singhal et al. (2019); Sawhney (2020)
2	Less skilled workforce	B2	Gandhi et al. (2018)
3	Communication gap	B3	Dhull and Narwal (2018)
4	Heavy Taxes	B4	Wu et al. (2018)
5	Poor policy framing and lack in implementation	B5	Al-maskari et al. (2019)
6	Higher cost of sustainable products	B6	Jones et al. (2011)
7	Ignorance of management towards ECM	B7	Luthra et al. (2015)
8	Poor financial support	B8	Luthra et al. (2019)
9	Lack in technological up gradation	B9	Bhatia et al. (2018)
10	Over consumption of natural resources	B10	Schmidt and Matthies (2018); Shah et al. (2019)

1.2 Solutions to Remove Barriers or to Lower the Impact of Barriers

For implementing ECM smoothly, proper knowledge of various solutions to remove barriers or to lower the impact of barriers is also very essential. In this research study efforts have been put to identify the solutions either to remove the barriers or to lower the impacts of barriers. From the literature and expert's input, eleven solutions have been identified and ranked by using PROMETHEE MCDM technique. All the eleven barriers are given in the Table 2.

Table 2: Solutions to remove barriers or to lower the impact of barriers

S. No.	Specific Solution	Notation	References
1	Strong and clear policies formation	S1	Al-maskari et al. (2019)
2	Strict execution of policies formed	S2	Moktadir et al. (2018)
3	Training for skill enhancement of the workforce	S3	Luthra et al. (2019)
4	Designing the products for remanufacturing	S4	Xiang and Ming (2011); MacArthur (2013)
5	Promoting Electronic sales and purchase	S5	Adjei-Bamfo et al. (2019); Ibem et al. (2020)
6	Financial support for technological up gradation	S6	Bhatia et al. (2018); Bhandari et al. (2019)
7	Firm focused producer towards environment issues	S7	Ojo and Fauzi (2020); Yang and Lin (2020)
8	Good Information sharing system	S8	Waqas et al. (2018)
9	Tax relaxation on remanufactured products	S9	Tian (2018); Mi and Coffman (2019)
10	Waste management	S10	Rodrigues and Borges (2020)
11	Policies formation for cost reduction of sustainable products	S11	Jones et al. (2011)

3. METHODOLOGY

In this research study, all the solutions have been ranked with the help of PROMETHEE methodology by taking barriers as criterion. The weights of criteria (barriers) have been calculated by using AHP MCDM methodology based on the ratings of experts. First of all the weight of criteria (barriers) have been calculated using AHP methodology. Then all the solutions are ranked using PROMETHEE methodology with respect to the criteria (barriers). All these techniques (AHP and PROMETHEE) are explained as under.

3.1 Analytical Hierarchy Process (AHP)

For calculating the weights of various barriers, AHP

methodology has been adopted. AHP is MCDM technique developed by Thomas L. Saaty in 1970s (Saaty, 1980). It is used for analysing complex problems and making the **decisions** (Hembram and Saha, 2018; Zhou and Yang, 2020). The step by step procedure is given below:

Step 1: Formulation of the objective of work. The objective of the present work is to evaluate the barriers in adoption of ECM by using AHP methodology.

Step 2: Construct pair wise comparison matrix. Each factor is given weight with respect to the other factor in the matrix. A scale adopted for getting ratings from experts is given as below: ('1'- Equally significant, '3'-Fairly significant, '5'-Medium significant, '7'-Strongly significant, '9'-Most significant and '2,4,6,8'-In between Values).

Step 3: To check the consistency. For checking the consistency of matrix, first calculate the maximum Eigen value and then calculate the value of consistency index (CI) by using the equation:

$$CI = (\lambda_{max} - n) / (n - 1)$$

After calculating the value of CI, calculate the ratio of CI and RI (Random index), which is known as Consistency Ratio (CR). If the value of CR comes under 0.1, then the matrix is considered to be consistent.

By following the above steps, relative weights of all the barriers can be found.

3.2 Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE)

In this research study, PROMETHEE methodology has been applied to analyse the various solutions to adopt the ECM. PROMETHEE is known as one of the most efficient outranking method (Singh et al., 2020). It is a best suitable methodology available for ranking, which involves 'm' alternatives Ai, i = 1…..…m, to be evaluated on 'n' criteria Cj, j = 1…….n (Macharis et al., 2004; Singh et al., 2020). PROMETHEE methodology can be applied by using the steps as given below (Brans et al., 1986; Macharis et al., 2004; Jiang et al., 2020; Singh et al., 2020).

Step 1: Construct the decision Matrix R = $[r_{ij}]_{m\times n}$ where r_{ij} represents the evaluation of ith alternative on jth criteria using the scale as '1'-Least significant, '2'-Less significant, '3'-Equally significant, '4'-Fairly significant, '5'-Medium significant, '6'-Strongly significant, '7'-Most significant.

Step 2: Normalise the matrix R using linear normalisation given as

$$R_{norm} = [\tilde{r}_{ij}]_{m\times n}, \text{ where}$$

$$\tilde{r}_{ij} = \begin{cases} (r_{ij} - \min_{i\in I}\{r_{ij}\})/(\max_{i\in I} r_{ij} - \max_{i\in I} r_{ij}) \\ \text{if jth criterion is a beneficial criterion;} \\ (r_{ij} - \min_{i\in I}\{r_{ij}\})/(\max_{i\in I} r_{ij} - \max_{i\in I} r_{ij}) \\ \text{if jth criterion is a cost criterion.} \end{cases}$$

Step 3: Calculate the aggregate preference index as:

$$\pi(A_i, A_i^{'}) = \frac{1}{k_i}\sum_{j\in j_i} P_j(A_i, A_i^{'})$$

Step 4: Compute the leaving flow and entering flows as follows:

$$\phi^{+}(A_i) = \frac{1}{m-1}\sum_{\substack{i'=1 \\ i\neq i'}}^{m} \pi(A_i, A_{i'})\ i \in I$$

$$\phi^{-}(A_i) = \frac{1}{m-1}\sum_{\substack{i'=1 \\ i\neq i'}}^{m} \pi(A_{i'}, A_i)\ i \in I$$

Step 5: Calculate the value of net flow as:

$$\phi(A_i) = \phi^{+}(A_i) - \phi^{-}(A_i), i \in I$$

Step 6: Rank the alternatives based on the value of net flow. Alternative with higher value of net flow is considered as better alternative.

4. DATA COLLECTION AND DATA ANALYSIS

In this study, data collection has been done from literature survey and inputs from experts'. This data is analysed by using AHP-PROMETHEE hybrid framework. The outcomes are given in sub-sections as below.

1.1 Collection of Experts' Input

A panel of five experts was formed for getting the experts' input. All the five experts are highly skilled professionals in related research domain. Out of selected five experts, three experts were from the middle level management and one from top level management of manufacturing industry based in the northern region of India and one expert was from academics having vast research exposure in the same domain. All the experts from industry are engineering graduates from reputed institutes of national importance and the expert from academia is doctorate by education. All the three experts from middle management of industry are having more than 10 years of experience in design and development and the expert from top management is having more than 20 years of experience. The expert from academia is working as associate professor in reputed engineering institution. After formation of experts' panel, all the identified barriers and solutions were presented to the experts for validation. As a cumulative result of literature review and inputs from experts, ten barriers and eleven solutions have been finalised. After finalisation of barriers and solutions, a questionnaire was developed and shared with the experts to collect the input from experts. The responses received from all the experts, were analysed using AHP-PROMETHEE hybrid framework.

1.2 Analysis and Findings

In this work, first of all the weights of criteria (barriers) have been calculated using AHP methodology. Then all the solutions to adopt the ECM have been ranked using PROMETHEE methodology with respect to the criteria (barriers). AHP methodology has been applied as discussed in section 3.1. Pair wise comparison matrix made by experts, were checked for consistency. The CR value for matrix lies under 0.1, which ensures the consistency of the matrix. Further the calculations were made for finding the weights of various criteria as given below in Table 3.

[Table 3 about here]

The above Table 3 shows the comparison matrix (Aggregated for all five experts) for various barriers. After finding the weights of criteria, comparison matrix for ranking the various solutions to adopt the ECM (Aggregated for all five experts) was formulated as given in Table 4.

[Table 4 about here]

Further decision matrix for ranking the various solutions to adopt the ECM based on aggregated preference function has been shown in Table 5.

[Table 5 about here]

Finally, the solutions are prioritised with the help of PROMETHEE methodology and ranking of solutions has been shown in Table 6.

[Table 6 about here]

5. DISCUSSION OF FINDINGS

The above Table 3 shows the weightage and ranking of the barriers in attaining the goal of ECM. The result shows that Poor policy framing and lack in implementation, Ignorance of management towards sustainable production, Higher cost of sustainable products, Less skilled workforce, Poor financial support and Lack in technological up gradation are the top rated barriers followed by Communication gap, Heavy taxes, Higher cost of sustainable products and Over consumption of natural resources. All these barriers must be handled very carefully for successful adoption of ECM. Further to remove or to reduce the effects of these barriers, eleven solutions have been identified from literature and expert's input. All these solutions were ranked using PROMETHEE methodology. The above Table 6 shows the ranking of the solutions to be adopted for attaining the goal of ECM. The ranking shows that Strong and clear policies formation along with its execution, Firm focused producer towards environment issues, Designing the products for remanufacturing, Training for skill enhancement of the workforce, Financial support for technological up gradation are the top rated solutions to be adopted to promote the concept of ECM. Next come Good information sharing system, Waste management, policies formation for cost reduction of sustainable products, Tax relaxation on remanufactured products and Promoting Electronic sales and purchase sustainable products. Adopting all these solutions can help in adopting ECM successfully.

Table 3: Comparison matrix for various barriers

Principal Eigen value = 10.234, CR= 0.018

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	Relative Weight	Rank
B1: Poor adoption of remanufacturing and reusing	1	1	3	4	0.33	7	1	2	3	8	0.146	3
B2: Less skilled workforce	1	1	3	3	0.25	4	0.5	1	2	5	0.105	4
B3: Communication gap	0.33	0.33	1	1	0.17	2	0.25	0.5	1	4	0.048	7
B4: Heavy Taxes	0.25	0.33	1	1	0.14	1	0.2	0.5	0.5	3	0.038	8
B5: Poor policy framing and lack in implementation	3	4	6	7	1	9	2	5	5	9	0.309	1
B6: Higher cost of sustainable products	0.14	0.25	0.5	1	0.11	1	0.17	0.25	0.33	1	0.025	9
B7: Ignorance of management towards ECM	1	2	4	5	0.5	6	1	2	3	8	0.167	2
B8: Poor financial support	0.5	1	2	2	0.2	4	0.5	1	1	4	0.08	5
B9: Lack in technological up gradation	0.33	0.5	1	2	0.2	3	0.33	1	1	3	0.061	6
B10: Over consumption of natural resources	0.12	0.2	0.25	0.33	0.11	1	0.12	0.25	0.33	1	0.02	10

Table 4: Comparison matrix for ranking the various solutions to promote ECM

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
S1: Strong and clear policies formation	6.2	5.8	5.2	4.8	7	4.8	6	6	6	5.2
S2: Strict execution of policies formed	6	6	5.2	4.2	6.8	5	5	5.2	4.8	5
S3: Training for skill enhancement of the workforce	5	6	4.8	5.2	4.8	4.6	5	4.2	4	4.8
S4: Designing the products for remanufacturing	6	5.8	4.2	4	4	5	5	5	4	4.8
S5: Promoting Electronic sales and purchase	5	4.2	3.4	4	4.2	6	4.2	4	4	4.6
S6: Financial support for technological up gradation	6	5	5.2	5	4	5	5	5	4	5
S7: Firm focused producer towards environment issues	6	6	4	4	6.8	5	5	5	5.2	4.6
S8: Good Information sharing system	5	5	5	5.2	4	5	4.8	5	5	4.8
S9: Tax relaxation on remanufactured products	5	6	4.4	4	3	4.2	4	6	4.2	6
S10: Waste management	5	4.8	6	6	4	4.8	5	4	4	5
S11: Policies formation for cost reduction of sustainable products	6.8	5.8	4	3.2	3.8	3.2	4	2.8	2.8	5

Table 5: Decision matrix for ranking the various solutions to promote ECM based on aggregated preference function

Aggregated preference function	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S 10	S 11	Leaving Flow
S 1	----	0.16904	0.44879	0.42963	0.69805	0.44412	0.19700	0.52941	0.63862	0.56189	0.61621	0.473280528
S 2	0.01345	----	0.28967	0.27224	0.54067	0.29488	0.03558	0.38399	0.49422	0.41444	0.47683	0.321601659
S 3	0.01709	0.01357	----	0.10082	0.26813	0.12284	0.03391	0.13683	0.24979	0.11464	0.28470	0.134236969
S 4	0.00178	0	0.10468	----	0.28387	0.04666	0.00654	0.14447	0.24900	0.16623	0.20744	0.121071297
S 5	0.01071	0.00892	0.0125	0.02437	----	0.02437	0.00892	0.02437	0.12547	0.02616	0.13633	0.0402175
S 6	0.0045	0.01085	0.11492	0.03489	0.27209	----	0.04143	0.10436	0.27734	0.11956	0.23947	0.12194529
S 7	0.00178	0.00762	0.28205	0.25084	0.51271	0.29750	----	0.37625	0.48436	0.41707	0.45459	0.308482176
S 8	0.00721	0.01738	0.04632	0.05011	0.18951	0.02177	0.03760	----	0.19380	0.05751	0.24086	0.086211726
S 9	0.02309	0.03428	0.06595	0.06131	0.19727	0.10143	0.05238	0.10047	----	0.13809	0.15981	0.093412546
S 10	0.03105	0.03919	0.03765	0.06323	0.18265	0.02834	0.06978	0.04887	0.22278	----	0.24103	0.096461346
S 11	0.04866	0.06488	0.14885	0.06774	0.25612	0.11155	0.07060	0.19552	0.2078	0.20433	----	0.137609915
Entering Flow	0.01593	0.03657	0.15514	0.13552	0.34011	0.14935	0.05537	0.20445	0.31432	0.22199	0.30573	

Table 6: Ranking of solutions

Solutions	Leaving Flow	Entering Flow	Net Flow	Rank
S 1	0.4732805	0.0159364	0.4573441	1
S 2	0.3216017	0.0365786	0.2850231	2
S 3	0.134237	0.1551424	-0.020905	5
S 4	0.1210713	0.1355228	-0.014452	4
S 5	0.0402175	0.3401105	-0.299893	11
S 6	0.1219453	0.149351	-0.027406	6
S 7	0.3084822	0.0553789	0.2531033	3
S 8	0.0862117	0.2044596	-0.118248	7
S 9	0.0934125	0.3143227	-0.22091	10
S 10	0.0964613	0.2219968	-0.125535	8
S 11	0.1376099	0.3057313	-0.168121	9

6. CONCLUSION

In this research study, efforts have been made to develop the understanding of the barriers and solutions that can help in attaining the goal of ECM. As a result of literature review and inputs from experts', eleven solutions to adopt ECM have been identified and ranked by using PROMETHEE methodology with respect to barriers as criteria. It was found that strong and clear policies should be formed and implemented and producer should be firm focused towards environment issues. Emphasis should be given on designing the products for remanufacturing and providing the training for skill enhancement of the workforce. The ranked solutions may be very helpful in better understanding the concept of ECM. The understanding of various barriers and solutions will help government, policy makers and managers in adopting ECM. This work will also be fruitful for the researchers and academicians in their research work.

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