Ranking of Barriers to Green Manufacturing Implementation in SMEs Using Best-Worst Method

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Abstract. Nature has provided us with limited resources on the earth, but the requirement is unlimited, one is fulfilled another will crop up. Modern manufacturing scenario and rough consumption of natural resources create huge challenges in front of human beings in the form of environmental degradation and wastage of material. The purpose of this study is to identify the barriers to green manufacturing (GM) from selected Small and Medium Enterprises (SMEs) in Delhi and NCR region and rank them as per their priority. An extensive literature review together with expert's opinion was done to identify the GM barriers. A newly developed approach known as Best-Worst method (BWM) was adopted for the ranking of identified GM barriers. This study identifies 21 barriers to GM implementation which are arranged into 5 main barriers for well understanding. Further, the findings of this study show that, “Lack of new technology facilities and processes”, “Lack of experts related to new technology”, “Lack of expertise training programs”, “High initial capital cost to implement GM” and “Weak Legislation” are top-five barriers that lead to difficulties in GM implementation in SMEs while least important observed barrier is “Not enough and understandable information”. Therefore this study provides knowledge about the green manufacturing barriers and their ranking most severe to less severe that is most important to less important and this study also provides a systematic way to sort out the barriers in GM implementation according to their priority. In the end, the study provides conclusions and some implication of the study as well as the scope for future research.

Keywords: Green Manufacturing, barriers, BWM, SMEs.

1. Introduction
Numerous researches have been done during the past few decades to control environmental degradation and several suggestions were proposed. The manufacturing sector is one of the major sector that is responsible for this degradation. Environmental and natural resource degradation is a huge challenge in front of human beings. In manufacturing sector, Small and Medium Enterprises (SMEs) are mostly responsible for the generation of industrial pollution as they are in huge numbers and still growing at a rapid pace. Therefore, government is...
intended to focus and assist them by developing guidelines for sustainable green environment. Still SMEs failed to act responsively due to growing new manufacturing scenario. Hence, the requirement for new methodologies emerges to endure this relentless challenge and support aggressiveness. To overcome these challenges, Green Manufacturing (GM) becomes a necessary and reliable manufacturing strategy as it can successfully save the quality of the environment and reduce the manufacturing wastes and enhance recycling (Prasad and Sharma, 2014). Therefore, GM is an idea of eco-friendly manufacturing effort which acts like eliminating the waste and pollution, recycling and reuse of materials, by re-defining the existing production process or system through research and process design. GM goals are also for conserving natural resources for future generations. Therefore, GM can be implemented in two different ways (Dani, 2018)

1. “The manufacturing of green products, particularly those used in renewable energy systems and clean technology equipment of all kinds.”
2. “The greening of manufacturing – reducing pollution and waste by minimizing natural resource use, recycling and reusing waste, and reducing emissions.”

Green products and green production techniques are competitive weapons. GM has also become a vehicle for long-term job creation in India. According to Goswami and Chaudhury, 2017, investment in green structure and sustainable power sector can develop around six million skilled and 2.5 million un-skilled jobs till 2020. The Union Ministry of New and Renewable Energy (MNRE) have announced a target of installing 175 giga watts (GW) of renewable energy capacity by March 2022. The Government of India has set a target of introducing 60 GW of wind control limit by 2022, against which 35 GW limit has just been introduced (MNRE, 2019). One major sector of green manufacturing is in the metals industries which can exceed expectations as in recycling and reusing waste materials. Several organizations and producer's are focused to forms set up for the group, reuse, and recycle scrap material i.e. gathering scrap in assigned canisters or boxes and reusing these materials, it additionally improve producer's main concern, support representative inspirations, and show social duties to the outside world (Dani, 2018). SMEs and micro and medium enterprises (MSMEs) represent 95 percent of the complete modern industrial movement in India and can assume an essential job creation.

From the above discussion it is clear that the GM implantation is mandatory for developing nations like India and SMEs are the backbone of these countries. Further, SMEs are the driving force behind the dynamic growth of any economy, therefore, they are working tirelessly to implementing GM strategies since effective implementation of GM will lead to gaining a competitive advantage over other and sustain in long run (Mathiyazhagan et al., 2014). But, SMEs face a lot of hindrances in implementing GM in their organizations. Thus, there is the strong need for SMEs to identify and categories GM barriers and rank them utilizing a robust multi-criteria decision-making (MCDM) technique so that these barriers can eliminate one by one according to their ranking order. Keeping in view on the above mentioned points, this study has the following objectives.

1. To identify the GM barriers in SMEs through literature review and expert’s opinion.
2. To categorize the identified GM barriers into different criterion and sub-criterion.
3. To rank the identified GM barriers of SMEs using best-worst method (BWM).

With these objectives keeping in mind, this research aims in identifying and ranking the barriers to GM implementation in SMEs with regards to an emerging economy like India. An
extensive literature review together with expert’s opinion has been done to identify barriers to GM implementation and from a robust MCDM technique called BWM created by Rezaei (2015) has been used to rank these barriers.

The remainder of this paper is organized in the following manner. In Section 2, an extensive literature review is done for the identification of possible barriers to GM implementation in SMEs. Section 3, discusses the research methodology. In section 4, result and analysis were done according to steps discussed in BWM. Section 5, presents the detail discussion on the present study. Section 6, presents the conclusions highlights the limitations of this study and discusses possible future scope.

2. Literature Review

Green manufacturing (GM) is a modern manufacturing strategy, recently it’s become profitable due to eco-friendly manufacturing activities, and have kept on still developing. GM involves the change of mechanical tasks in three different ways, (1) utilizing Green vitality, (2) creating and selling Green items and (3) utilizing Green procedures in business activities (Bhattacharya et al. 2011). Rapid consumption of natural resources, growing energy expenditure, increasing customer awareness about environmentally conscious products and the requirement for consistency with ecological enactment through the advancement of green procedures prompted the development of a GM strategy worldview (Gandhi et al., 2017). However, Indian SMEs are still struggling to implement GM strategies. SMEs have poor records when it comes to implementation of GM strategies. Therefore to finding the causes behind this, broad survey has been accomplished to explore the barriers to GM implementation in SMEs. Mittal et al. (2013) identified drivers and barriers to GM implementation in two dissimilar economies - a developed economy and a rising economy and have been approved by statistical analysis. Mittal and Sangwan (2014), in this paper the authors have identified 12 GM barriers and prioritize them according to Fuzzy theory based on ecological, social and financial points of view. Ghazilla et al. (2015), identified 39 drivers and 64 barriers which encourage and restrain the execution of GM strategies in Malaysian SMEs. Kumar et al. (2016), identified that GM strategies are difficult to actualize in Indian situation because of the presence of barriers, such as lack of top management commitment, expertise training program and fund. Majumdar and Sinha (2018), identified 12 important barriers to green supply chain management in Southeast Asian nations. Piyathanavong et al. (2019), identify 10 barriers related to the implementation of GM in Thai manufacturing strategies. These various studies and some other important studies conducted for GM implementation are summarised in Table 1.

Table 1. Previous GM studies found in literature review

| Researchers and years | Major findings                                                                                                                                                                                                 | Used Methodology                          |
|-----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|
| Mittal et al. (2013)  | In this study, drivers and hindrances to GM have been approved utilizing a factual examination of the information gathered through the poll study. This research has given a wide viewpoint on the drivers and hindrances to GM in two unique economies - a developed economy and a rising economy. | statistical analysis (Standard Deviation, Independent T-Test) |
| Authors | Description | Methodology |
|---------|-------------|-------------|
| Mittal and Sangwan (2014) | In this paper, the authors have identified 12 GM barriers and prioritize them according to Fuzzy theory based on natural, social and financial viewpoints. | Fuzzy TOPSIS |
| Ghazilla et al. (2015) | Total 39 drivers and 64 barriers were identified and analysed for GM in Malaysian SMEs. The drivers were classified into 7 categories and the obstructions are arranged into 8 categories. | Literature review and Delphi method |
| Kumar et al. (2016) | They conducted a study to identify the barriers of GLSPD and 21 barriers are identified from the literature review and then an ISM technique is applied. Further, MICMAC analysis was also done and found that 7 barriers are distinguished as driver hindrances, 9 as a reliant, five obstructions as linkage and no boundary as independent. | Literature review ISM approach |
| Gandhi et al. (2017) | They conducted a study to determine the drivers of incorporated lean and green manufacturing are chosen through writing survey and specialists' sentiments. In this investigation, 15 normal drivers are distinguished and among them 'top administration duty' is the most basic driver in the fruitful usage of LM and GM practices. | Fuzzy TOPSIS, Fuzzy SAW and Borda Methods |
| Xia et al. (2018) | The authors categorize barriers of Green technology adoption for enterprises into competence and psychology and then the skill class is investigated with three basic gatherings including individual, procedure, and acquirement and psychology is also sub-categorized into three groups as Individual barriers, Group barriers, and Social barriers. | AHP and Fuzzy set theory |
| Majumdar and Sinha (2018) | In this paper, the authors identify 12 important barriers to green supply chain management in southeast Asian nations. ISM is utilized to change over the impression of space specialists into an unmistakable organized guide which portrays the logical relationship among these barriers. | Literature Review, Survey Questionnaire ISM |
| Piyathanavong et al. (2019) | Authors identify 10 barriers for the execution of Green Manufacturing in the Thai manufacturing area and this paper grows our insight in the field of tasks and ecological manageability. | Survey Questionnaire |

After examining the recent papers on barriers to green manufacturing implementation, it is found that there is a lack of proper research in the context of the barriers to GM implementation in Indian SMEs, which should tell the barriers to GM implementation in a systematic way and there ranking based on their weights with the help of a robust and reliable MCDM technique.

Based on gaps identified, an extensive literature review (2010 to 2019) is done and many (around 43) barriers are identified and from several rounds of discussion with experts 21 are identified as most important barriers related to GM implementation in SMEs in Delhi and NCR region.
2.1 Most Important Identified Barriers to GM Implementation in SMEs and their Categorization

For well understanding it is necessary to categorize these 21 most important identified barriers into their proper related areas which will be known as main barriers. It is observe that these barriers can be categorised into five main barriers i.e. Management/organization related barriers (MO), Law / Legislation related barriers (LG), New technology related barriers (NT), Financial and other Fears related barriers (FF) and Information related barriers (IN). Element of main barriers will be known as sub-barriers. In this way schematic categorization is done according to their nature which is shown in Table 2

| Main Barriers | Sub-barriers | References |
|---------------|--------------|------------|
| Management / organization related barriers (MO) | Lack of expertise training program towards GM in SMEs (MO1) | Panizzolo et al. (2012), Mathiyazhaganet al. (2013) |
| | Lack of top management Commitment (MO2) | Murillo-Luna et al. (2011), Mittal et al. (2013), Kumar et al. (2015) |
| | Undeveloped organizational GM culture and absence of inspiration and support (MO3) | Govindan et al. (2014) |
| | Lack of green manufacturing thinking (MO4) | Reyes et al. (2014) |
| | High hesitation to convert traditional practices to GM or Difficulties in changing positive GM mentalities into activities (MO5) | Zhu et al. (2012a, b), Mittal et al.(2013), Mathiyazhagan et al. (2013), Mangla et al.(2017) |
| Law / Legislation related barriers (LG) | Weak Legislation (LG1) | Brammer et al. (2012), Zhu et al. (2012), Mittal et al. (2013) |
| | Uncertain Future Legislation (LG2) | Singh et al. (2012), Bey et al. (2013), Ghazilla et al. (2015), Mittal and Sangwan (2015), Luthra, et al. (2015), Ghazilla et al. (2015), Hojnik and Ruzzier (2016), Murillo-Luna et al. (2011), Ghazilla et al. et al. (2015) |
| | The absence government Support and policies to GM implementation (LG3) | |
| | Lack of Monitoring, Controlling, supporting and direction from administrative specialists on GM (LG4) | |
| New technology related barriers (NT) | Lack of new technology facilities and processes to support GM in SMEs (NT1) | Murillo-Luna et al. (2011 ), Ghazilla et al. (2015) |
| | Lack of experts related to new technology for GM implementation in SMEs (NT2) | Ghazilla et al. (2015) |
| | Risk of implementing new technology (NT3) | Ghazilla et al. (2015) |
| Financial and other Fears related barriers (FF) | Competition and uncertainty (FF1) | Mudgal et al. (2010), Luthra, et al. (2013), Johansson and Sundin (2014) |
|---------------------------------------------|----------------------------------|--------------------------------------------------------------------|
| Uncertain Benefits from GM implementation (FF2) | | Mittal et al. (2013) |
| Poor supplier commitment towards GM or Lack of green supplier (FF3) | | Mathiyazhagan et al. (2013), Luthra, et al. (2015b), Kumar, et al. (2015) |
| High initial capital cost to implement GM (FF4) | | Mudgal et al. (2010) |
| Absence of adaptability to change over to GM-based frameworks (FF5) | | Mudgal et al. (2010), Ghazilla et al. (2015) |
| Fear of failure (FF6) | | Jinzhou (2011) |
| Information related barriers (IN) | Inappropriate identification of GM activities, Data Collection, and Retrieval System (IN1) | Johansson and Sundin (2014), Luthra, et al. (2015) |
| Difficulties in obtaining GM/GT information for potential improvements (IN2) | | Murillo-Luna et al. (2011), Ghazilla et al. (2015) |
| Not enough and understandable information (IN3) | | Mangla et al., (2017) |

3. Research Methodology

For the ranking of GM barriers, the following methodology is followed. Initially, the GM barriers are identified through extensive literature review together with expert’s opinion. Through a detailed literature review, many (around 43) barriers were identified and for sorting them again discussion will be done among 6 experts (three from academic and three from SMEs) with questionnaires in which they rated all the 43 barriers on 5 points Likert scale as per their knowledge and experience. In which those barriers which were scored 2 or less than 2 on the Likert scale by at least 2 experts was removed for the next analysis. From this process, 21 GM barriers were remains as most important and finally, categorized these GM barriers into five main criterions which are called main GM barriers and elements of main barriers are called sub-barriers. After that, for the ranking of these GM barriers, a new MCDM technique called BWM (Best-Worst method) is used, which is given by J. Rezaei (2015). There are many MCDM techniques available (Talib and Rahman, 2015; Talib et al., 2011) like Analytical Hierachal Process (AHP), Analytical Network Process (ANP), Multi-Attribute Utility Theory (MAUT), Simple Multiple Attribute Rating Technique (SMART), Technique for order preference by Similarity to Ideal Solution (TOPSIS), Weighted Product Model (WPM), Weighted Sum Method (WSM), ViSeKriterijumska Optimizacija I Kompromiso Resenje (VIKOR), and Preference ranking organization method for enrichment evaluation (PROMETHEE) method, etc. to rank the GM barriers by calculating weights of the barriers but BWM is a very strong MCDM technique for pairwise comparison. BWM performs fundamentally superior to AHP as for the consistency proportion, and the other assessment criteria like least infringement, complete deviation, and congruity (J. Rezaei, 2015). The Best-Worst method is a recently developed robust optimization technique. The
BWM is a multi-criteria decision-making method that utilizes two vectors of pairwise comparisons to determine the weights of criteria. First, the best (for example most attractive, most significant), and the worst (for example least attractive, least significant) criteria are identified by the decision-maker, after which the best criterion is compared to the other criteria \([BO]\) and the other criteria to the worst criterion \([OW]\) using a no. on (1-9) scale (Rezaei-2015).

After that, a non-linear minmax model or linear minmax model is used to identify the weights such that the maximum absolute difference between the weight ratios and their corresponding comparisons is minimized. For the solution of non-linear minmax model, Interval Analysis is required which gives multiple optimal solutions and linear minmax optimization model gives unique solution from linear programming where it can be solved using any commercial software package (Best-Worst Method-Solver on Microsoft Excel solver).

Recently BWM has been used in a lot of contexts and areas all over the world among the researchers and industrialist such as Energy efficiency in buildings (Gupta et. al., 2017), Airports evaluation and ranking model(Shojaei et.al., 2017), Assessing the social sustainability of supply chains(Ahmadi et.al., 2017), Evaluating firms’ R&D performance (Negin and Rezaei, 2017), Efficiency of university-industry PhD projects (Negin and Rezaei, 2016), A group multi-criteria decision-making(Safarzadeh et.al., 2018), Measuring the relative importance of the logistics performance index indicators (Rezaei, et.al., 2018), etc.

3.1 Steps used to obtain the weights of GM barriers using BWM.

In BWM Rezaei proposed the following five steps.

**Step 1.** Identification of barriers to GM implementation in SMEs for analysis.

In this step, we identify and finalized the GM barriers through extensive literature review and experts opinion.

**Step 2.** From the finalized GM barriers identify the best (B) (e.g. the most desirable, the most important) and the worst (W) (e.g. the least desirable, the least important) GM barriers or decision criteria based on the decision-maker(s)/expert(s) opinion. Table 3 represents the best and worst criteria according to different expert’s choices.

**Step 3.** Experts are determining the preference of the best decision criterion (B) over all the other decision criteria, using a 9-point scale (numbers between 1 and 9; in which for no.1: B is equally important to \(j\), and for no.9: B is extremely more important than \(j\)). The result is a best-to-others (BO) vector as follows.

\[ A_B = (a_{B1}, a_{B2}, a_{B3}, \ldots, a_{Bn}) \]

Whereas \(a_{Bj}\) indicates the preference of the best criterion (B) over any criterion \(j\) and it is clear that \(a_{BB} = 1\).

**Step 4.** Now experts are also determining the preference of all the decision criteria over the worst criterion (W), using a 9-point scale (numbers between 1 and 9; in which for no.1: \(j\) is equally important to \(W\), and for no.9: \(j\) is extremely more important than \(W\)), which results in the others-to-worst (OW) vector as follows.

\[ A_W = (a_{1w}, a_{2w}, a_{3w}, \ldots, a_{nw})^T \]
Where $a_{W}$ indicates the preference of any criterion $j$ over the worst criterion $W$ and it is clear that $a_{W}=1$.

**Step5.** Find the optimal weights ($w_{1}^{*},w_{2}^{*},w_{3}^{*},\ldots,w_{n}^{*}$) for all the GM barriers.

To obtain the weights of GM barriers we consider a linear model of BWM because we want to increase the efficiency of the decision-making process along with simple calculation and to obtain a unique optimal solution.

The optimal weights should be determined such that the maximum absolute differences for all $j$ can be minimized for

$$\{ |w_{B} - a_{B}w_{j}| \cdot |w_{j} - a_{jw}w_{w}| \}$$

or equivalently:

$$\text{Min } \max_{j} \{ |w_{B} - a_{B}w_{j}| \cdot |w_{j} - a_{jw}w_{w}| \}$$

s.t.

$$\sum_{j} w_{j} = 1$$

$$w_{j} \geq 0, \text{ for all } j$$

(1)

The problem (1) is rewritten as a linear optimization problem as follows:

$$\text{Min } \xi^{L}$$

s.t.

$$|w_{B} - a_{B}w_{j}| \leq \xi^{L}, \text{ for all } j$$

$$|w_{j} - a_{jw}w_{w}| \leq \xi^{L}, \text{ for all } j$$

$$\sum_{j} w_{j} = 1$$

$$w_{j} \geq 0, \text{ for all } j$$

(2)

The problem (2) is a linear optimization problem with a unique solution, values for optimal weights ($w_{1}^{*},w_{2}^{*},w_{3}^{*},\ldots,w_{n}^{*}$) and the optimal objective function value $\xi^{L}$ are obtained by solving it.

$\xi^{L}$ or $\text{Ksi}$, is the consistency, it values close to zero show a high level of consistency of the pairwise comparisons provided by the decision-maker(s)/expert(s) (Rezaei, 2015)

For more accurate results we use excel solver for calculating the weights of GM barriers and consistency of GM barriers. Best and Worst barriers identified by three SMEs managers and three academic experts are represented in Table 3.
Table 3. Expert’s Chosen for the selection of GM barriers

| Green manufacturing main barriers | Sub-barriers | No. of experts Considered as best | No. of experts Considered worst |
|-----------------------------------|--------------|-----------------------------------|---------------------------------|
| Management/organization related barriers (MO) | MO1          | 4                                 |                                 |
|                                   | MO2          | 1                                 |                                 |
|                                   | MO3          | 1                                 |                                 |
|                                   | MO4          | 5                                 |                                 |
|                                   | MO5          | 1                                 |                                 |
| Law / Legislation related barriers (LB) | LG1          | 5                                 |                                 |
|                                   | LG2          | 4                                 |                                 |
|                                   | LG3          | 2                                 |                                 |
|                                   | LG4          | 1                                 |                                 |
| New technology related barriers (NT) | NT1          | 6                                 |                                 |
|                                   | NT2          |                                   |                                 |
|                                   | NT3          | 6                                 |                                 |
| Financial and other Fears related barriers (FF) | FF1          | 5                                 |                                 |
|                                   | FF2          | 1                                 |                                 |
|                                   | FF3          | 1                                 |                                 |
|                                   | FF4          | 4                                 |                                 |
|                                   | FF5          | 1                                 |                                 |
|                                   | FF6          |                                   |                                 |
| Information related barriers (IB) | IN1          | 6                                 |                                 |
|                                   | IN2          |                                   | 1                               |
|                                   | IN3          |                                   | 5                               |

4. Results and Analysis

The analysis was done according to the steps discussed in BWM. For calculating the weights of GM barriers and consistency of GM barriers Best-Worst Method-Solver is to be used. Table 4 represents the pairwise comparison of the main GM barriers and from Table 5 to 9 represents the pairwise comparison of sub-barriers to GM implementation. Figures show their weights respectively. Table 10 shows the Cumulative weights of all the main barriers and sub-barriers to GM implementation and the Global weight of sub-barriers are calculated by multiplying the sub-barriers weights with their respective main barriers weights. Finally, according to the global weights of all the sub-barriers, their ranking has been done. Highest value of the weight gets the first rank and the lowest weight is in the last position e.g. in Table 10, NT1 gets the maximum global weight i.e. 0.239 so that it obtains the first rank and IN3 get minimum global weight i.e. 0.004 so it obtains the last rank. The Ksi shows to what extent the results are reliable, the Ksi value closer to zero is better e.g. management/organization related barriers have minimum Ksi i.e. 0.066 this represent that in this category the barriers are closer to equivalent importance with respect to worst barriers and that’s why we can say that, this category barriers have been high consistency to each other.

4.1 Determination of the optimal weights of main GM barriers using BWM The experts individually made pairwise comparisons and suggested the preferences of the “Best” over other barriers and the preferences of other barriers over the “Worst” using number from 1 to 9
which led to the formulation of BO and OW vectors as shown in Tables 4 and figure-1 shows their weight calculated from equation (2) or from Best-Worst Method-Solver on Microsoft Excel and their consistency respectively.

**Table 4.** Comparison of main GM barriers

| BO | Management/organization related barriers (MO) | Law / Legislation related barriers (LG) | New technology related barriers (NT) | Financial and other Fears related barriers (FF) | Information related barriers (IN) |
|----|---------------------------------------------|----------------------------------------|-------------------------------------|---------------------------------|----------------------------------|
| Best barrier: NT | 2 | 4 | 1 | 3 | 7 |
| OW | Worst barrier: IN |
| Management/organization related barriers (MO) | 6 |
| Law / Legislation related barriers (LG) | 4 |
| New technology related barriers (NT) | 8 |
| Financial and other Fears related barriers (FF) | 5 |
| Information related barriers(IN) | 1 |

![Weights](image)

**Figure 1.** Weights of Main Barriers

It is quite evident from figure-1 that the value of Ksi which represents the consistency of comparisons is very close to zero indicating highly reliable weights of the barriers. Figure-1 further reveals that “New technology related barriers (NT)” and “Information related barriers (IN)” are the most important and the least important barriers, respectively.

**4.2 Determination of the relative weights of the sub-category enablers using BWM**

For the determination of the relative weights of the sub-barriers, experts individually identified the “Best” and the “Worst” barriers and indicated the preference best to other and other to worst using a number between 1 and 9 leading to the generation of BO and OW vectors. These vectors were used in Equation (2) which was solved to produce optimal weights of the sub-barriers and their consistency (Ksi) for each sub-barrier of each main barrier. Pairwise comparison of different sub-barriers are represented in their respective Tables 5 to 9 and their calculated weight with their consistency (Ksi) are represented in figure from (2-6). All tables and figures can be understood as discussed above.
Table 5. Pairwise comparison for Management/organization related barriers

| BO | MO1 | MO2 | MO3 | MO4 | MO5 |
|----|-----|-----|-----|-----|-----|
| Best barrier: MO1 | 1   | 4   | 3   | 9   | 2   |

| OW | MO1 | MO2 | MO3 | MO4 | MO5 |
|----|-----|-----|-----|-----|-----|
| Worst barrier: MO4 | 8   | 4   | 5   | 1   | 3   |

Figure 2. Weights of Management/organization related barriers

Ksi = 0.06635077

Table 6. Pairwise comparison for Law / Legislation related barriers

| BO | LB1 | LB2 | LB3 | LB4 |
|----|-----|-----|-----|-----|
| Best barrier: LG1 | 1   | 8   | 5   | 2   |

| OW | LG1 | LG2 | LG3 | LG4 |
|----|-----|-----|-----|-----|
| Worst barrier: LG2 | 7   | 1   | 4   | 5   |

Figure 3. Weights of Law / Legislation related barriers

Ksi = 0.10699588
Table 7. Pairwise comparison for new technology-related barriers

| BO   | NT₁ | NT₂ | NT₃ |
|------|-----|-----|-----|
| Best barrier: NT₁ | 1   | 2   | 5   |

| OW       | Worst barrier: NT3 |
|----------|--------------------|
| NT₁      | 5                  |
| NT₂      | 4                  |
| NT₃      | 1                  |

![Weights](image)

**Figure 4.** Weights of new technology-related barriers

Table 8. Pairwise comparison for Financial and other Fears related barriers

| BO   | FF₁ | FF₂ | FF₃ | FF₄ | FF₅ | FF₆ |
|------|-----|-----|-----|-----|-----|-----|
| Best barrier: FF₄ | 9   | 4   | 3   | 1   | 2   | 5   |

| OW       | Worst barrier: FF₁ |
|----------|--------------------|
| FF₁      | 1                  |
| FF₂      | 3                  |
| FF₁₃     | 5                  |
| FF₄      | 8                  |
| FF₅      | 7                  |
| FF₆      | 4                  |

![Weights](image)

**Figure 4.** Weights of Financial and other Fears related barriers
Figure 5. Weights of Financial and other Fears related barriers

Table 9. Pairwise comparison for Information related barriers

|   | IB₁ | IB₂ | IB₃ |
|---|-----|-----|-----|
| BO |     |     |     |
| OW |     |     |     |

Best barrier: IN₁

Worst barrier: IN₃

Kₜ = 0.18181818

Figure 6. Weights of Information related barriers

4.3 Determination of the global weights of the sub-barriers

Table 10 shows the global weights of all sub-barriers to GM implementation. The Global weights of sub-barriers are calculated by multiplying the sub-barriers weights with their respective main barriers weights. Finally, according to the global weights of all the sub-barriers, their ranking has been done. Highest value of the global weight gets the first rank and the lowest global weight is in the last position i.e. NT₁ gets first rank and IN₃ gets last rank.

Table 10. Cumulative table for weights of the main barriers and the sub-barriers of GM implementation

| Main barriers | Weights of main barriers | Sub - barriers | Local Weights of sub-barriers | Global weight of sub-barriers | Ranking |
|---------------|--------------------------|----------------|------------------------------|-------------------------------|---------|
| Management/organization related barriers (MO) | 0.247 | MO₁ 0.445 | **0.110** | 3 |  |
|               | MO₂ 0.128 | MO₃ 0.171 | 0.042 | 8 |  |
|               | MO₄ 0.047 | MO₅ 0.209 | 0.052 | 6 |  |
| Category                                      | Name       | Weight | Rank |
|----------------------------------------------|------------|--------|------|
| Law / Legislation related barriers (LG)      | LG1        | 0.510  | 0.063 | 5    |
|                                             | LG2        | 0.058  | 0.007 | 19   |
|                                             | LG3        | 0.123  | 0.015 | 16   |
|                                             | LG4        | 0.309  | 0.038 | 9    |
| New technology related barriers (NT)         | NT1        | 0.575  | 0.239 | 1    |
|                                             | NT2        | 0.325  | 0.135 | 2    |
|                                             | NT3        | 0.100  | 0.042 | 7    |
| Financial and other Fears related barriers (FF) | FF1      | 0.039  | 0.006 | 20   |
|                                             | FF2        | 0.113  | 0.019 | 14   |
|                                             | FF3        | 0.150  | 0.025 | 13   |
|                                             | FF4        | 0.383  | 0.063 | 4    |
|                                             | FF5        | 0.225  | 0.037 | 10   |
|                                             | FF6        | 0.090  | 0.015 | 15   |
| Information related barriers (IN)            | IN1        | 0.636  | 0.031 | 12   |
|                                             | IN2        | 0.272  | 0.013 | 17   |
|                                             | IN3        | 0.091  | 0.004 | 21   |

5. Discussion

Best–Worst method is applying for ranking of barriers to green manufacturing. Table 10 shows the weights of whole main barriers as well as sub-barriers, the rankings are obtained on their respective global weights. Total five main barriers were concluded and among them, New-technology related barrier (NT) is ranked first through analysis. This result shows the past research conformance (Xia et al., 2018) In which they found that the new green technology application was generally thought for green manufacturing. therefore, they study the technical compatibility with its operational system consisted of competence and psychology section and established an identification framework and indicators system of barriers in the way of green technology adoption. Another research shows that insufficient knowledge about the available new technology choices and limited access to green literature is the top-ranked barrier which hinders the implementation of GM in the industry (Mittal and Sangwan, 2014). Some other researches show that top basic obstructions which impede the execution of GM in SMEs have insufficient R&D support because of the absence of assets and specialized ability concerning green practices (Ghazilla et al., 2015). Majumdar and Sinha (2018), is also indicated that The intricacy of the green procedure and framework plan which is a technology-related hindrance is the most elementary obstruction which prevents the GM implementation in material and attire store network of Southeast Asia. In this way, these results demonstrate the importance of our study and make them valid.

Management/organization related barriers (MO) obtain the second rank among the main barriers. This result shows the past research conformance with Gandhi et al., (2017), in which they observed that top administration responsibility is prescribed as the most significant driver for the usage of GM in Indian SMEs. Government of India has just begun management development program (MDP) as one of the segments of the national manufacturing competitiveness program (NMCP) to improve the decision-making ability of managers of SMEs and to enhance profitability/productivity. Financial and other Fears related barriers (FF) obtain the third rank among main GM barriers. Therefore, financial support is necessary for
small organizations to GM implementation because it has High initial capital cost (Gandhi et al., 2017). Financial and other Fears related barriers are also due to Weak market positions for GM-based products or Low Customer Demand is generally found among customers, they do not aware the benefit of GM based product, they think that the GM based product is costly (Mudgal et al., 2010). But cooperation between advertisement and political inspiration can change purchase and utilization, the behaviour of consumers'. These combined efforts are more effective towards green attitude; possibly these combine efforts could create a better environment for all consumers. These combine efforts extensively affected consumers' purchase, usage, and recycling intentions and attitude. (Kidwell et. al. 2013)

Among 21 sub-barriers, Lack of new technology facilities and processes to support GM (NT1) is ranked first and second rank is also related to new technology its indicate that for GM implementation our concentration is to be on developing new technology and to fulfil the required experts related to new technology(Ghazilla et al.(2015). Lack of expertise training program is the third most important sub-barriers which is also the most important barrier in the Thai manufacturing organization (Piyathanavong et al., 2019). After implementing GM it may become a major barrier (Panizzolo et al., 2012; Mathiyazhagan et al., 2013). High initial capital cost to implement GM (FF4) is the fourth major sub-barrier, this barrier plays an extensive role when we want to initiate implementing GM in our organization (Mudgal et al., 2010). Weak Legislation (LG1) is the fifth major sub-barrier to GM implementation, 'weak legislation' in terms of complete absence of environmental laws or complex and ineffective environmental legislations play effective role towards dirty manufacturing specially in Indian SMEs so the Government ought to likewise guarantee the uniform natural enactment in all states/areas of the nation to prevent organizations from moving the messy manufacturing to places with remiss ecological performance (Mittal, et al., 2013).

6. Conclusions, Limitations and Future Research

The manufacturing sector is one of the vital components for developing the national economy. Therefore every country is engaged in developing the manufacturing sector but the limited natural resources and environmental degradation pose very tough challenges in front of human beings. To overcome these challenges a new manufacturing strategy was developed which is known as GM. However, the implementation of GM in SMEs is delayed due to barriers. Neither there are any systematic arrangements of these GM barriers nor any powerful method is applied for their ranking, is presented in any literature. To eliminate these barriers, a systematic understanding and their prioritization are required. To address these gaps, this study has developed a broad framework to identify GM barriers in SMEs and through using a strong MCDM technique named as Best-Worst method is used to rank these barriers. The structure was created with the assistance of extensive literature review and experts opinion. Total twenty-one (21) barriers are identified which are categorized into five (5) main barriers according to their nature and for well understanding. Then Best-Worst analysis is done on these barriers to rank them. The results of this analysis show that “Lack of new technologies facilities and processes” is found to be most important barrier followed by "Lack of experts related to new technology", "Lack of expertise training program", "High initial capital cost" and "Weak Legislation" related barriers. Therefore, the studies show that technological development is mandatory for implementing GM. The execution of GM is conceivable just with teamed up endeavours of government and industry in a vital manner by alleviating the GM barriers.
Although this study is done on a broad level it has several limitations. The barriers originated from various manufacturing divisions. This may have biased the results, therefore, it should be possible to see the effects of the current examination with comparative manufacturing segmentation. In this study, BWM is used for ranking GM barriers but there are other MCDM techniques like VIKOR, AHP, Fuzzy TOPSIS, MAUT, SMART, PROMETHEE, etc. can also be used to think about the outcomes for any progressions. Further, this study can be fertilized by taking a large number of SMEs and to use statistical tools for analyse the findings. The sensitivity analysis can be directed to break down the effect of variation in the weights of the barriers.

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