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An Evaluation of Drivers in Implementing Sustainable Manufacturing in India: Using DEMATEL Approach

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***Abstract*—**Due to growing concern about environmental and social consequences throughout the world, a need has been felt to incorporate sustainability concepts in conventional manufacturing. This paper is an attempt to identify and evaluate drivers in implementing sustainable manufacturing in Indian context. Nine possible drivers for successful implementation of sustainable manufacturing have been identified from extensive review. Further, Decision Making Trial and Evaluation Laboratory (DEMATEL) approach has been utilized to evaluate and categorize these identified drivers for implementing sustainable manufacturing in to the cause and effect groups. Five drivers (Societal Pressure and Public Concerns; Regulations and Government Policies; Top Management Involvement, Commitment and Support; Effective Strategies and Activities towards Socially Responsible Manufacturing and Market Trends) have been categorized into the cause group and four drivers (Holistic View in Manufacturing Systems; Supplier Participation; Building Sustainable culture in Organization; and Corporate Image and Benefits) have been categorized into the effect group. "Societal Pressure and Public Concerns" has been found the most critical driver and "Corporate Image and Benefits" as least critical or the most easily influenced driver to implementing sustainable manufacturing in Indian context. This paper may surely help practitioners in better understanding of these drivers and their priorities towards effective implementation of sustainable manufacturing.

***Keywords*—**Drivers, Decision Making Trial and Evaluation Laboratory (DEMATEL), India, Sustainable Manufacturing (SM).

I. Introduction

SUSTAINABILITY issues are becoming very popular in today's current scenario because the current assumption that natural resources are infinite and that the regenerative capacity of the environment is able to compensate for all human action is no longer acceptable [1]. Sustainability issues are also becoming relevant in one of most developing countries i.e. India because the most of world's manufacturing will be carried out in Asia continent within the next twenty years [2] and will create a lot of opportunities in this continent, but it will also bring about considerable environmental [3] and social issues [4] in the manufacturing.

Sustainable manufacturing is a systems approach for the creation and distribution of innovative products and services that minimizes resources; eliminates toxic substances; and produces zero waste that in effect reduces green house gases across the entire life cycle of products and services [5].

Sustainable manufacturing must respond to economical challenges by producing wealth and new services ensuring development and competitiveness through time; environmental challenges by promoting minimal use of natural resources and managing them in the best possible way while reducing environmental impact; and social challenges, by promoting social development and improved quality of life through renewed quality of wealth and jobs [6].

In many other countries in the Asia-Pacific region especially India expects economic, social, and environmental factors have also started to make manufacturing companies consider sustainability more seriously [7]-[9]. Therefore need arises to evaluate the drivers of sustainable manufacturing in India.

Literature review approach has been used for identifying relevant drivers in implementing sustainable manufacturing. A literature review is significant, an integral and valid part of any research to identify the conceptual content of the field and gives guidance towards theory development [10], [11]. Decision Making Trial and Evaluation Laboratory (DEMATEL) methodology has been utilized for evaluating the identified drivers of sustainable manufacturing. The DEMATEL approach has been identified as an appropriate tool for analyzing structure and relationships between drivers of sustainable manufacturing [12].

The remainder of this paper is organized as follows. Relevant literature on drivers in implementing GM has been presented in Section II. Methodology of the research has been explained in Section III. Data analysis and results have been presented in Section IV. Discussions of finding have been given in Section V. Concluding remarks have been given with the limitations of this research and the directions for future research in the last section.

II. Literature Review: Identification of Drivers in Implementing Sustainable Manufacturing

Extensive literature review has been made to identify drivers in implementing Sustainable manufacturing (SM). Nine possible drivers for successful implementation of sustainable manufacturing have been identified from extensive review and explained as:

A. Regulations and Government Policies

Government regulation and policies often play an important role in encouraging manufacturing firms to adopt sustainability practices [13]. The Government must ensure the

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uniform environmental regulations in all states/regions of the country to stop manufacturing firms from shifting the dirty manufacturing to places with lax environmental legislations [14]. Government must promote the development of indigenous green technologies in association with financial technical institutions and facilitate the industry to import and implement proven technologies [15].

B. Top Management Involvement, Commitment and Support

Members of top management are very influential in encouraging manufacturing firms to evaluate their role in society and are responsible for the firms' environmental management leadership [16], [17]. Top management involvement, commitment and support play a crucial role in resources allocation for environmental practices [18].

C. Holistic View in Manufacturing Systems

Sustainable manufacturing requires a holistic view spanning in product, manufacturing processes and supply chain including the manufacturing systems across multiple product life-cycles. In particular, recent trends in developing improved sustainability scoring methods for products and processes, and predictive models and optimization techniques for sustainable manufacturing processes [7].

D. Effective Strategies and Activities towards Socially Responsible Manufacturing

Internal strategies and policies are required to improve internal operations with continuous process improvements related to sustainability, such as, employee involvement, infrastructure development, waste reduction, energy conservation, and emissions control [19]. Manufacturing firms should adopt business strategies and activities that meet the needs of the firms and its stakeholders today, while protecting, sustaining and enhancing the human and natural resources that will be needed in the future [20].

E. Corporate Image and Benefits

Mitigating environmental, health, and safety impacts of a manufacturing firm is socially responsible and good business. Promoting environmental care may enhance a manufacturing firm's corporate image [19]. Establishing company's image and enhancing market competitiveness are considered as the key driving factors to sustainable manufacturing initiatives in a firm [21]. Manufacturing firms that adopt sustainable practices are able to achieve increased product quality, increased market-share and increased profits etc. [22].

F. Societal Pressure and Public Concerns

During recent years, the natural environment has become a demanding topic that manufacturing firms must think about sustainability due to the economic, ecological impacts and increasing awareness of environment protection among society [23]. Public concerns in terms of pressure from media, banks, insurance companies, NGOs, etc. has been identified as an important driver for green manufacturing for achieving environmental, economical and social benefits [14]. Public concern about societal issues drives the implementation of proactive environmental practices in manufacturing [24], [25].

G. Market Trends

Nowadays, manufacturing firms have started to adapt certain sustainability options within their organizations, with the awareness they receive from foreign business partners or due to the market pressure from environmentally conscious customers of foreign countries [26]. Manufacturing firms need to develop sustainable products to meet the market needs and stay alive in throat cut competition [27].

H. Supplier Participation

Supplier participation dimension plays a significant role in applying sustainability principles in the supply chain [28], [29]. The supplier selection process is critical for manufacturing firms because it influences and extensively participates in an organization's response to concerns about sustainability [30]. A supplier's participation is required to develop various skills, infrastructure and technologies, which are prime requisite of sustainable manufacturing [31], [32].

I. Building Sustainable Culture in Organization

Manufacturing firms must build sustainability culture in their organizations [33]. Culture of sustainability is one in which organizational members hold shared assumptions and beliefs about the importance of balancing economic efficiency, social equity and environmental accountability etc. [34].

These identified drivers from literature review have been consulted with a panel of seven experts (five from academia and two experts from manufacturing industry). Experts were asked to rate these identified drivers for implementing sustainable manufacturing in Indian industries on 5 point Likert scale (5 (where, 1-least significant and 5-most significant). Based on mean scores, all drivers have been finalized and shown in Table I.

TABLE I
IDENTIFIED DRIVERS FOR IMPLEMENTING SUSTAINABLE MANUFACTURING IN INDIA

S. N.	Drivers for Implementing Sustainable Manufacturing	Code	References	Mean
1	Regulations and Government Policies	RGP	[13]-[15]	4.86
2	Top Management Involvement, Commitment and Support	TMC	[16]-[18]	4.57
3	Holistic View in Manufacturing Systems	HVM	[7]	4.42
4	Effective Strategies and Activities towards Socially Responsible Manufacturing	ESP	[19], [20]	4.57
5	Corporate Image and Benefits	CIB	[19], [21], [22]	4.29
6	Societal Pressure and Public Concerns	SCP	[14], [23]-[25]	4.86
7	Market Trends	MRT	[26] and [27]	4.29
8	Supplier Participation	SPP	[28]-[32]	4.42
9	Building Sustainable culture in Organization	BSO	[33], [34]	4.29

Further, these identified drivers for implementing sustainable manufacturing in Indian context will be evaluated according to their importance.

III. Methodology: DEMATEL Approach

Decision Making Trial and Evaluation Laboratory (DEMATEL) approach has been used for evaluation of drivers in implementing sustainable manufacturing in Indian perspective. The DEMATEL approach, a mathematical procedure originated from the Geneva Research Centre of the Battelle Memorial Institute, was designed to deal with important issues of world societies [35].

A. Steps in DEMATEL Method

The DEMATEL is based on digraphs, which can separate involved factors into cause group and effect [36]. The steps for applying DEMATEL approach are given as follows:

Step 1. Define expert panel and evaluation criteria for successful sustainable manufacturing

In this step, a panel of experts (two experts from industry and five from academia) has been formed to provide their opinions. Drivers in implementing sustainable manufacturing in Indian perspective identified from literature approach have been discussed with experts and finalized as evaluation criteria.

Step 2. Construct initial direct relation matrix

Pair-wise comparisons have been made to develop the initial direct relation matrix using 0-4 scale (0 = no influence; 1 = very low influence; 2 = low influence; 3= high influence; 4 = very high influence) according to opinions of. If there are 'M' experts whom have to evaluate causality among the identified drivers of sustainable manufacturing and given by $x^{k}_{ij.}$ The entries written by experts forms a n×n matrix i.e. $X^{k} = x^{k}_{ij.}$; Where, k = 1, 2, 3 4...n (number of experts). Further, the n × n average matrix Z, which is also called initial direct relation matrix for all decision makers, can be calculated as follows:

$$\frac{1}{k\sum x^{k}_{ij}} \tag{1}$$

Step 3. Obtain the normalized initial direct relation matrix (D) for the initial direct-relation matrix (Z) by using following:

$$m=\min\left[\frac{1}{\max\sum x^{k=n}_{j=[aij]}};\ \frac{1}{\max\sum x^{k=n}_{i=[aij]}}\right] \tag{2}$$

$$D = M \times Z \tag{3}$$

Step 4. Construct the total-relation matrix

The normalized matrix is transformed to total relation matrix and expressed using (4) as given below:

$$T = (I - D)^{-1} \tag{4}$$

where, I: identity matrix ; T: total relation matrix:

$$T = [t_{ij}]n \times n$$

Step 5. Calculate the sum of rows and the sum of columns. The summation of rows and columns of the total relation matrix T are computed and Rand C n×1 vectors and are given as:

$$[R_i]n \times 1 = [\sum_{j=1}^{n} t^{ij}]n \times 1 \tag{5}$$

$$[C_j]1 \times n = [\sum_{j=1}^{n} t^{ij}]\ 1 \times n \tag{6}$$

Step 6. Draw a cause and effect diagram by mapping the dataset of $(\mathbf{R_i + C_j\ ;\ R_i - C_j})$.

$[R_i]n \times 1$ represents the total effects, provided by one criterion say (i) to the other criteria (j), whereas $[C_j]1 \times n$ represents the total effects, experienced by criteria j from the other criteria i. While, the summation of $(\mathbf{Ri + Cj})$ called "Prominence" depicts the measure of significance of criterion in system and also provides a measure for showing the total effects i.e. both influenced and influential power for the criteria while, $(\mathbf{Ri - Cj})$ called "Relation" shows the entire effect of a criterion in a system. Further, when $(\mathbf{Ri - Cj})$ is positive, the particular criteria falls into cause group, and when it is negative, it corresponds to the effect group.

IV. Data Analysis and Results

In first step, a panel of experts has been formed to define the decision goals for evaluating drivers in implementing green manufacturing in India. Nine drivers for implementing successful sustainable manufacturing have been identified from extensive literature and validated through experts' opinions. Further, experts have made pair-wise comparisons between identified drivers to develop the initial direct relation matrix or average matrix using 0-4 scale. Initial direct relation matrix has been shown in Table II.

TABLE II
Initial Relationship Matrix for Drivers in Implementing Sustainable Manufacturing in India

Drivers →	RGP	TMC	HVM	ESP	CIB	SCP	MRT	SPP	BSO
RGP	0	2.5	2	3	3	1	3.5	3.5	3.5
TMC	2	0	2.5	3	2.5	1	3	3.5	3.5
HVM	1	2	0	1.5	3.5	2	1	3	2.5
ESP	1	1	3	0	4	1	3	3.5	3.5
CIB	2.5	2	3	1	0	2.5	1.5	1	1
SCP	1.5	2	2	3	4	0	3.5	3.5	3.5
MRT	2	2	2	1.5	3.5	2	0	2.5	3
SPP	2	2	2.5	1	3.5	1.5	1	0	2.5
BSO	1.5	1	2.5	1	3	2	1.5	2	0

In the next step, the normalized direct-relation matrix has been obtained by (2) and (3). Further, the total direct relation matrix has been obtained using (4) and shown in Table III.

In the next step, the sum of rows (R) and the sum of columns (C) have been calculated by using (5) and (6). After that, datasets (R + C) and (R −C) have been calculated and have been shown in Table IV.

TABLE III
TOTAL DIRECT RELATIONSHIP MATRIX FOR DRIVERS IN IMPLEMENTING SUSTAINABLE MANUFACTURING IN INDIA

Drivers →	RGP	TMC	HVM	ESP	CIB	SCP	MRT	SPP	BSO
RGP	0.29	0.40	0.49	0.41	0.65	0.33	0.48	0.56	0.58
TMC	0.36	0.29	0.49	0.39	0.61	0.32	0.44	0.55	0.56
HVM	0.27	0.31	0.31	0.28	0.54	0.30	0.30	0.44	0.43
ESP	0.31	0.31	0.48	0.25	0.63	0.31	0.42	0.51	0.52
CIB	0.31	0.30	0.40	0.26	0.38	0.30	0.31	0.36	0.36
SCP	0.37	0.40	0.51	0.42	0.71	0.30	0.49	0.58	0.59
MRT	0.33	0.34	0.43	0.31	0.59	0.33	0.30	0.47	0.49
SPP	0.30	0.31	0.40	0.26	0.53	0.28	0.30	0.32	0.42
BSO	0.26	0.25	0.38	0.24	0.48	0.28	0.30	0.37	0.30

TABLE IV
CALCULATION OF (R+C), (R-C) AND RANK FOR DRIVERS IN IMPLEMENTING SUSTAINABLE MANUFACTURING IN INDIA

Drivers in implementing SM ↓	R	C	R+C	R-C	Rank
RGP	4.1899	2.7959	6.9859	1.3940	II
TMC	4.0026	2.9153	6.9178	1.0873	III
HVM	3.1974	3.8854	7.0828	-0.6880	VI
ESP	3.7285	2.8157	6.5442	0.9128	IV
CIB	2.9807	5.1108	8.0915	-2.1300	IX
SCP	4.3597	2.7600	7.1197	1.5997	I
MRT	3.5831	3.3357	6.9187	0.2474	V
SPP	3.1223	4.1569	7.2792	-1.0346	VII
BSO	2.8604	4.2490	7.1094	-1.3886	VIII

Based upon their (R-C) score, these identified drivers have been ranked. "Societal Pressure and Public Concerns" driver has been reported highest (R-C) value 1.5997 and ranked first. Similarly, "Corporate Image and Benefits" driver has been reported as lowest (R-C) value -2.1300 and ranked last.

In the last step, (R + C) and (R −C) datasets has been used to draw the cause and effect diagram as shown in Fig. 1.

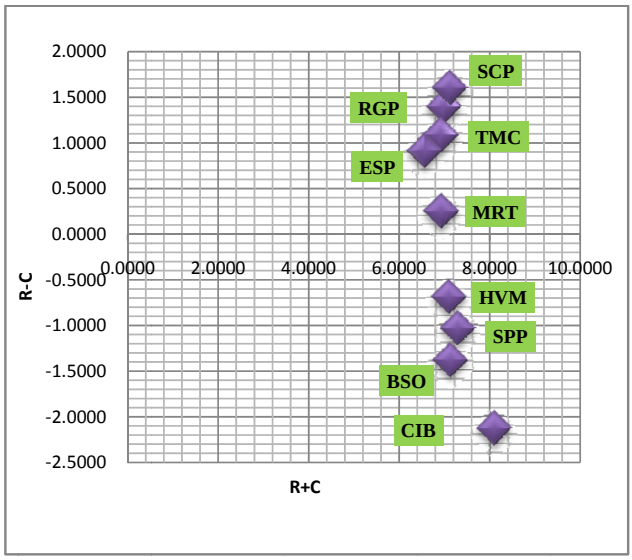

Fig. 1 The cause and effect diagram of drivers for implementing sustainable manufacturing in India

From Fig. 1, drivers namely Societal Pressure and Public Concerns (SCP); Regulations and Government Policies (RGP); Top Management Involvement, Commitment and Support (TMC); Effective Strategies and Activities towards Socially Responsible Manufacturing (ESP) and Market Trends (MRT) have been categorized into the cause group while the effect group was composed of drivers such as Holistic View in Manufacturing Systems (HVM); Supplier Participation (SPP); Building Sustainable culture in Organization (BSO) and Corporate Image and Benefits (CIB).

V. DISCUSSIONS OF FINDINGS

Sustainable manufacturing has been receiving considerable attention from business managers/SC practitioners. Sustainable manufacturing is a new research paradigm in which manufacturing industries produce products in a sustainable manner while maintaining global competitiveness and coping with recent challenges and problems [37]. This paper provides identification and evaluation of drivers in implementing sustainable manufacturing in Indian context. A comprehensive literature review was conducted to identification of drivers in implementing sustainable manufacturing in Indian context. Most relevant nine drivers for successful implementation of sustainable manufacturing have been identified and validated through experts' opinions. Further, an application of DEMATEL approach has been made to distinguish whether a driver belongs to the cause group or the effect group. The cause group implies the meaning of the influencing drivers, whereas the effect group denotes the meaning of the influenced drivers. In this research, the following results have been obtained:

- ✓ Societal Pressure and Public Concerns (SCP); Regulations and Government Policies (RGP); Top Management Involvement, Commitment and Support (TMC); Effective Strategies and Activities towards Socially Responsible Manufacturing (ESP) and Market Trends (MRT) have been found positive (R-C) values and categorized into the cause group.
- ✓ Holistic View in Manufacturing Systems (HVM); Supplier Participation (SPP); Building Sustainable culture in Organization (BSO) and Corporate Image and Benefits (CIB) have been found negative (R-C) values and categorized into the effect group.

Cause group drivers are very critical due to their direct impact on the system and it would be significant to focus primarily on the cause group attributes in the beginning, as their influence on the effect group attributes is significant [12]. Therefore, a high level of focus is essential on the cause group rather than effect group. If, we want to achieve successful implementation of sustainable manufacturing in Indian industries, it is necessary to control and pay attention to the cause group factors to reach high level of performances in terms of the effect group drivers such as Holistic View in Manufacturing Systems; Supplier Participation; Building Sustainable culture in Organization and Corporate Image and Benefits.

Societal Pressure and Public Concerns (SCP); Regulations and Government Policies (RGP) and Top Management Involvement, Commitment and Support (TMC) have been reported as three top most important drivers for implementing sustainable manufacturing.

This paper may play important role to understand various drivers in implementing sustainable manufacturing. Evaluation of these drivers will help to understand their importance and priorities in implementing sustainable manufacturing in Indian context.

VI. Concluding Remarks

Due to globalization, intense global competition, rapid technological changes, shorter product life cycles, environment and social issues, Indian manufacturing are under tremendous pressure to implement sustainable manufacturing. This study offers a meaningful base to deepen the understanding towards successful implementation of sustainable manufacturing in Indian context. An attempt has been made to present an operational model for segmenting drivers for implementing sustainable manufacturing. This developed operation model will surely help practitioners in priority setting of these drivers towards effective and successful implementation of sustainable manufacturing in Indian industries. Our research has implications for researchers and practitioners in better understanding of issues related to sustainable manufacturing.

Drivers identified from extensive literature review. The literature was not sufficient in Indian context. We have taken literature from various developed/developed countries in identifying drivers for sustainable manufacturing. All pair comparisons in DEMATEL have been made on the basis on the experts' opinions selected from academia and industry. Opinions of experts may be different. Experts are not randomly selected.

Further, other multi-criteria decision making models (AHP, ANP, TOPSIS and VIKOR etc.) may be applied for the same problem and results obtained from these methods may be compared with the results of the present study. In future research may be focused on empirical study/case study in specific Indian industry for analyzing drivers for successful achievement of sustainable manufacturing practices.

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