

Review on multi-criteria decision analysis in sustainable manufacturing decision making

Anbesh Jamwal¹, Rajeev Agrawal¹, Monica Sharma¹, Vikas Kumar^{2,3}

¹Department of Mechanical Engineering, Malaviya National Institute of Technology, J.L.N. Marg, Jaipur, Rajasthan-302017 (India)

²Faculty of Accounting, Ton Duc Thang University, Ho Chi Minh City, Vietnam

³Bristol Business School, University of the West of England, Bristol, UK

ABSTRACT

At present sustainable development, assessment of sustainable manufacturing practices, and prioritization of barriers, drivers, and indicators have become complex due to the involvement of existing benchmarks like social, economical, technical, and environmental. Literature review available on sustainable manufacturing practice assessments which considers all three dimensions is relatively limited. Recently, in sustainable manufacturing decision making, approaches to evaluate sustainable manufacturing practices have used both quantitative and qualitative data. This study aims to present a systematic review of multi-criteria decision making (MCDM) applications in sustainable manufacturing. In the present study papers available in the Scopus database were reviewed on the applications of different MCDM techniques in the sustainable manufacturing area. The study highlights how the manufacturing industries can benefit from MCDM techniques in decision making. This review article develops insights into various multi-criteria decision-making techniques progress made by considering the sustainable manufacturing applications over MCDM methods. An extensive review in the sphere of sustainable manufacturing has been performed by considering the Scopus database and utilizing MCDM techniques. It is found that most of the studies available in the sustainable manufacturing (SM) area are based on fuzzy-based single model approaches.

Keywords: Sustainable manufacturing; sustainable development; MCDM; barriers; drivers; indicators.

1. INTRODUCTION

The manufacturing sector is playing a vital role in the development of the global economy by supplying goods and services which have a great influence on the economy and society of developing and developed nations. Manufacturing products manufactured by various manufacturing processes result in the emission of many toxic pollutants and hazardous gases which lead to the harmful effect on both society and the environment (Joung et al., 2013). At present, industries are under pressure from both NGOs and other social organizations to reduce the negative impact of manufacturing processes on the environment and society which can improve the employee's health and safety (Walker et al., 2008). These issues can be solved by adopting environmentally conscious manufacturing in the industries. Adoption of sustainable manufacturing (SM) practices in an organization can help to increase resource efficiency and reduce wastes while conserving energy (King & Lenox, 2009). However, industries of developing nations are facing an issue in SM adoption due to a lack of proper frameworks, assessment of SM practices, and evaluation of barriers, indicators, and drivers (Wang et al., 2015). Evaluation of SM practices is a key operational task for manufacturing industries in developing nations. Manufacturing industries must consider economic, social, and environmental dimensions in their manufacturing practices to achieve sustainability in their organizations (Gimenez et al., 2012).

The research in the SM practices is driven by several drivers, indicators, and enablers which includes the adoption of mathematical practices and methodologies for assessment purpose and smooth implementation (Rahman et al., 2019). Consequently, in past few years, multi-criteria decision tools have become popular which can help to structure and support such types of decisions in manufacturing industries (Khalili & Duecker, 2013). Typically, when industries require or choose SM practices some specific requirements are introduced. Therefore, to meet this objective different selection methods with model flexibility with different applications are needed this can help in the smooth implementation of SM practices (Bhatt et al., 2020). Assessment and evaluation of SM practices are increasing interest in the manufacturing industries. This area involves the selection of SM practices, evaluation of drivers, barriers, and indicators of SM (Malek & Desai, 2020; Rostamzadeh et al., 2015). Recently established research work has utilized the SM practices selection which considers environment protection

issues (Chege & Wang, 2020; Moktadir et al., 2020). The effective way to manage the organization environment policy is by linking with sustainable practices in industries i.e. through prioritization of drivers and indicators (Whitehead, 2016). A review of applications of multi-criteria decision making techniques (MCDM) in different areas has been carried out by several researchers including sustainable energy planning (Pohekar & Ramachandran, 2004), sustainable energy decision making (Wang et al., 2009), forest management and planning (Ananda & Herath, 2009), supplier evaluation and selection (Ho et al., 2010), green supplier evaluation and selection (Govindan et al., 2015). However, to date, none of the review studies have reported the applications of MCDM in SM. Existing studies report on the MCDM application in a particular area but an overview of that particular area with study mapping is not discussed. To fill this research gap we have conducted a systematic literature review for MCDM applications in SM. In the present study, we have discussed the research progress of MCDM applications in SM and identified the research gaps. Based on the findings an MCDM based framework is proposed at the end of the study and its implications are being highlighted. The research question (RQ) to explore the area of MCDM applications in SM and the research objectives (RO) are as follows:

RQ: What are the current research progress and future research agendas in MCDM applications for SM?

To address the research question, a set of objectives are proposed as follows;

RO1: To identify and collate the studies focused on investigating the MCDM applications for SM.

RO2: To highlight the weaknesses and strengths of existing MCDM techniques for SM.

RO3: To understand how industries can take benefits from the MCDM applications in SM practices.

RO4: To propose a MCDM based framework for SM practices.

This study is one of the earliest studies that identify the research progress and gaps in MCDM applications for SM. We identify various indicators, challenges, and enablers to SM that have been prioritized and evaluated with MCDM techniques. This will help researchers, practitioners, and policymakers to understand the different types of indicators, challenges, and enablers to SM

in different regions and different industrial sectors. This study further reviews paper from top journals, top-cited articles, and top institutes to provide a more in-depth review of MCDM applications in SM. Finally, based on the findings of our study, we have proposed a conceptual framework which discusses how industries can take advantage of MCDM applications in SM.

The next sections of the paper present an overview of SM practices and various definitions available of SM given by authors. Section 3 presents a research methodology adopted for a systematic literature review. Section 4 represents Multi-criteria decision analysis. Section 5 presents the findings and discussions based on the systematic literature review. Section 6 presents the proposed research framework with its implications. Section 7 presents the conclusion and limitations of our study.

2. SUSTAINABLE MANUFACTURING PRACTICES

In the present time, SM practices are adopting by various manufacturing industries in both developed and developing nations (Wang et al., 2019). The implementation level of SM practices depends on factors such as type of industry, size of the industry, and type of product (Gupta et al., 2015). In the developing nations, the concept of environment-conscious manufacturing with the consideration of sustainability dimensions is new as compared to developed nations like the USA, UK, and Germany (de Sousa Jabbour et al., 2018; Pang & Zhang, 2019). SM focuses on minimizing or eliminating the negative impact of manufacturing processes by the adoption of eco-efficient practices which includes waste minimization and new technologies (Yogesh Bhatt et al., 2020; Haapala et al., 2011; Malek & Desai, 2020). Over the years researchers have proposed many definitions in the area of SM. For example, (Melnik & Smith, 1996) defined SM as the manufacturing which minimizes the negative impact of manufacturing on the environment and increase resource efficiency. de Ron (1998) stated that SM focused on waste elimination in production and processing by adopting new environmental technologies. Fleischmann et al. (2000) defined SM is the creation of non-polluting products, conserve both natural resources and energy, as well as these products are economical and safe for the employees working in the organizations and consumers. Maxwell & van der Vorst (2003) defined SM is focused on the use of natural resources for designing the industrial systems. Zangeneh et al. (2009) defined SM

minimize both environment impact and waste. Jayal et al. (2010) defines SM practices helps in pollution prevention. Dubey et al.(2016) defined SM as world class manufacturing which helps to achieve manufacturing excellence. Bhanot et al. (2015) defined SM as the manufacturing practices which help to reduce waste and conversation of energy while increasing the resource efficiency. Malek & Desai(2020) defined SM as the manufacturing process aims to reduce negative environment impacts from both products and processes. SM with its all pillars and objectives is shown in Figure 1.

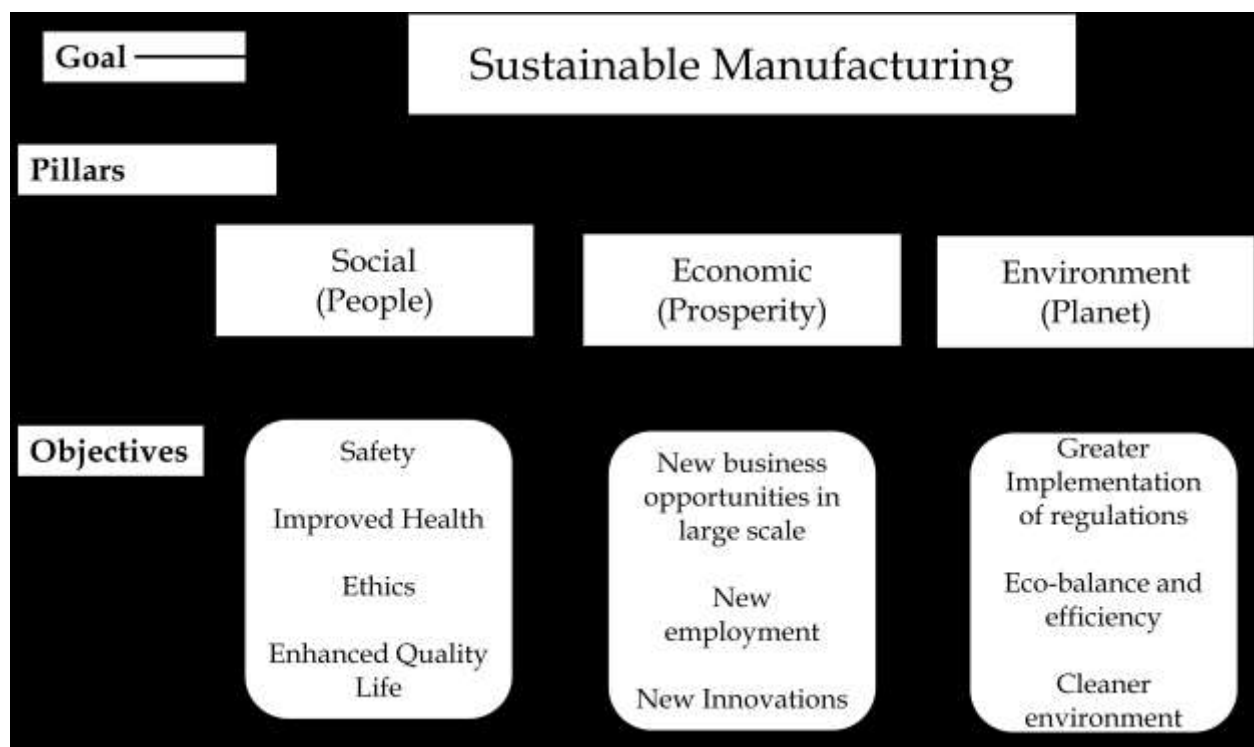


Figure 1: Goal, Pillars, and objectives of SM.

3. RESEARCH METHODOLOGY

Literature reviews are known as valuable comprehensive studies that are used for research investigation in emergent fields to identify areas for future research guidance and direction

(Rowley & Slack, 2004). A systematic literature review is a suitable approach to organize, synthesize and identify research scopes and opportunities with the understanding of research problems and limitations based on studies published before in a particular research area (Abdirad & Krishnan, 2020; Tesch da Silva et al., 2020). A systematic literature review can be defined as:

“An efficient technique for hypothesis testing, for summarising the results of existing studies, and for assessing consistency among previous studies; these tasks are clearly not unique to medicine” (Petticrew, 2001).

SLR approaches have been applied in different research domains (Biggi & Giuliani, 2020; Van Cutsem et al., 2017). However, MCDM application in SM is an emerging research area that has still many research gaps. A large number of scientific research articles are available in various databases i.e. Web of Science, Google Scholar, and Scopus. But these research articles are not fully accessible to policymakers or practitioners (Antony et al., 2020). Identification of relevant literature and research gaps is a time-consuming process that is not practically possible for practitioners. In this study, we have followed the systematic literature review approach to map the research progress in MCDM application for SM. As Tranfield et al.(2003) discussed, there are large numbers of articles are available on various scientific databases which discussed the new research opportunities in a particular research area. However, recent studies published in the area of SM have discussed the research gaps and future opportunities. However, the applications of MCDM in this area is not discussed in these studies. For instance, Wang et al. (2009) discussed the research opportunities for MCDM applications in sustainable renewable energy by considering 147 articles. Pohekar & Ramachandran (2004) discussed the applications of MCDM techniques to sustainable energy planning with 104 articles. Govindan et al. (2015) discussed the research opportunities for MCDM applications in green supplier selection by considering 33 papers published between 1999-2011.

By considering previously published studies on MCDM applications in different research areas it is evident that systematic literature review is an effective approach to identify the research progress and identify new research scopes in a particular research area. Generally, a systematic literature review is composed of three main stages that are discussed below and shown in Figure 2.

Stage 1-Planning the review: In this stage scope of the study is defined. The planning stage is considered as a critical stage in SLR because literature range and subject discrimination are defined in this stage only. This stage helps to identify what has been covered and what has not been covered in MCDM applications for SM. A research protocol recommended by (Tranfield et al., 2003) has been followed which is discussed in Table 1:

Table 1: Research protocol for Systematic literature review

Research Protocol	Description
Database	The Scopus database is considered for the present study. Scopus is the largest database that consists of research articles, conference papers, and book chapters.
Language	English Only
Time-period	2000-2020
Search fields	Keywords, article title, or abstract
Search terms	“Sustainable manufacturing” OR “Green manufacturing” AND phrase in Title, Abstract, and Keywords as “MCDM” OR “AHP” OR “TOPSIS” OR “DEMATEL” OR “ANP” OR “BWM” OR “VIKOR” OR “PROMETHEE” OR “MAUT” OR “MOORA” OR “MAVT” OR “SWARA”.
Inclusion criteria	<ol style="list-style-type: none"> 1. The articles selected only if it is related to sustainability, Sustainable manufacturing, or Green manufacturing. The article should discuss the MCDM applications. 2. The article should mention the use of keywords mentioned in search terms. 3. Both the terms “MCDM” AND “Sustainable manufacturing” OR “Green manufacturing” should be used to support the challenges, enablers, and research trends in the particular research area.
Exclusion criteria	<ol style="list-style-type: none"> 1. Papers not related to SM, editorial items, conference reviews, undefined and duplicate articles. 2. A paper must include the Search keywords in its Abstract, Title, or Keywords and full text for articles are not available. 3. The presented definitions are not related to Sustainability or Sustainable manufacturing. 4. A paper doesn't mention the search terms and in which these terms are used as: <ol style="list-style-type: none"> a) Only as examples

	<ul style="list-style-type: none"> b) Only discussed as future scope c) Only used in keywords or abstract without the proper research theme.
Data analysis and synthesis	In this study, we have analyzed articles based on MCDM,

Stage 2- Conducting a review: In the second stage we have used the relevant search strings to shortlist the article collection shown in Table 1. As discussed by Tranfield et al.(2003) we have only included those articles which meet the inclusion criteria. The detailed description of inclusion and exclusion for articles is discussed in Table 1. Next, we have considered only Journal articles and conference papers. As we found that some of the articles from the peer-reviewed conference were in the most cited articles on the Scopus database. To provide a more holistic view of SM we have considered conference articles from reputed publishers. Further, the final refinement of articles is done by reading the abstracts and keywords of each article.

Stage 3- Reporting and Dissemination: In this stage finding from the literature review is presented in each MCDM category. We have also discussed the various research themes in the MCDM category. Further, we have discussed the different criteria, factors, barriers, and enablers discussed in the MCDM related studies. This will help the researchers to get an idea about the different factors considered in past studies. Based on SLR, we have proposed a research framework for MCDM application in SM which is presented in the last section of the paper with implications for researchers and implications for policymakers and practitioners.

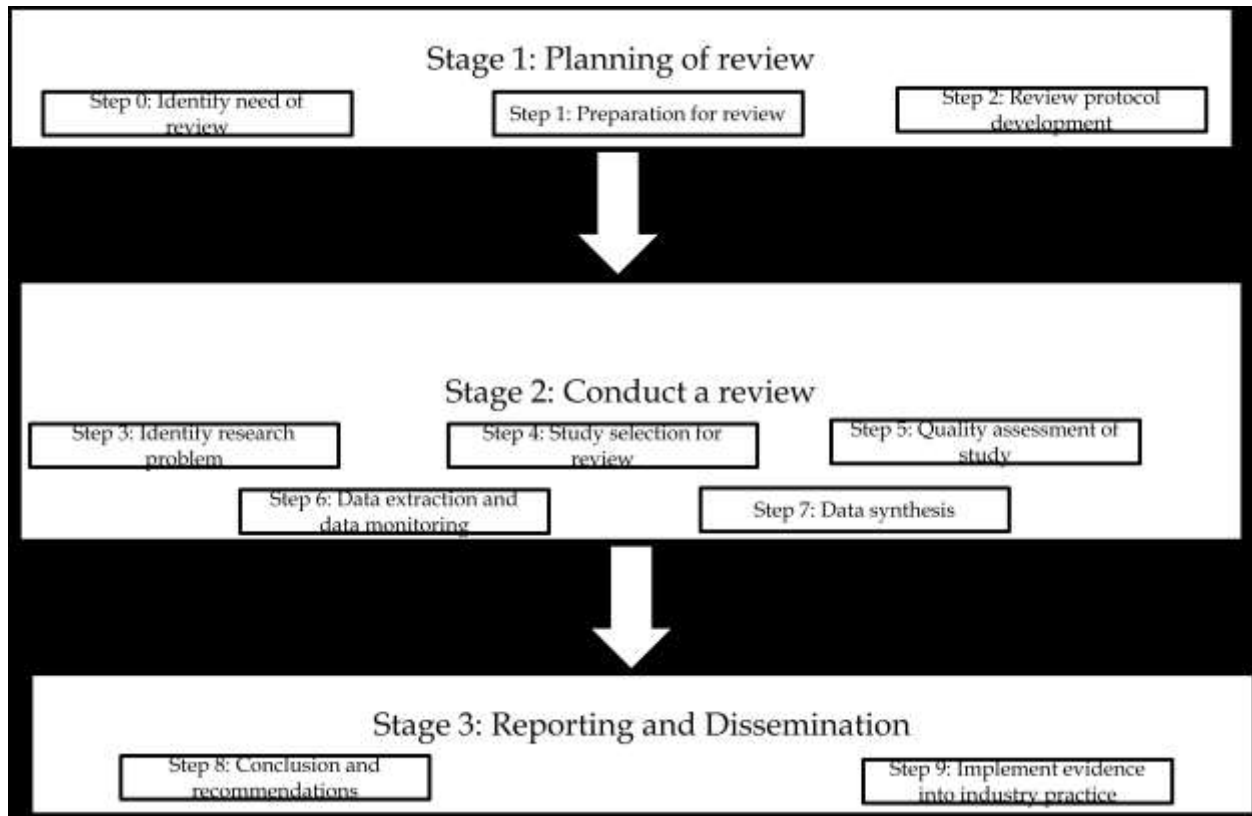


Figure 2: Main steps for systematic literature review

The research flow chart considered for the present study for article extraction and framework development is shown in Figure 3. In the Initial search total of 172 articles were found which reports about the MCDM applications in SM but after exclusion criteria presented in Table 1 and removing irrelevant studies by reading their abstracts and titles total of 78 articles were finalized for review.

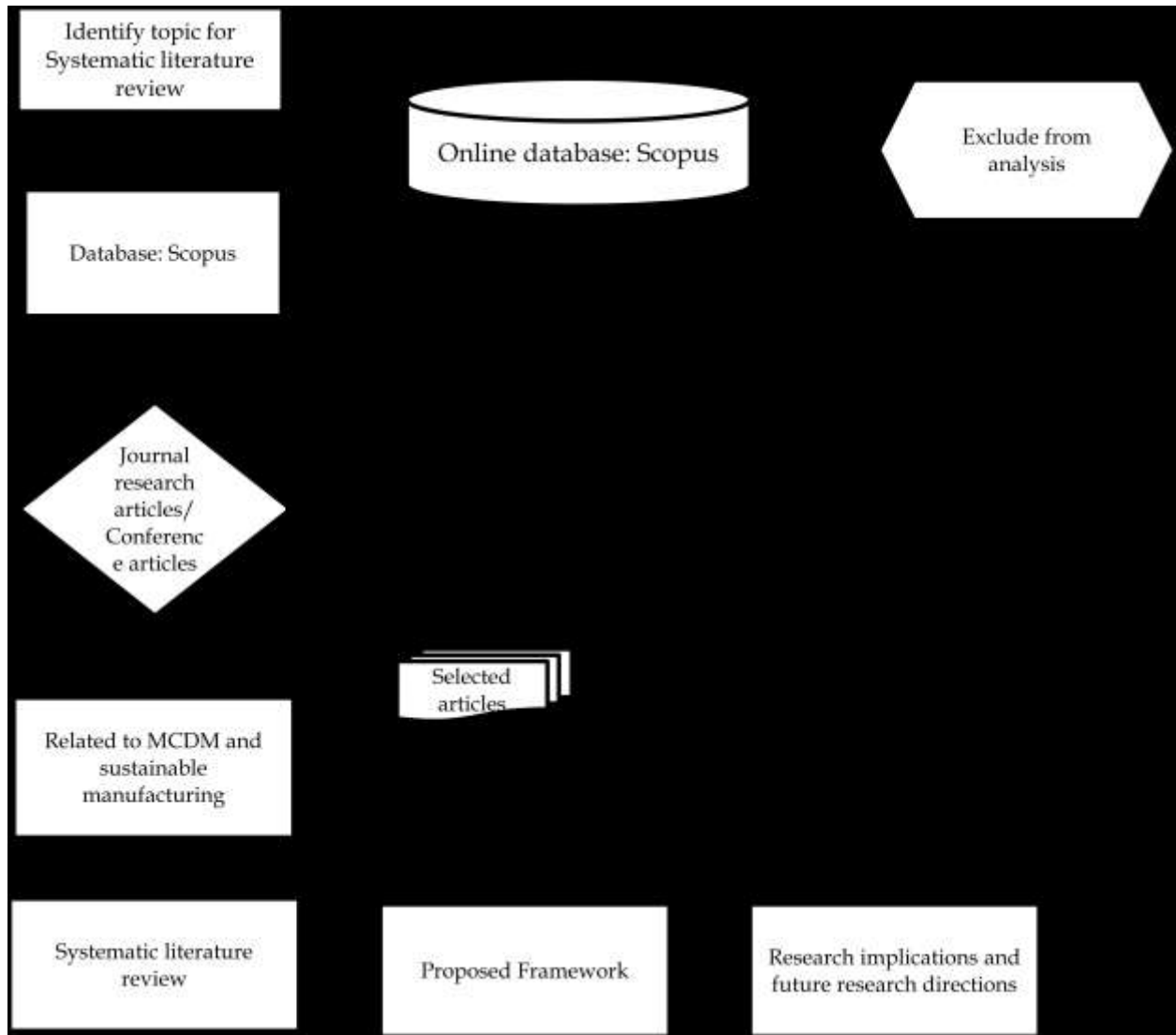


Figure 3: Flow chart for the present study

3.4. Content and Year and Journal wise analysis

Pressure from both Government regulations and customer awareness promotes environment-conscious manufacturing with consideration of sustainability dimensions. A total of 61 articles was published from 2010-2016. And in the last four years, 2017-2020 total of 82 articles were published which shows that now researchers are focusing on the assessment of SM practices with MCDM approaches. Figure 4 shows the year-wise publication in the SM area with MCDM approaches.

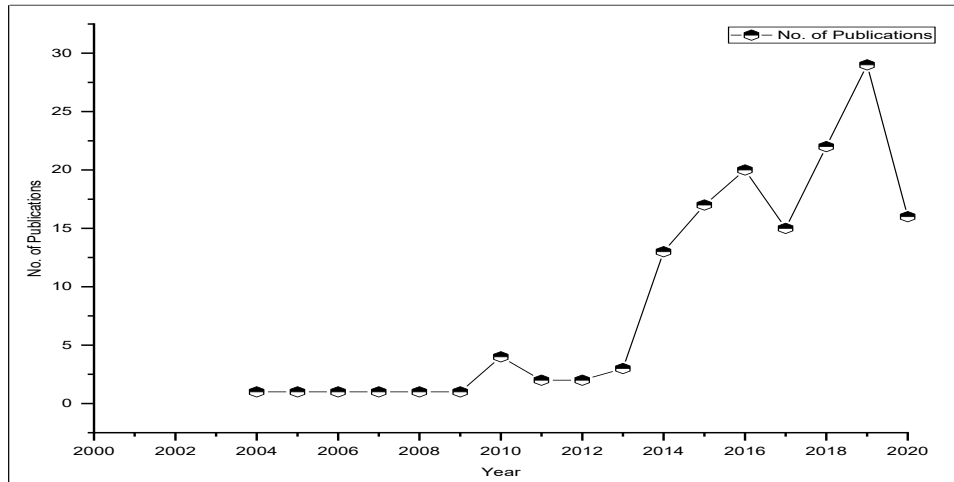


Figure 4: Year-wise publication analysis

Table 2 shows the top authors working in the area of SM with MCDM approaches with Top sources. It is found that “Mittal V.K” having most of the publications (7) which is followed by “Sangwan K.S.”,(7), “Ray A” (6), and “Ocampo L.A.”, (5). The top two authors are from developing nations which shows that developing nations are more focused on the assessment of SM practices with MCDM approaches. In top sources “Journal of cleaner production” having a maximum number of publications (10) which is followed by “Sustainability Switzerland” (9), “International Journal of Advanced manufacturing technology” (5), and “IOP conference series materials science and engineering” (5).

Table 2: Top authors and Top sources analysis

S.No.	Top authors		Top sources (TP: Total Publications)	
	Author Name	TP	Journal Name/ Source Name	TP
1	Mittal, V.K.	7	Journal of Cleaner Production	10
2	Sangwan, K.S.	7	Sustainability Switzerland	9
3	Ray, A.	6	International Journal of Advanced Manufacturing Technology	5
4	Ocampo,	5	IOP Conference Series Materials Science and Engineering	5

	L.A.			
5	Govindan, K.	4	Procedia CIRP	5
6	Jagdish	4	Applied Mechanics and Materials	4
7	Jaiswal, P.	4	Lecture Notes in Mechanical Engineering	4
8	Sindhvani, R.	4	Proceedings of the International Conference on Industrial Engineering and Operation Management	4
9	Gupta, S.	3	Advances In Intelligent Systems and Computing	3
10	Kannan, D.	3	AIP Conference Proceedings	3

Table 3 shows the Top keywords, subject areas and most cited articles in the SM area with MCDM approaches. In top subject areas “Engineering” has a maximum number of articles (99) which is followed by “Business, Management and accounting” (44) and “Environmental science” (36). “Manufacture” is mostly used keyword with maximum occurrence (63) which is followed by “Decision making” (52) and “Sustainable manufacturing” (52).

Table 3: Top subject areas, Top used keywords, and most cited articles analysis

S.No.	Top subject areas		Top Keywords used		Most cited articles	
	Subject Area	TP	Keyword	Occurrence	Article	Citations
1	Engineering	99	Manufacture	63	(Govindan, Diabat, et al., 2015)	130
2	Business, Management and Accounting	44	Decision making	52	(Thanki et al., 2016)	110
3	Environmental science	36	Sustainable manufacturing	52	(Sivapirakasam et al., 2011)	85
4	Decision sciences	31	Green manufacturing	49	(Vinodh & Jeya Girubha, 2012)	57
5	Computer Science	29	Sustainable development	38	(Govindan, Kannan, et al., 2015)	55
6	Energy	22	Sustainability	25	(Harik et al., 2015)	52
7	Social sciences	16	Analytic hierarchy process	21	(Gandhi et al., 2018)	47

8	Materials science	9	Manufacturing	21	(Amrina & Vils, 2015)	45
9	Mathematics	8	Analytical hierarchy process	19	(Chuang & Yang, 2014)	40
10	Economics, Econometrics and Finance	7	Hierarchy systems	19	(Mittal & Sangwan, 2014b)	39

3.5. Country-wise and Institute wise analysis

Table 4 shows the country and institute-wise analysis of SM articles with MCDM approaches. It is found that “India” has most of the articles (64) which is followed by “China” (20), “Indonesia” (10), “Philippines” (9), and “United Kingdom” (9). It can be seen that most of the research is done in developing nations. Industries of developing nations are more focused on SM practices **due to customer pressure and strict government policies related to the environment**. “Amity University, Noida” has maximum publications (9) which are followed by “Birla Institute of Technology and Science, Pilani” (8) and “Syddansk Unieritet” (7).

Table 4: Country and Institute wise analysis

S.No.	Country	TP	Country Category	Institute	TP
1	India	64	Developing	Amity University, Noida	9
2	China	20	Developing	Birla Institute of Technology and Science, Pilani	8
3	Indonesia	10	Developing	Syddansk Uniersitet	7
4	Philippines	9	Developing	Cebu Technological University	6
5	United Kingdom	9	Developed	National Institute of Technology, Silchar	6
6	Denmark	7	Developed	National Institute of Technology, Tiruchirappalli	5
7	United States	6	Developed	Indian Institute of Technology, Kharagpur	4
8	Malaysia	5	Developing	National Institute of Technology, Jamshedpur	4

9	Taiwan	5	Developing	De La Salle University-Manila	4
10	Australia	3	Developed	Universitas Andalas	4

4. MULTI CRITERIA DECISION ANALYSIS

Decision analysis in manufacturing is an important tool that helps to solve many issues characterized by multiple objectives, alternatives, and criteria (Chakraborty, 2010). Generally, multi-criteria decision-making problems comprise five basic components i.e. expert preferences, the goal of the study, alternatives present for the problem, criteria available, and outcomes of the study (Pohekar & Ramachandran, 2004). MCDM can be classified into three basic types which have been shown in [Figure 5](#).

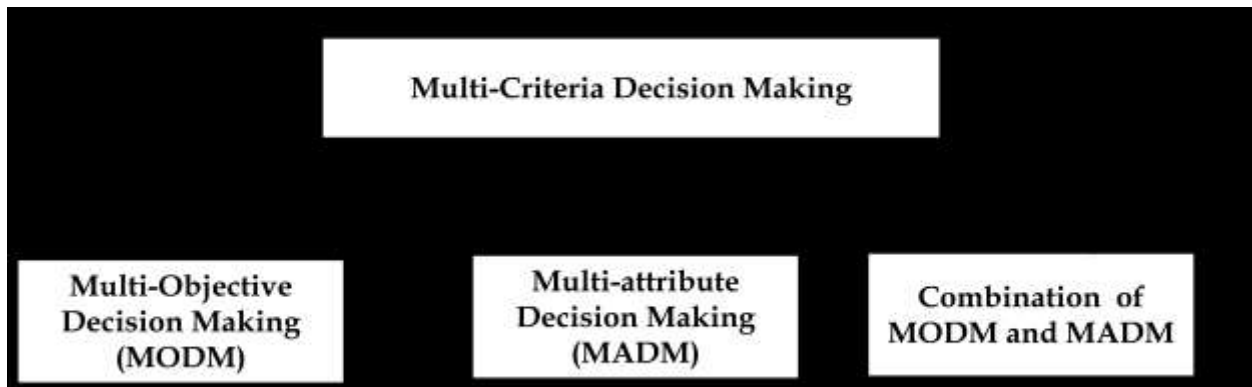


Figure 5: Classification of Multi-criteria decision-making techniques

MADM models are aimed at the identification of the most satisfactory alternatives or the ranking options of the alternatives based on the relevance of their objective. This method is used to solve the problems which involve the selection from a finite number of available alternatives. It specifies how the attribute information will be processed to arrive at the choice with the requirement of both intra and inter attribute comparisons (Torfi et al., 2010). MADM methods consist of four main components i.e. alternatives, attribute, the relative importance of each attribute or alternative, and measure of performance of an alternative with respect to a particular attribute (Pohekar & Ramachandran, 2004). Multi-attribute decision methods can be categorized into (1) Simple additive weighting method (2) Weighted product method (3) Analytic hierarchy process method (4) Revised AHP (5) Multiplicative AHP method (6) TOPSIS method (7)

Modified TOPSIS method, and (8) VIKOR (Compromise ranking method). MODM models are suitable to evaluate the continuous alternatives for which users can predefine the constraints in the form of the vectors of decision variables (Ribeiro, 1996). In the past few years, different multi-criteria techniques have been applied in the SM area (Bhanot et al., 2017; Malek & Desai, 2019). The model developed for the problem depends on the designer's perspective which can be a direct or indirect approach. In the indirect approach, all possible alternatives or criteria are separated into the different components in which weights are assigned based on previous similar problems and expert's opinions (Mardani et al., 2015). In the direct approach inputs of weights are done based on the inputs collected from the survey and society. The classification of the multi-criteria models has been shown in Figure 6.

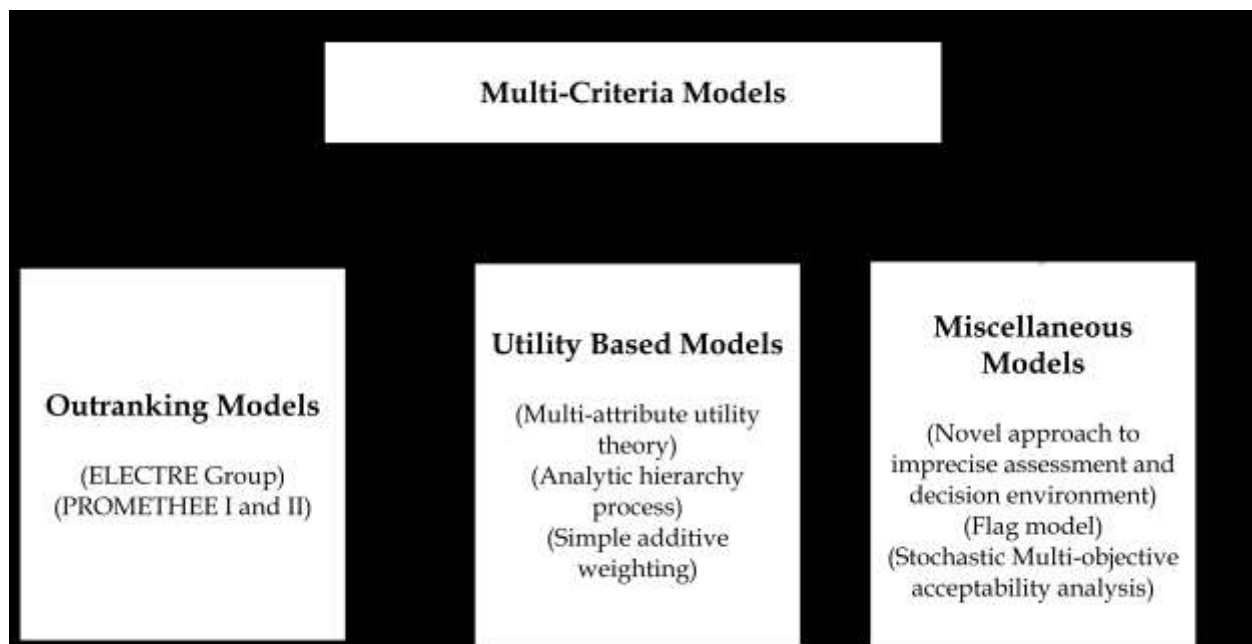


Figure 6: Classification of Multi-criteria decision models

MCDM models are always considered complex models because of the involvement of factors such as stakeholders, economic, technical, standards, social and institutional which need both the managerial and engineering level analysis (Antucheviciene et al., 2015). This procedure is still controversial as the objective of the problem may be lead to different solutions at different time sets based on inputs from the person involved in the study (Subramanian & Ramanathan, 2012). Based on function, a particular problem can be solved by different methods. **Different studies on SM with outranking models, utility-based models, and a miscellaneous model is discussed in the**

next sections of the study. Every method having its advantages and disadvantages. A general procedure for any problem which follows the MCDM technique is represented in Figure 7.

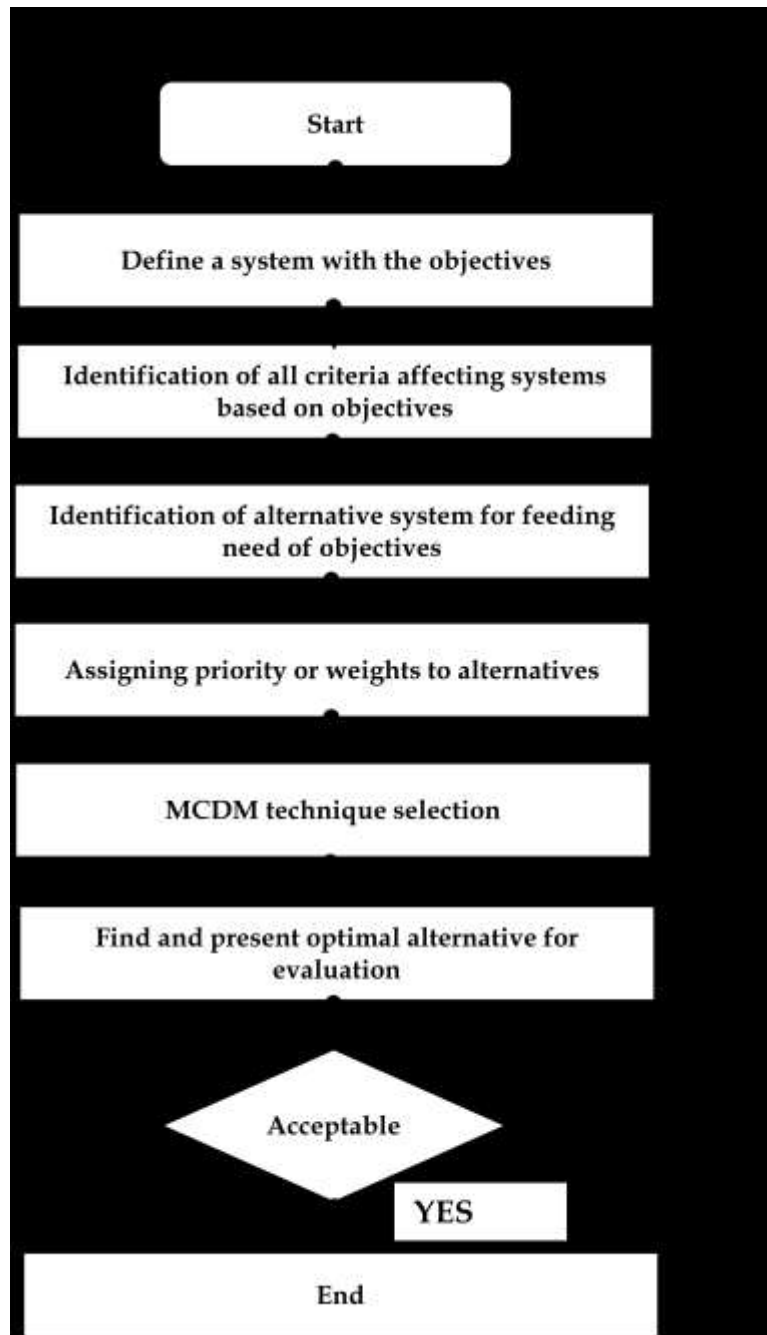


Figure 7: A General procedure for Multi-criteria decision making analysis

In the present study following methods have been discussed:

1. Analytic Hierarchy Process (AHP)
2. Analytic Network Process (ANP)
3. Best Worst Method (BWM)
4. DEMATEL
5. MAUT
6. VIKOR
7. TOPSIS
8. PROMETHEE

Table 5 shows the description of these methodologies with their procedures, application area, strength, and weakness from the existing literature available on these methods.

Table 5: Different MCDM with their applications, steps, strengths, and weakness

Method Name	Application Area	Year and Principle	Steps involved	Strengths	Weakness
Analytical hierarchy process (AHP) (Saaty, 2008; Vaidya & Kumar, 2006)	<ul style="list-style-type: none"> a) Logistics and Transportation engineering application b) Resource management c) Energy planning d) Strategy selection 	1980, Pairwise comparison	<ul style="list-style-type: none"> a) Define objectives into the hierarchy model. b) Calculate weights for each criterion. c) Calculate the score for each alternative under the respective criteria. d) Calculate the overall score of all alternatives. 	<ul style="list-style-type: none"> a) Adaptable to objectives. b) Suitable and flexible for decision support. c) Wide range of applications areas ineffectiveness, planning, and risk analysis. d) Consistency can be measured based on expert judgment. e) Provide a simple and flexible model for the problems. 	<ul style="list-style-type: none"> a) Sometimes not provides the solutions for the linear equations. b) Only TFN can be used. c) It is based on the possibility and probability measures. d) Subjective in nature which means it is not sure that decisions provided are always true.
Analytic Network Process (ANP) (Saaty & Vargas, 2013)	<ul style="list-style-type: none"> a) Project Partnering b) Process modeling c) Clinical applications 	1996, Pairwise comparison (Network structure)	<ul style="list-style-type: none"> a) Development of the structure of the decision model. b) Calculation of pair-wise 	<ul style="list-style-type: none"> a) This technique can be used to simplify complex problems. b) It can be used 	<ul style="list-style-type: none"> a) If there is a large number of factors then it leads to an unwieldy

	<ul style="list-style-type: none"> d) Solid waste management e) Evaluation of technologies f) Selection and prioritization purposes. 		<ul style="list-style-type: none"> c) Comparison on the sub-clusters and clusters. c) Calculation of relative weights of element and CR calculation for matrices. 	<ul style="list-style-type: none"> for prioritization purposes. c) It included both tangible and intangible factors. d) It uses the quantitative description of subjective judgment. e) It allows feedback and dependence in the hierarchy. 	<ul style="list-style-type: none"> b) It heavily relies on the experience and judgment of experts.
Best Worst Method (BWM) (Rezaei, 2015)	<ul style="list-style-type: none"> a) Supplier development b) Evaluation of strategies c) Selection purposes d) Prioritizing the barriers and enablers. 	2015, Pairwise comparison	<ul style="list-style-type: none"> a) Designation of the different criteria. b) Deduction of both the best and worst criteria. c) Preference rating of both best and worst criteria over other criteria. d) Calculate optimal weights for criterion. e) Check the consistency level of the comparison. 	<ul style="list-style-type: none"> a) Needs fewer comparison data as compared to other MCDM techniques. b) Can be applied to different MCDM problems with both qualitative and quantitative criteria. c) Easy to understand and easy to apply as compared to other MCDM. 	<ul style="list-style-type: none"> a) There is a limitation of 9 point comparison scale. E.g. if a criterion is 12 times important than other than there is no option for scale.
Decision-making trial and evaluation laboratory (DEMATEL) (Wu & Lee, 2007)	<ul style="list-style-type: none"> a) Evaluating success factors. b) Find the casual relationship between factors. c) Finding the critical factors. 	1972, Pairwise comparison (casual relationship)	<ul style="list-style-type: none"> a) Generation of group direct influence matrix. b) Establishment of normalized direct influence matrix. c) Construction of total influence matrix. d) Generation of influential relation map. 	<ul style="list-style-type: none"> a) It can analyze the mutual influences between the factors effectively. b) It helps to visualize the relationship between the factors with the help of IRM. c) It can be used to rank the alternatives as well as it helps to find out the critical evaluation criteria. 	<ul style="list-style-type: none"> a) Ranking of alternatives is done based on the independent relationship among the alternatives. b) Relative weights of experts are not considered in personal judgments.
MAUT	<ul style="list-style-type: none"> a) Process 	1967,	<ul style="list-style-type: none"> a) Find the 	<ul style="list-style-type: none"> a) It accounts for 	<ul style="list-style-type: none"> a) Sometimes it

(Multi-attribute utility theory) (Dyer, n.d.)	<ul style="list-style-type: none"> b) Manufacturing c) Business policies 	Direct comparison	<ul style="list-style-type: none"> dimensions for each objective and assigned a weight to each objective. b) Weight% calculation and update the values of each dimension. c) Multiply the new updated values with old values obtained from the dimensions. d) Add product for each dimension and final sum for each option to determine the final decision. 	<ul style="list-style-type: none"> any difference in any of the criteria. b) It dynamically updates the values which change due to any impact. 	<ul style="list-style-type: none"> is difficult to get precise inputs from the experts. b) There is some uncertainty in the outcome of the decision criteria.
Preference ranking organization method (PROMETHEE) (Jean Pierre Brans & Mareschal, 1990)	<ul style="list-style-type: none"> a) Manufacturing engineering b) Risk analysis c) Industrial engineering 	1984, Pairwise comparison	<ul style="list-style-type: none"> a) Find the evaluation matrix. b) Pairwise comparison between each criterion. c) The preference function is assigned with values ranging from 0 to 1. d) Calculate the global matrix. e) Determine the rank by adding the column. 	<ul style="list-style-type: none"> a) It incorporates fuzzy and uncertain information. b) It deals with both quantitative and qualitative information. c) It involves group-level decisions. 	<ul style="list-style-type: none"> a) The major limitation is that it cannot structure the objective properly. b) It is complicated so the users are only limited to experts. c) It depends on the decision-makers to assign the weights.
TOPSIS (Technique for order preference by similarity to ideal solutions) (Lai et al., 1994)	<ul style="list-style-type: none"> a) Supplier selection. b) Logistic management c) Manufacturing optimization 	1981, Compromise ranking	<ul style="list-style-type: none"> a) Calculate matrices. b) Normalization and decision. c) Calculate both negative and positive ideal solutions. d) Calculate the relative and separation closeness. 	<ul style="list-style-type: none"> a) It works with the fundamental ranking. b) It uses full information. c) Information allocated not need to be independent. 	<ul style="list-style-type: none"> a) Doesn't calculate the difference between negative and positive ideal solutions. b) There is a monotonically decrease and an increase in the attribute values.
VIKOR (VlsekriterijumskaOptimizacija)	<ul style="list-style-type: none"> a) Manufacturing Engineering 	1998, Compromise	<ul style="list-style-type: none"> a) Calculate the Best and Worst values. 	<ul style="list-style-type: none"> a) This technique is the updated version of 	<ul style="list-style-type: none"> a) It needs some modification

cija I Komparamiso oResenje) (Opricovic & Tzeng, 2007)	b) Business Management c) Health care sector d) Mechanical Engineering	ranking	b) Calculate the weighted- normalized Manhattan distance (S_j) and weighted- normalized Chebyshev distance (R_j). c) Calculate the Q_j value. d) Ranking and sorting of alternatives by S , R , and Q values. e) Finding the compromise solution from the final three rank lists.	TOPSIS. b) It calculates the ratio of both negative and positive ideal solution and removes the impact.	when there is terse data and it is difficult to model a real- time model. b) Difficult to use when there is a conflict situation arises.
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In the past few years, many software based on these MCDM methods has been developed in which some are commercial, and others are open access. **These softwares can be used for the MCDM analysis which will help to save computation time.** The lists of MCDM based software with their application area are shown in Table 6.

Table 6: MCDM based software

S.No.	Software Name	Developer	Applications
1.	Bubble Chart Pro OPTIMAL	George Huhn	1. Linear programming optimization 2. Prioritization based on simple multi-attribute ranking methods
2.	BENSOLVE	Benjamin Weibing and Andreas Lohne	1. Vector liner programming 2. Multiple objective linear programming
3.	ChemDecide	Dr. Richard Hodgett (Ph.D. research work at Newcastle University Sponsored by Britest)	1. Equipment selection 2. Aid route selection 3. Sourcing decision 4. Chemical storages
4.	Criterium Decision Plus	InfoHarvest Inc.	1. Environmental management 2. Vendor Selection 3. Project Management decisions 4. Procurement decisions
5.	D-SIGHT	Company	Multi-criteria decision analysis
6.	DECISIONARIUM	Prof. Raimo P. Hamalainen, Aalto University (School of Science)	1. Robust portfolio modeling 2. Preference programming purposes
7.	DEXi	Marko Bohanec	Complex decision-making problems
8.	Decision Explorer	BANXIA software	Complex decision-making problems

	Decision Deck	Open source-based software	1. Risk analysis 2. Sorting 3. Risk management
9.	ElectioVis	Open-source software	Simulation analysis
10.	Expert Choice	Commercial software	1. Asset management 2. Aerospace industry 3. Health care 4. Risk management
11.	FLO	Open-source software	Routing problems
12.	GUIMOO	Open-source software	Metaheuristics based optimizations
13.	Interalg	Open-source software	Multi-objective optimization problems
14.	IDS	Open-source software	TQM applications
15.	IND-NIMBUS	Open-source software	Single and multi-objective optimization problems
16.	IDSS	Open-source software	1. Multi-objective optimization in fuzzy environment 2. Preference modeling
17.	IRIS	Open-source software	Risk analysis and Risk assessment
18.	MakeItRational	Commercial software	Project management
19.	MACBETH	Commercial software	1. Resource allocation 2. Public policy planning 3. Strategic plan development
20.	modeFRONTIER	Commercial software	Multi-objective optimization problems
21.	SANEX	Non-Commercial software	1. Aerospace applications 2. Environmental management 3. Defense support systems
22.	Triptych	Commercial software with a free trial version	1. Biomedical applications 2. Equipment development decision support systems
23.	Winpre	Open-source software	1. Decision support 2. Traffic planning
24.	1000Minds	Open-source software	Resource allocation problems

4.2. MCDM models in the Sustainable manufacturing

MCDM methods are successfully utilized in the SM and solving the prioritizing problems related to enablers, issues, and indicators (Deshmukh & Hiremath, 2019). In this section, a comprehensive review of various methods with a focus on the SM will be presented. There are three types of MCDM models which are outranking models, goal, aspiration and reference models, and value measurement models (Zavadskas et al., 2014). Some studies reported the use of a combination of these models also (Bhalaji et al., 2020; Ocampo et al., 2020). In the past few years, researchers have developed many prioritizations and assessment tools for MCDM with the

integration of fuzzy logic (Ighravwe & Oke, 2017; Quader et al., 2015). A summary of the MCDM approaches used in the SM area is discussed in Table 7.

Table 7: Summary of literature review available on MCDM approaches used in SM practices.

S.No.	Authors	MCDM Approach used	Objectives	Outcomes
1	(Fan et al., 2010)	AHP	Identification and assessment of sustainability indicators to SM practices for manufacturing industries.	(a) Industries are more focused on the Economic and social indicators rather than environment indicators (b) Most of the indicators have been considered in the various industries but not uniformly distributed.
2	(Vinodh et al., 2012)	ANP	Evaluation of SM practices in Indian Relay manufacturing industries.	(a) In the proposed model 3 other system except the existing system is proposed. (b) System C has a maximum desirability value of 0.376. (c) It is found that the proposed model will help the industries to evaluate their SBP.
3	(Sundharam et al., 2013)	BSC and AHP	Evaluation of KPIs for various industry sectors for SM manufacturing practices.	(a) KPIs for various industrial sectors are evaluated by BSC and targets are set to achieve. (b) Sustainability depends on the production of profitable products. (c) AHP analyzed the customer data and priorities which helps in product improvement.
4	(Vinodh et al., 2013)	VIKOR	Sustainable concept selection in Indian modular switches manufacturing industry.	The proposed model based on VIKOR reveals that LCIA is the best concept among all concepts.
5	(Aminuddin et al., 2014)	ANP	Various indicators related to SM are found out and MCDM based model is proposed for industries.	The ANP model shows that the Green manufacturing alternative having the maximum weightage 0.212803 which is followed by lean manufacturing 0.164279 and procurement practices 0.15011 and Labor practices and decent work 0.136216
6	(Ocampo et al., 2014)	PROFUZ-ANP	Integration of manufacturing strategies with SM strategies.	The results of the study can be viewed from two different perspectives (1) A better approach in sustainability is hearing the stakeholder voice (2) sustainability is the growing concept in the business practices experts have imprecise knowledge of the sustainability concept. The proposed model provides content for the SM strategy.

7	(Orji & Wei, 2014)	Fuzzy-DEMATEL-TOPSIS	Sustainable supplier selection in the Sustainable gear manufacturing industry.	(a) A decision support tool is proposed for the sustainable gear manufacturing industry. (b) Social factors are majorly affecting the sustainability with the sub-factors like Quality and Work Safety.
8	(Amrina & Vils, 2015)	AHP	Identification of SM indicators related to Cement manufacturing industries	(a) The case study is validated in the cement industries of Indonesia. (b) Economic criteria having a maximum weight of 0.3985 which is followed by environmental criteria 0.3059. (c) Inventory cost is the main indicator with the weight of 0.0917 which is followed by Labor cost of 0.0763
9	(Shojaeipour, 2015)	AHP	Development of automated evaluation tool based on influencing factors i.e. materials for process plan selection, waste production, etc.	(a) Proposed model is validated with a case study. (b) The model is based on process knowledge customization which integrates both manufacturing resources and process knowledge which helps in process planning. (c) Unlike other proposed models in previous studies, the model is based on the systematic methodology which is focused on the process planning regarding the manufacturing resources.
10	(Amrina et al., 2016)	Fuzzy-ANP	Identification of SM indicators related to Cement manufacturing industries.	The proposed model is validated with the case study carried out in the three cement industries and it is found that SM helps to improve the performance of the cement industries in terms of environmental aspects.
11	(Ocampo & Promentilla, 2016)	ANP	Integration of manufacturing strategies with SM strategies.	The proposed model is validated with the case study which integrates the SM and manufacturing strategies. Monte Carlo simulation is also done to check the robustness of the proposed model.
12	(Watróbski & Sałabun, 2016)	Characteristic objects method	Investigation of 8 different characteristics objects related to SM.	The proposed model reveals that the COMET model can be used for ranking purposes for SM and it is more efficient than AHP and other MCDM techniques. In this human error can be minimized.
13	(Singh et al., 2016)	AHP-VIKOR under Fuzzy environment	Identification of various SM strategies and development of a framework for manufacturing industries.	The proposed Fuzzy-AHP-VIKOR model is validated with the case study of Indian SMEs and found that among the three strategies considered A1 strategy having the smallest VIKOR value. Further, sensitivity analysis is done for the robustness test.
14	(Li & Mathiyazhagan, 2016)	DEMATEL	Identification of indicators for the supply chain of automobile components manufactured by SM.	The proposed model is validated in the Indian SMEs and found that among 15 indicators carbon management is the most influencing indicator in the Indian automobile industries.

15	(Kek & Vinodh, 2016)	ANP	Investigation on the sustainability performance of the selective laser sintering process and injection moulding technique.	(a) Proposed model is validated with a case study. (b) Based on the inventory data it is found that SPPSS for the SLS is 0.068 and IM is 0.038. It is found that IM is a more sustainable process than SLS when production volume is higher.
16	(Shankar et al., 2016)	AHP	Identification of drivers for advanced manufacturing techniques for Sustainable operations.	(a)The proposed model is validated with the case study of Indian manufacturing industries. (b) Quality is the primary driver which has a major influence on the manufacturing industries of India to adopt SM practices.
17	(Khatri & Metri, 2016)	SWOT-AHP	17 critical factors in four SWOT groups were identified for the selection of SM practices.	The proposed model shown is validated in the Indian SME's and it is found that Strength having a maximum value of 33.3% which is followed by Weakness 27.5%. Operational excellence having the maximum weightage of 13.4% followed by higher resource utilization of 11.9%.
18	(Quader & Ahmed, 2016)	Fuzzy DEMATEL and Fuzzy-AHP	The objective of the study is to evaluate of CCS system in the steel and iron industries with four main criteria i.e. engineering, social, environmental, and economic.	The proposed model is validated in the Steel and Iron industries of Bangladesh. It is found that CO2 capturing technologies in the steel and iron industries difficult as critical factors and some barriers are associated with the CCS.
19	(Garbie, 2015)	AHP	Non-conventional competitive manufacturing strategies for SM practices were investigated with minimizing complexity, industrial leanness, and agility.	(a) Proposed model is validated with a case study in the manufacturing industry. (b) Complexity measurement is important for any manufacturing industry.
20	(Ighravwe & Oke, 2017)	Fuzzy-TOPSIS	A total of 20 factors related to SM was found out with the help of an exhaustive literature survey and the model is developed with the help of TOPSIS	(a) Proposed MCDM based model is validated in the manufacturing industry (b) Maintenance workforce training is the most influencing factor in the manufacturing industries which affects the manufacturing plans.
21	(Nenni & Micillo, 2017)	AHP	Development of SM decision support system for food industries.	(a) Proposed MCDM framework is validated in the food industry. (b) A multi-level hierarchy model is developed to sustainability in the food industry in all three sustainability dimensions. (c) Sensitivity analysis is done to test the robustness of the AHP model.

22	(Shukla et al., 2017)	AHP	An empirical study to evaluate the SM practices in India.	MCDM based model is proposed and validated in the Indian automobile industry.
23	(Mathiyazhagan et al., 2018)	DEMATEL	Key challenging factors in the SM practices implementation were identified and MCDM based model is proposed.	(a) Based on 16 key challenges MCDM model is proposed. (b) Cost implication and non-utilization of the available training courses for the workers are the main key challenges in Indian industries.
24	(Ocampo, 2018)	Probabilistic Fuzzy-ANP	The study aimed at the identification of manufacturing strategy to integrate both classical manufacturing with sustainability strategies.	ANP based framework is proposed to identify the best strategy and find the relationship between the various components.
25	(Pourjavad & Shahin, 2018)	Fuzzy DEMATEL and FIS	Sustainable framework development for service measurement and manufacturing supply chain management.	(a) MCDM based model is proposed and validated in a Pipefitting industry (b) Sensitivity analysis is also done to find the influence of the service and manufacturing criteria.
26	(Singla et al., 2018)	TOPSIS and VIKOR	Push strategies affecting SM were identified in an investigation of 92 companies.	(a) A MCDM based model is proposed with the help of TOPSIS and VIKOR. (b) Strategies like innovative capability, corporate strategies, and R&D are the main strategies that help in the implementation of SM practices.
27	(Orji, 2019)	TOPSIS	SM barriers for the organizational change for metal manufacturing industries are identified and the MCDM model is proposed.	(a) The proposed framework is validated in the Chinese metal manufacturing industry. (b) ISM technique is applied for selecting the barriers based on the experts' input (c) TOPSIS method is applied for prioritization of barriers. (d) The inefficient legal framework in the metal manufacturing industries is the main key barrier.
28	(Sahu & Kohli, 2019)	Fuzzy based Incentre centroid technique	The study is focused on the evaluation of SM practices in the pharmaceutical industries of India.	(a) The proposed model is validated with the case study of the pharmaceutical industry of India. (b) The model helps to identify strong and weak sustainable practices in the pharmaceutical industries.
29	(Nujoom et al., 2019)	DEMATEL	The multi-objective SM decision model is developed and validated with a case study.	(a) MCDM based model is proposed and validated with a case study (b) Optimal no. of machines for each configuration is identified.
30	(Tigane et al., 2019)	TOPSIS	The study is focused on finding the best scheduling of the given jobs by minimizing the total energy consumption and makespan.	NSGA-II based approaches are taken into consideration to solve the mathematical model and then the TOPSIS based multi-objective model is proposed to find the best solution.
31	(Singh et al., 2019)	AHP and DEMATEL	13 Indicators were evaluated for Cement	(a) MCDM based is proposed for Cement industries (b) Material

			industries and MCDM based model is proposed.	consumption has less weight and material cost having maximum weight among 13 indicators for Indian cement manufacturing industries.
32	(Askary et al., 2019)	AHP	Enablers for Indian industries were identified. Based on all 12 enablers MCDM model is proposed.	(a) The proposed MCDM model is validated with the Indian manufacturing industry case study. (b) Emission standard having the highest weightage among all the enablers which is followed by 3R.
33	(Ahuja et al., 2019)	DEMATEL	The study is focused on the adoption of SM practices in which Human critical success factors were identified and analyzed	(a) MCDM based model is proposed and validated with a case study (b) Green motivation and customer relationships are influencing success factors.
34	(Rehman et al., 2019)	PROMETHEE, VIKOR, and Fuzzy-AHP	24 alternatives for SM operations were identified based on internal and external demands.	(a) MCDM based model is proposed and weights were identified with MCDM approaches for different configurations.
35	(Rosebrock & Bracke, 2019)	TOPSIS	(a) Two manufacturing processes were compared. (b) Environmental impacts were analyzed with GABi and ranked with TOPSIS.	There is less wear in the electrowinning process as compared to other processes.
36	(Ocampo et al., 2020)	Fuzzy-ANP	In this work classical function of manufacturing and sustainability is integrated based on experts inputs	The proposed model is useful for complex decision-making problems and the results of the study show the contents of the SM strategy
37	(Ocampo, 2019)	Fuzzy AHP-TOPSIS	Strategies for SM practices for food manufacturing is identified and guidelines were provided for policymakers	(a) MCDM based model is proposed and validated in Philippines industries (b) TQM practices are best practices in sustainable food manufacturing.
38	(Boral et al., 2020)	Type 2 Fuzzy-DEMATEL and Modified Fuzzy MAIRCA	FMEA is done for SM practices in manufacturing industries.	(a) MCDM based model is proposed and validated in the gearbox manufacturing industry.
39	(Kumar & Mathiyazhagan, 2020)	DEMATEL	Critical success factors for sustainable lean manufacturing practices are identified for Indian industries and interrelationship between these factors is identified.	(a) MCDM based model is proposed for manufacturing industries. (b) Effectiveness and innovative technology are the main influencing factors for industries.
40	(Bhanot et al., 2020)	DEMATEL	Critical indicators to SM were identified through	(a) A MCDM model is proposed for SM practices in Indian industries (b)

			the literature review and the MCDM model is proposed.	Waste management and process management are the influencing factors for Indian SMEs.
41	(Ocampo et al., 2020)	Fuzzy-DEMATEL-ANP-TOPSIS	Best practices for sustainable food manufacturing is identified in Philippine industries	(a) MCDM based model is proposed (b) TQM practices and resources efficiency are important factors in sustainable food manufacturing.
42	(Pagone et al., 2020)	TOPSIS	A total of 18 criteria in 4 main categories was identified for sustainable material selection in the automobile industries.	(a) A MCDM based model is proposed for sustainable material selection. (b) Aluminum is found to be suitable material for industries followed by zinc and magnesium.
43	(Bhalaji et al., 2020)	Hybrid (Fuzzy-DANP and PROMETHEE)	Identification of SM risks in surgical cotton manufacturing industries in the Southern Indian region.	(a) Critical SM risks for the cotton industry are identified. (b) An MCDM based model is proposed for managers so that industries can identify risks at early stages and enhance their production efficiency.

4.2.1. Value measurement models

Value measurement models are utility-based models which included the methods like AHP, MAUT, weighted product method, and weighted sum method (Massam, 1988). These methods are used for ranking the indicators or a barrier in the area of SM. MAUT method is not much precise as compared to the AHP method for ranking purposes. Although, the AHP method has many flaws when compared to the MAUT method. But in most of the studies, AHP is used due to its flexibility (Kurttila et al., 2000). AHP method has been widely used in the SM for the enabler's ranking. There are many drawbacks to the MAUT method over other techniques. MAUT having many advantages in decision making which include risk analysis but AHP has emerged as a better tool for decision support for supplier assessment, enabler ranking, and indicator prioritization. Amrina & Vilsa (2015) identify the indicators of SM for the cement industries of Indonesia. A total of 19 alternatives in three criteria i.e. social, environmental, and economical was found out. AHP method is used to prioritize the indicators. The proposed model is validated with the case study of Indonesian cement industries and found that economic criteria having a maximum weight of 0.3985 which is further followed by environmental criteria 0.3059, Among the 19 alternatives inventory control is the main indicator with a weight of 0.0917. Shankar et al.(2016) adopted the AHP technique to integrate advanced manufacturing techniques

with sustainable operations. The drivers for the study were found with the help of a literature survey is available in the Indian context. The proposed model is validated with the Indian manufacturing industry and found that quality is the primary driver which has a major influence on the manufacturing industries of India. Thanki et al. (2016) proposed an integrated lean-green implementation framework for Indian SMEs using the AHP approach. Four criteria i.e. cost, delivery, time, and quality with 8 alternatives were taken into consideration for lean practices. Similarly, two criteria i.e. business performance and environmental performance with 8 alternatives were considered as green practices. Ranking of the practices is done with the analytic hierarchy process approach. Conventional AHP method having data validity and inconsistency limits which have an impact on the accuracy of the results. So, the AHP method with the fuzzy logic theory is used to overcome these limitations. A fuzzy-AHP method is similar to the conventional AHP method but it sets the AHP scales into the fuzzy triangle scale to be accessed priority. The use of AHP with fuzzy logic in green manufacturing context with the consideration of drivers and barriers have been studied in the (Govindan et al., 2015; Ighravwe & Oke, 2017; Quader & Ahmed, 2016). Govindan et al., (2015) suggested that green issues in the global industries have gained importance. Twelve common drivers for green manufacturing are identified from the existing literature and expert opinion from the 120 industries from South India. Two-stage frameworks were proposed with the fuzzy approach to rank the drivers for green manufacturing. Fuzzy-AHP is adopted as a solution methodology and further sensitivity analysis is done for validation purposes. It is found that environmental issues in the industries play an important role in manufacturing decisions. AHP is the simple and flexible technique to handle the criteria quantitatively and qualitatively although sometimes it becomes difficult to solve when the number of criteria is in large numbers.

4.2.2. Goal and reference level models

Goal programming is defined as an optimization technique to solve manufacturing problems with multiple objectives. These objectives are generally incommensurable and conflict with each other in the decision-making horizons. At present, Goal programming has a wide range of application areas in SM or green manufacturing. Mokhtari & Hasani (2017) proposed a multi-objective cleaner production-transportation model for planning in the manufacturing plants

supported by fuzzy logic. Computational experiments-, as well as real-life case studies, were done for evaluation of the proposed algorithm. Barbosa & Gomes (2015) used the goal programming and AHP technique for the assessment of efficiency and sustainability of the Brazilian chemical industries. Total of 4 variables with 21 performance indicator was considered for the study. In which goal programming was adopted for the continuous improvement of the process. It is found that goal programming is less subjective with a straight forward procedure. Tian et al.(2018) adopted the integrated AHP, GRA, and TOPSIS approach for the green performance evaluation of electromechanical products design to facilitate green manufacturing. The finding of the study reported that the selection of green design alternatives for green manufacturing is very important to facilitate green manufacturing in the industries. Drawbacks of the TOPSIS method are presented in Table 5. TOPSIS method is highly preferred for the selection of the strategies. The drawbacks of the TOPSIS can be eliminated by using integrate different hybrid approaches.

4.2.3. Outranking models

Outranking models include Multi-criteria decision models like ELECTRE and PROMETHEE (Doumpos et al., 2009). These models are preferred in the decision-making problems because of their broad perception as these models provide a decision problem statement by giving the practical view of the problem which includes all the queries (de Boer et al., 1998). These models are used in the decision making for green or SM in which PROMETHEE is very popular for decision making in sustainable or green manufacturing (Gitinavard et al., 2017; Zhang & Haapala, 2015). Based on sociology and mathematics PROMETHEE model was developed at the beginning of the 1980s and has been studied and refined since then. PROMETHEE technique having a particular application in the decision-making environment and it is used in the manufacturing industries for decision making (Brans & Vincke, 1985). Apart from manufacturing PROMEHTEE having application areas in transportation, government, and healthcare (Goumas & Lygerou, 2000). Rather than finding the best decision for the problem these models focus on finding the alternatives which give the best solution for the problem by providing a comprehensive and rational framework for the decision problem (Dağdeviren, 2008). There are two types of PROMETHEE ranking in which PROMETHEE I focus on the partial ranking of the actions based on positive and negative flows and PROMETHEE II focuses on the

complete ranking of the actions based on the multi-criteria net flow (Goumas & Lygerou, 2000). (Vinodh & Girubha, 2011) adopted the PROMETHEE technique for sustainable concept selection for manufacturing industries by considering criteria i.e. social, natural, and economic. The outcome of the study stated that the change of materials in manufacturing is the best orientation and it should be done at the very first stage to achieve sustainability in the manufacturing industries. (Govindan et al., 2015) used the integrated DNP and PROMETHEE approach for evaluating the green manufacturing practices in the South Indian region. The proposed framework is validated with the case study in the leading tyre manufacturing industry. Green manufacturing helps to increase both the profit and performance of the industries. Total of 5 dimension i.e. environmental drivers, regulatory drivers, internal drivers, potential drives and external drives were categorized into 31 criteria for the study. (Vinodh & Girubha, 2011) adopted ELECTRE method for the sustainable concept selection. Total of 16 evaluation considered in the study such as adaptability, environmental degradation, maintenance and profits. It is found that many industries are adopting sustainable concepts in the manufacturing to survive. ELECTRE II is used for the concept selection in the study which showed that ELECTRE II method can be used in the decision making problems when the number of alternatives are in large number. The results of the study reveal that change in manufacturing processes having the good impact on the sustainability of the manufacturing industries. Changing in the manufacturing processes having better results when compared with the change in materials. It is found that authors have used mostly PROMETHEE in comparison to ELECTRE approach for sustainable or green manufacturing practices evaluation. ELECTRE methods is used when difference between the criteria values are not well considered or when the alternatives are incomplete or indifferent. PROMETHEE is used when partial or complete orders are required.

4.3. Performance indicators/ criteria/ barriers/ enablers and drivers in the sustainable manufacturing

As discussed in the literature, SM practices are broadly evaluated based on economical, social, and environmental dimensions using the various MCDM models.

In Table 8 summarized information from the available literature is considered in this review work which presents the main objective, KPIs, study type, barriers, enablers, or drivers considered by the various authors. The process of evaluation of SM practices has become more tedious with consideration of more prospects and criteria. In Table 8 different studies have been considered which reports the different criteria, indicators, drivers, or barriers in SM with their study type.

Table 8: Summarized information of different criteria, factors, barriers, drivers considered in different studies

S.No.	Author	Objective of the study	Criteria considered/Indicators/Factors	Study type
1	(Pineda-Henson & Culaba, 2004)	Green Productivity (GP) indicators for SM processes are identified to measure the environmental performance and prioritization is done based on the AHP method.	GP Water utilization ratio, GP human toxicity air emission ratio, GP energy utilization ratio, GP ecotoxicity terrestrial waste ratio, GP human toxicity land waste, GP ecotoxicity water waste ratio, GP human toxicity land waste ratio.	Generalized
2	(Hongwei et al., 2008)	Influencing factors for greenness is found out for five objective levels. The interrelationship between the factors is to find out with the help of ISM and the AHP method is used to rank the factors.	Air pollution, Solid water pollution, Water pollution, Noise pollution, Energy utilization ratio, Type of energy, Consumption of energy, Cost of utilization, Cost of society, Cost of production, Kinds of materials, Time required to produce one unit product and period of the exploitation of products.	Generalized
3	(Fan et al., 2010)	Indicators for SM were identified. The indicators were ranked with the AHP method and also study is concluded with statistical results for further development and practical application of the study.	Material usage, Percent of material from recycled inputs, Total energy consumption, Total water consumption, Total renewable energy used, Total recycle water used, Total greenhouse gas emitted, NO _x -SO _x emission, Total volume of discharged water, Total weight of solid waste, Total weight of hazardous waste, Investment in local suppliers, Investments in environmental protection, Total suppliers without EHS violations, Employee turnover rate, Lost workday due to health issues, Gender ratio, Total no. of investments in human rights clauses, Employee job satisfaction ratio.	United States
4	(Mittal &	In the study total of	Public pressure, Current legislation, Future	Generalized

	Sangwan, 2014b)	13 drivers were found out in the three dimensions of sustainability for green manufacturing practices. Fuzzy-TOPSIS methodology is used to prioritize drivers.	legislation, Incentives, Public image, Peer pressure, Top management commitment, Customer demand, Cost saving, Technology, Supply chain pressure, Organization resource, Competitiveness.	
5	(Mittal & Sangwan, 2014a)	In the study total of 12 barriers were identified in three dimensions for green manufacturing practices and Fuzzy TOPSIS is used for prioritization.	Low enforcement, Weak legislation, Low public pressure, Uncertain future legislation, Uncertain benefits, High-short term costs, Tradeoffs, Low customer demands, Technological risks, Low top management commitment, Technology risks, Lack of awareness or information, Lack of organizational resources.	Generalized
6	(Chuang & Yang, 2014)	In the study 74 assessment factors were found out in the dimensions like Green design, Green process, and Green packaging. The weights of the factors were calculated using the ANP method.	Top 5 factors in each dimension: Environmental pollution from products, Energy savings of products, Extent of eco-impact by waste, Health and safety, Proportion of product reuse, Proportion of non-toxic materials, Proportion of biodegradable materials, Inspection pass rate of green parts and green procurement capabilities, Proportion of reusable packaging, Integration of eco-marks into packaging design, Packaging simplification and ease of disintegration	Generalized
7	(Govindan, et al., 2015)	In the study total of 31 criteria were found out in 5 dimensions i.e. Environmental drivers, potential drivers, regulatory drivers, internal and external drivers. DANP and PROMETHEE are used for model development. Data is collected through a questionnaire survey and the case is validated in the South Indian tyre manufacturing industry.	Green design, Environmental conservation, Green purchasing, Optimized usage of resources, Financial benefits, Green innovations, SC requirements, Potential use of energy resources, Reverse SC, Export barriers overcome, Improved business performance, Productivity benefits, Pre-emption of future regulations, Compliance with regulations, Extended producer responsibility, Tax exemption for certified firms, Liability risks, Stakeholders, Employee demands, Improve documentation, Internal motivation, Customer, Media, Competitors, Market trend, Company performance, Company image, Banks, Auditors, and community groups.	Indian tyre manufacturing industry
8	(Amrina & Vilsa, 2015)	In the study, 19 indicators were	Labour costs, Inventory costs, Materials costs, Raw material substitution, Product	Indonesian cement

		identified in three dimensions and the AHP method is used for the model development.	delivery, Energy consumption, Air emission, Fuel consumption, Noise pollution, Material consumption, Non-product output, Land utilization land water utilization, Accident rate, Labour relationship, Employee involvement, Gender equity, Training and education, Occupational health and safety.	industries
9	(Thanki et al., 2016)	The study focuses on the lean-green manufacturing practices assessment in the Indian manufacturing industries with the AHP approach. In this study total of 8 alternatives were found for the two dimensions i.e. business performance and environmental performance.	Quality, Lead time, Cost and productivity, Product design, Brand value, Profitability, Customer satisfaction, Market position.	India
10	(Madan Shankar et al., 2017)	In the study total of 22 SM practices were analyzed with the help of the DEMATEL approach.	Development of bill of materials, Responsive product strategy, Quality improvement tools, Advanced product design, Supply chain restructuring, Enterprise level system integration, Resource utilization and economy, Improved process performance, Reduction of product development time, Reduction of manufacturing costs, Using advanced materials and manufacturing techniques, Energy saving, Promoting 6R, Water consumption, Sustainable material, and design selection, Improve the effectiveness of the environmental policy, Awareness creation, Developing education and training, Accident investigation, Guarding, Personal protection equipment, Motivation of workers.	India
11	(Mathiyazhagan et al., 2018)	This study focuses on the identification of SM challenges to the Indian automobile industry. In the study, 16 challenges were identified and analyzed with the DEMATEL approach	Fossil fuel subsidies, External inadequacy in government support systems, Requirement of patience and perseverance by investors, Preserving environmental awareness of suppliers, Technology allocation of carbon emissions, Lack of bank loans to support green products, Knowledge environmentally ignorant suppliers, Deficient industrial infrastructure, High degree of uncertainty, New concept for many Indians, Involvement and support non-utilization of available training courses for workers, Cost implication, Lack of CSR, Poor organizational culture, Non-recyclability of	India

			some automobile parts.	
12	(Singh et al., 2019)	In the study, 10 critical enablers to SM adoption find out for Indian manufacturing industries. AHP technique is used for the model development	Investment in innovation and technology, Practices in organization for reduction of energy, Raw material or any other natural resource, Organizational belief of long-term benefits through sustainability, Improve company image through green manufacturing products, Social culture responsibilities towards green products, Available of supporting infrastructure for environmentally friendly manufacturing, Organizational rules, Regulations, and laws for better environmental practices, Organization concerned about health and safety issues, Disposal of wastes, government promotions and regulations.	India
13	(Bhanot et al., 2020)	This study focuses on the identification of critical indicators to SM practices and analyzes them with DEMATEL, maximum mean de-entropy theorem, ISM, and SEM.	Cost of production, Cutting Quality, Production Rate, Process Management, Material Aspects, Energy Intensity, Water intensity, Waste Management, Environmental Regulations, Workers Health, Training and Education, Workers Safety and Labour Relations.	India

5. Findings and discussion

The adoption of SM in industries results in the reduction of costs, an increase in profit margins, promote innovation, and reduce the negative impact of manufacturing processes on the environment. But many times adoption of SM fails due to ignorance or less consideration of social factors. For any manufacturing firm to be efficient and successful implementation of SM practices in developing nations have to consider multiple indicators. Different scenarios in manufacturing firms in developing regions can be created by considering and prioritizing the criteria with different constraints which help to achieve the real-time solution of the problem. In manufacturing industries, most of the time, evaluation of SM practices has been done by considering a single scenario. Consideration of social factors in industries plays an important role in environmentally conscious manufacturing in developing nations. As also mentioned in the quote (Kumar et al., 2017) “*Technology needs to be created for people, people need not be created for technology*”. So, sustainable system designs to facilitate SM must consider the social factors with equal importance as the other factors. Due to the inclusion of multiple indicators and

drivers in SM complexity in the problem statement has increased over the years. The analytical hierarchy process due to its flexibility and simplicity has gained popularity in the past few years although some other outranking techniques such as PROMETHEE become popular. It is found that no single MCDM model can rank the problem best or worst because of the limitation of techniques. Every method has its strength and weakness depends on its applications. Now the researchers are focusing on hybrid techniques to tackle this issue. Nonetheless, MCDM models are not only the methods but it seems to capture all the objectives and consequences of the problem. It is found that MCDM methods are still missing at the local organization level which affects the adoption of SM practices. Most, of the MCDM, has been applied in the major industry sectors, very limited studies are focused on the application of MCDM in SM for SMEs. There is a need to consider the local resources and local environmental factors for SMEs for SM adoption. Most importantly, a process of the hierarchy can be implemented by moving from a local environment to a global scenario which will help to implement the SM practices in a better way. Hence, manufacturing with the aim of sustainability should not be evaluated by considering a single scenario only but there should be consideration of multiple scenarios.

From this review, we found that in SM mostly studies are focused on the use of individual methodology rather than the use of multiple methodologies. In most of the studies, the social dimension of SM is not considered. The weightings of SM practices evaluation depends on business priorities and organization strategies. In such cases weightings are assigned subjectively and arbitrarily which leads to the strategy selection for SM which may be not accurate based on the organization's requirements. In studies, authors have used many approaches for primary selection for strategies but it is not mentioned why this strategy is the best choice and other strategies which are failed during the selection might improve their performance in the future. In addition we found that sensitivity analysis is not done in most of the studies. Sensitivity analysis helps to investigate the impacts of criteria weights on the strategy selection for manufacturing processes with the best environmental and economic performance. So, sensitivity analysis should be done in future studies with MCDM approaches. We have further observed that authors have focused on the methodologies and criteria for the SM research but these investigations need to be including the level of acceptance of models by both researchers and practitioners in future studies. Comparative analysis also should be done in future studies which should be both practical and research-oriented. Validation and reliability of techniques should be included in the

future study for additional development. Many researchers, including us, may be biased for a particular approach over another approach. For more progress in this research area, more investigations with experimental settings are needed especially with the consideration of ecological and environmental factors.

6. Proposed Framework

Based on the literature findings in this section we have proposed an MCDM based framework for manufacturing industries presented in Figure 8. The proposed framework is divided into three phases. In the first phase of MCDM based SM framework industries need to consider performance indicators or strategies in three aspects of sustainability i.e. economic, social, and environmental. In the previous studies, authors have identified performance indicators, barriers, enablers, influencing factors, and manufacturing strategies related to SM as discussed in Table 8 which can be used by industries for their problem formulation. However, some modification needs to be done as strategies, enablers, and barriers for any industry depends on the type of industry sector or geographical region of industry. Some authors have considered all factors related to SM but in some studies, only critical factors are reported. So it is advised to conduct a pilot study before finalizing the factors with industry experts this will help to make a robust framework for SM. In the second phase of the framework, data collection can be done with the help of questionnaire surveys and interviews. This data can be analyzed with the MCDM techniques i.e. AHP, ANP, DEMATEL, or any other hybrid approach. Other models such as value measurement models, goal and reference level models, and outranking models can also be used for the data analysis. Based on the results obtained from these models manufacturing strategies can be planned for industries. In the third phase, benefits are discussed from three aspects of sustainability.

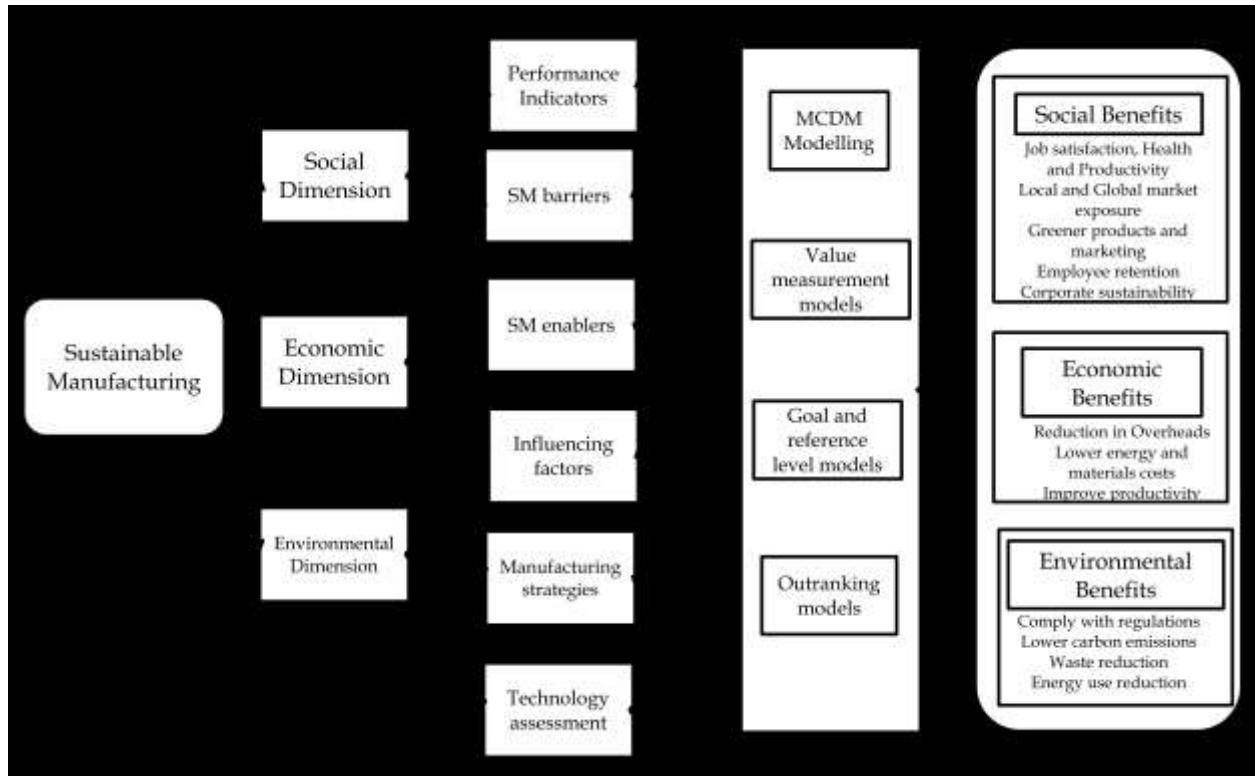


Figure 8: Proposed MCDM based framework for Sustainable manufacturing practices

6.1 Implications for researchers

Based on the findings from the systematic literature review some research questions and future research scopes can be concluded which can be addressed by future studies on MCDM applications in SM:

1. In this study, we have found that developing countries are focusing on the use of MCDM applications in the SM area but all these studies are generalized and not specific to particular industry-specific. As implementation of SM practices depends on the industry sector and other factors hence frameworks cannot be generalized. Still, there is a need to conduct the industry sector-specific studies e.g. pharmaceutical and chemical industry sectors in particular where carbon emission levels are much higher as compared to other industry sectors should be investigated.
2. The findings from this study conclude that there are many research opportunities for MCDM applications in SM. The industries can take benefits from these practices in all three aspects of sustainability. In past studies, we have found that very few studies focus

on the social aspects which can be addressed in future studies to achieve sustainability in the business practices.

3. It would be more interesting if future studies can address the implementation issues of SM in Industry 4.0. As industries nowadays are focusing on the Industry 4.0 implementation and it is obvious that there is a need to maintain sustainability in Industry 4.0 practices. We found that still there are very limited studies that report about the SM in the Industry 4.0 platform. This is an emerging research area that can be addressed in future studies.
4. It is found that hybrid approaches are more reliable than conventional MCDM approaches. Very few studies reports about the use of hybrid approaches and sensitivity analysis for results. This is the major research gap in most of the studies which are expected to be addressed in the future.
5. Still, the conventional methods are used for MCDM model assessment and evaluation. In this study, we have provided various software and their applications that can be used in future studies for MCDM applications in SM. This will help the researchers to save time in data analysis and assessment in MCDM models.

6.2 Implications for practitioners and policymakers

Policymakers and practitioners play an important role in the successful implementation of SM practices. As we know that SM practices require high investment costs in initial but despite that SM practices help to maintain economic and environmental sustainability by minimizing wastes and carbon emissions. Both practitioners and policymakers can subsidize the investments for SM practices with the adoption of new technologies i.e. IoT and Cyber-physical systems. These technologies are considered as key technologies for Industry 4.0 and help to enhance the sustainability in manufacturing practices. In the future, different manufacturing scenarios can be considered with different constraints for SM practices which will help to achieve real-time solutions to manufacturing problems in industries. It is found that in most studies only a single scenario is considered without highlighting the social factors. Policymakers and practitioners are expected to consider more social factors in future SM plans as it is helpful for environmentally conscious and socially responsible manufacturing for emerging economies. Lack of skilled

labour is still a major problem for the emerging economies which can be solved by conducting environmental awareness programs and training sessions at the local level.

7. Conclusion

This paper reviewed the MCDM approaches in the SM area by selecting the literature available on the Scopus database from January 2000- April 2020. In these studies, many individual and integrated approaches have been adopted to assess or evaluate SM practices. It is found that SM assessment with MCDM techniques has become popular in the last four years. Now the researchers are more focused on the evaluation of SM practices with MCDM techniques. We found that AHP (Analytical Hierarchy Process) is a widely used approach in the area of SM and most of the studies consider the environmental criteria. Most of the studies on the MCDM technique with SM is done in developing nations. In the developing nations, the policies for manufacturing are also reconstructing for the adoption of SM practices which will help the industries to reduce the negative impact of manufacturing on the environment and increase their market value. Considering the multiple sustainability scenarios, drives, factors, and indicators, MCDMs are suited for the revolutionary objectives. To achieve the real-time best solution to the problem overcoming all the local and environmental issues, MCDM models can be utilized with multiple criteria and multiple scenarios.

Besides the recommendations like crisp results in barriers, drivers, or indicators prioritization, FMEA for failed SM practices might be added to aid the decision-makers and researchers in the evaluation of SM practices. The critical analysis done in this paper needs to tie the model developers of industries with behavioral decision making literature. In future studies, experimental designs are necessary along with application validation. There are ample opportunities in SM for future investigations in many research directions indicated in this study. This review paper summarizes the important aspects of MCDM models in SM and outlines drivers, indicators, and factors considered in the different SM practices. This can be used to address the core issues to achieve the sustainability goals in the manufacturing industries of developing nations in different industry sectors. In future studies, other databases such as Web of science and Sciencedirect can be considered for review analysis. Further, this study can be extended by conducting bibliometric analysis with content analysis or cluster analysis.

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