Vol. XII & Issue No. 5 May - 2019
INDUSTRIAL ENGINEERING JOURNAL

IDENTIFICATION OF ELEMENTS TOWARDS ESTABLISHING SUSTAINABLE MANUFACTURING SYSTEM: AN ANALYSIS USING AHP AND R3I COMBINED METHODOLOGY

Subrata Kumar Patra
Tilak Raj
B. B. Arora

ABSTRACT:

In order to cope-up with the mounting global business challenges and to comply with the environmental regulations, manufacturers are gradually shifting their focus towards sustainable manufacturing practices. Espousal of sustainable manufacturing technology and sustainable practices are the need of the hour. The current study is planned for the identification of various elements towards the development of Sustainable Manufacturing System (SMS). A combination of AHP (Analytic hierarchy process) and R3I (Relative Reliability Risk Index) methodology will be used for identifying vital manufacturing elements that would be able to develop SMS in a manufacturing setup. The present analysis is primarily based on literature review and expert opinion. The combined AHP and R3I analysis will help in ranking the identified elements based on their relative weightages. The analysis might provide a significant decision-making Input to the managers willing to work for the development of SMS.

KEYWORDS: *SMS; sustainable manufacturing system; SD; sustainable development; AHP; analytic hierarchy process; CSR; corporate social responsibility; issues; elements; R^3I; relative reliability risk index; MCDM; multi criteria decision making; entropy method*

1. INTRODUCTION

Growing issues of environmental degradation as a result of manufacturing activities are encouraging the policy-makers to chalk out strategies for sustainable business practices. In order to endeavour and sustain in the competitive global business environment, manufacturers are striving hard and concentrating their focus towards sustainable business practices. Implementation of Sustainable manufacturing technology and sustainable practices are the need of the modern generation. This is especially true because sustainable practices will not only diminish the environmental degradation triggered by manufacturing activities but will also assist in long-term economic gain of the business. Various initiatives like redesigning of products, reorganization of processes, renovation of system, enhancement of energy efficiency, adoption of clean and renewable energy, reduction of waste, emission, pollution, devotion towards resource conservation and recycling practices, special focus on E-waste management and similar other steps with the active participation of all stakeholders might help in realizing the same. A critical examination of various elements accompanied with traditional manufacturing systems might provide significant acumens that would be supportive towards the development of SMS.

1.1 Manufacturing for Sustainability

Present global competition call for business excellence that seeks harmonization between business and manufacturing strategies. A study on manufacturing methods suggests that strategic alignment of competitive sovereignties with business strategy will enhance the business excellence of the manufacturing organizations (Balkrishna Eknath Narkhede, 2016).

Any manufacturing process helps in the conversion of natural resources into finished goods to fulfil the requirement of the consumers. Many of the manufacturing activities however, give rise to environmental problems like generation of waste, emission, pollution and associated problems which might cause global warming, unpleasant environment, shortage of resources and several health-related issues- the impact of which cannot be underestimated. To fulfil the rising demand of the society, manufacturers are under constant pressure to yield a vast range of consumer goods and value-added products. Therefore, there is an urgent need towards balancing between business growth and environmental protection.

Bhaskar B. Gardas et al. (2016) cited that in order to cope up with the depleting resources, organizations are gradually focusing towards environment friendly manufacturing practices and energy efficient processes.

Geir B. Asheim (1994) described Sustainability as a necessity of present generation to manage the resources in such a way that the average quality of life enjoyed by the present generation be maintained for all future generations. Development will therefore be sustainable if it involves a non- decreasing average quality of life.

Sustainable Manufacturing is the technique to create manufactured products through economically-sound processes that can minimize negative environmental impact while conserving energy and natural resources (www.epa.gov/sustainability /sustainable-manufacturing).

2. LITERATURE REVIEW

Manufacturing industries are capable of enlightening the human environment by way of making a variety of goods using raw materials or degrading the environment through environmental pollution (Our Common Future, un-documents.net/ocf-08.htm).

Unsustainable consumption and Production are treated as the primary reasons towards continued global environmental degradation (Rio Earth Summit, 1992; World Summit for Sustainable Development, 2002).

Vijay Srinivasan (2011) viewed that after the European regulation on Restriction of the use of Hazardous Substances (RoHS) came into effect in 2006, it had impacted the global electrical and electronics industries. He assessed that ROHS had inspired many businesses to adopt sustainable practices after their realization of potential business opportunities that might be achieved through sustainable practices. Sustainability was also believed to be the key driver for innovation.

Innovative manufacturing techniques might be helpful in reducing carbon emissions. This can be appreciated through the evolution towards renewable and alternative energy resources such as hydropower, solar, wind power, biomass energy, geothermal energy thereby developing towards sustainable energy systems (Ji Han et al.,2012).

Sustainability indicators generally focuses on two broad objectives namely sustainability reporting and decision making for sustainability. Various sustainability indicators are environmental, social and technical indicators. Other sustainability indicators might be economic performance with technical performance and political/governance indicators with social indicators (J. Petrie et al., 2007).

In order to progress towards sustainability, eco-innovations are of paramount importance. This is so because eco-innovations are supportive toward promoting manufactured products by means of processes that use less resource and causes less environmental impact. Two analysis were carried out on eco-innovations. One analysis compared steel and aluminum for the making of car bodies where light weight was the main criteria; the other analysis studied the battery-powered and solar lawn mowers as compared to the conventional engine mowers where environmental performance was the main criteria. The analysis divulges that innovation theory is valuable towards the development of eco-innovations (Glenn Johansson, 1998).

Implementing and operating Sustainable technologies in an organization is a complex and challenging task. Michael Mutingi (2017) observed that several barriers deter the development towards Sustainable manufacturing system. Some of these are: lack of awareness on sustainability concepts, inadequate financial support and funding, lack of standards and guidelines, implementation and operational challenges, high initial costs for sustainable technology implementation, lack of management support, employee resistance, deficiency of pressure from the community, shareholders and investors.

AHP methodology is a system analysis technique for solving decision problems. It was developed by T. L. Saaty (1980).AHP is used to transmute complex decision problems into fundamental subjects to generate a hierarchical model in which the overall goal is placed at the highest level and various decision alternatives are positioned at the lower levels(S.L. Tung and S.L. Tang, 1998; Ming-Tang Wang, 2014).

AHP has been successfully used for the study and analysis of the quality of several telecommunications companies (Christos Douligeris and Ian J. Pereira, 1994). An AHP analysis was carried out to analyze drivers of Advanced Sustainable manufacturing system by K. Madan Shankar et al. (2016). Ming-Tang Wang (2015) used AHP in combination with ISM for Making an Innovative Rescue Caring Design in Landslide Area.

3. METHODOLOGY

The current research is aimed at identifying various elements that would be essential towards the development of SMS. For this purpose, literature review and expert opinions were followed. The identified elements were categorized and analysis carried out using MCDM (Multi Criteria Decision Making) techniques namely AHP and R^3I techniques.

3.1 Objectives of research

The main objectives of this research work are categorized below:

- Identification of various elements towards the development of Sustainable manufacturing system in a manufacturing setup
- Judgmental analysis to formulate the relationships among these elements
- Ranking of these elements using AHP
- Authentication and Validation of the result using R^3I (Relative Reliability Risk Index) technique
- Result and discussion
- Conclusion

A comprehensive literature review on traditional as well as sustainable manufacturing practices and associated issues helped indentifying an initial list of elements. Further brainstorming with the inputs from academicians and industry experts helped in finalizing the critical elements for the advancement towards SMS. At the end, a total of 31elements were agreed upon as reasonable and significant elements. These elements have been segregated into four main issues of SMS on the basis of their attributes and features. These four issues are:

- Environment related issues (E_1)
- Economic related issues (E_2)
- Social and behavioral issues (E_3)
- Technology and allied issues (E_4)

Table1 signifies these issues and various sub-elements linked to each of these issues.

Table 1: Various issues and linked elements towards SMS

Issues in Sustainable manufacturing system				Reference/ Sources
E_1	Environment related issues	E_{11}	Waste management	Karl R. Haapala et al. (2011), Neeraj Bhanot et al. (2015), Subrata Kumar Patra et al. (2017), A. Paulraj (2008), S. Gilbert (2000)
		E_{12}	Government support and environmental legislation	Michael Mutingi et al. (2017), I. S. Jawahir (www.ncsl.org), Neeraj Bhanot et al. (2015), Ming Chen (2006), A. Paulraj (2008), S. Luthra et al. (2011)
		E_{13}	Focus on 3 R's Principles	Neeraj Bhanot et al. (2015), Zohreh Molamohamadi and Napsiah Ismail (2013), Ming Chen (2006), S. Gilbert (2000)
		E_{14}	Resource conservation	Subrata Kumar Patra et al. (2017), S. Gilbert (2000), Neeraj Bhanot et al. (2015), Subrata Kumar Patra et al. (2015)
		E_{15}	Environment management systems	A. Paulraj (2008), S. Gilbert (2000), J. Sarkis (2010)
		E_{16}	Public awareness on environmental issues	Neeraj Bhanot et al. (2015), Subrata Kumar Patra et al. (2017), A. Paulraj (2008)
		E_{17}	Emission control	Karl R. Haapala et al. (2011),S. Gilbert (2000), Subrata Kumar Patra et al. (2015), Ming Chen (2006), Ji Hanet al. (2012)
E_2	Economic related issues	E_{21}	Commercial advantages	I. S. Jawahir (www.ncsl.org), Neeraj Bhanot et al. (2015), S. Gilbert (2000), Vijay Srinivasan (2011)
		E_{22}	Investment towards technology and innovation	Michael Mutingi et al. (2017), Neeraj Bhanot et al. (2015), V. Ravi and R. Shankar (2005)
		E_{23}	Cost control	Karl R. Haapalaet al. (2011), S. Gilbert (2000), Neeraj Bhanot et al. (2015), Vijay Srinivasan (2011)
		E_{24}	Availability of Capital and organizational resources	Michael Mutingi et al. (2017), Neeraj Bhanot et al. (2015), Subrata Kumar Patra et al. (2015)
		E_{25}	Incentives and subsidies funded by government to promote sustainable technologies	Neeraj Bhanot et al. (2015), Expert opinion
		E_{26}	Ease of soft loans and creditfacilities by financial institutions	Neeraj Bhanot et al. (2015), S. Gilbert (2000)
		E_{27}	ROR (Rate of return) on investment towards sustainable technologies	S. Gilbert (2000), Vijay Srinivasan (2011), Expert opinion
E_3	Social and behavioral issues	E_{31}	Vision for long term sustainable development	S. Gilbert (2000), Neeraj Bhanot et al. (2015)
		E_{32}	Employee health, safety and welfare	Karl R. Haapala et al. (2011), Expert opinion

		E_{33}	Top Management support and commitment	Zohreh Molamohamadi and Napsiah Ismail (2013), Neeraj Bhanot et al. (2015), V. Ravi and R. Shankar (2005)
		E_{34}	Motivation and teamwork of the employees	Chieh- Yu Lin and Yi - Hui Ho(2008), V. Ravi and R. Shankar(2005)
		E_{35}	Business ethics/ Company policy	Zohreh Molamohamadi and Napsiah Ismail (2013), I. S. Jawahir (www.ncsl.org), J. Sarkis (2010)
		E_{36}	Market demand for Green products	Michael Mutingi (2017), Neeraj Bhanot et al. (2015), S. Reijonen (2011), S. Gilbert (2000)
		E_{37}	Population explosion	Ji Han et al. (2012), Subrata Kumar Patra et al. (2015), Expert opinion
		E_{38}	Corporate Social Responsibility	I. S. Jawahir (www.ncsl.org), Vijay Srinivasan (2011), Jose Maria Agudo - Valiente et al. (2017)
E_4	Technology and allied issues	E_{41}	Process control	Neeraj Bhanot et al. (2015), Expert opinion, Subrata Kumar Patra et al. (2017)
		E_{42}	Quality control	Michael Mutingi et al. (2017), Neeraj Bhanot et al. (2015)
		E_{43}	Workers' training and education on sustainable technologies and practices	I.S.Jawahir(www.ncsl.org), Michael Mutingi et al. (2017), Neeraj Bhanot et al. (2015)
		E_{44}	Eco-innovation-oriented research	I.S. Jawahir(www.ncsl.org), Louis G. Tornatzky and M. Fleischer(1990),H.W.M. Van Bommel (2011), Vijay Srinivasan (2011), Glenn Johanssonand Thomas Magnusson(1998)
		E_{45}	Standardized metrics or performance benchmarks	Michael Mutingi et al. (2017), Neeraj Bhanot et al. (2015), J. Sarkis (2010), J. Petrie et al. (2007)
		E_{46}	Energy efficiency	Karl R. Haapala et al. (2011),www.energy.gov, Subrata Kumar Patra et al. (2015), Ming Chen (2006)
		E_{47}	Support for developing new Technologies(R&D)	I.S.Jawahir(www.ncsl.org),www. energy. gov, Subrata Kumar Patra et al. (2015)
		E_{48}	Implementation and operational issues	I. S. Jawahir (www.ncsl.org), J. Sarkis (1998), H.W.M.Van Bommel(2011)
		E_{49}	Pursuit towards clean and renewable energy	Subrata Kumar Patra et al. (2015), Expert opinion, Subrata Kumar Patra et al. (2017), Ji Han et al. (2012)

3.2 Analytic Hierarchy Process (AHP)

AHP technique is a multi- criteria decision-making tool. It is frequently used for solving decision problems involving multi-objectives. This methodology has been used in the present analysis to identify the critical elements towards the development of SMS. Relative weights are assigned to each element through expert opinion so as to evaluate their ranking (relative importance) over one another. The following steps have been used in the AHP analysis.

- Structuring the problem
- Formation of Pairwise comparison matrix
- Normalization and Consistency analysis

These are explained below:

a. Structuring the problem

This is done by developing a two-level hierarchy structure. The four main issues E_1- E_4 are placed at the criteria level. All the sub- elements (E_{11} - $E_{17,}$ E_{21} - $E_{27,}$ E_{31} - $E_{38,}$ E_{41} - E_{49}) are placed at the sub-criteria level.

b. Formation of Pairwise comparison matrix

A pairwise comparison of the criteria and sub-criteria are done using the **Saaty's scale**. Based on the relative importance of one element over the other, weights are assigned (in a judgmental scale of 1-9) based on the contribution of each element towards enhancing the sustainability and the development of SMS.

c. Normalization and Consistency analysis

This is done by calculating Consistency index (CI)and Consistency ratio (CR). CR is the ratio of CI and RI (CR =CI/RI), where RI is obtained from the Random index table of **Saaty (1980)**. The value of CR should be less than 0.10to achieve judgmental consistency. Finally, the normalized weight (priority)of each element is obtained.

d. Ranking of elements

The normalized weight of each element reflects their importance and priorities towards developing manufacturing structure that will be truly sustainable. Based upon their relative priority weights, elements are ranked.

A judgmental analysis has been carried out by involving a team of industry experts and researchers related to this study area. Table 2 reflects the Pair-wise comparison matrix among the primary issues.

Table 2: Pair-wise comparison matrix among Primary Issues

Issues in SMS	**E_1**	**E_2**	**E_3**	**E_4**
Environment related issues (E_1)	1	2	4	2
Economic related issues (E_2)	1/2	1	3	2
Social and behavioral issues (E_3)	1/4	1/3	1	1/4
Technology and allied issues (E_4)	1/2	1/2	4	1

By using step-by-step AHP methodology the values of CI and CR are obtained. This is indicated in table 3.

Table 3: Tabulation of results for SMS issues

CI	RI for n=4	CR= CI/RI	Consistency
0.050104	0.9	0.05567111	5.56%

The value of CR obtained from analysis is 0.0556, which is well below the acceptable limit of 0.10. This reflects that there is significant judgmental consistency in this analysis. Table 4 displays the priority weights for each issue. Issues are ranked based on their priority weights.

Table 4: Priority weights and ranking of SMS issues

SMS Issues	Priority weights	Rank
E_1	0.42	I
E_2	0.279	II
E_3	0.082	IV
E_4	0.219	III

Fig. 1 demonstrates the priority weights of the primary issues with the help of a Pie chart.

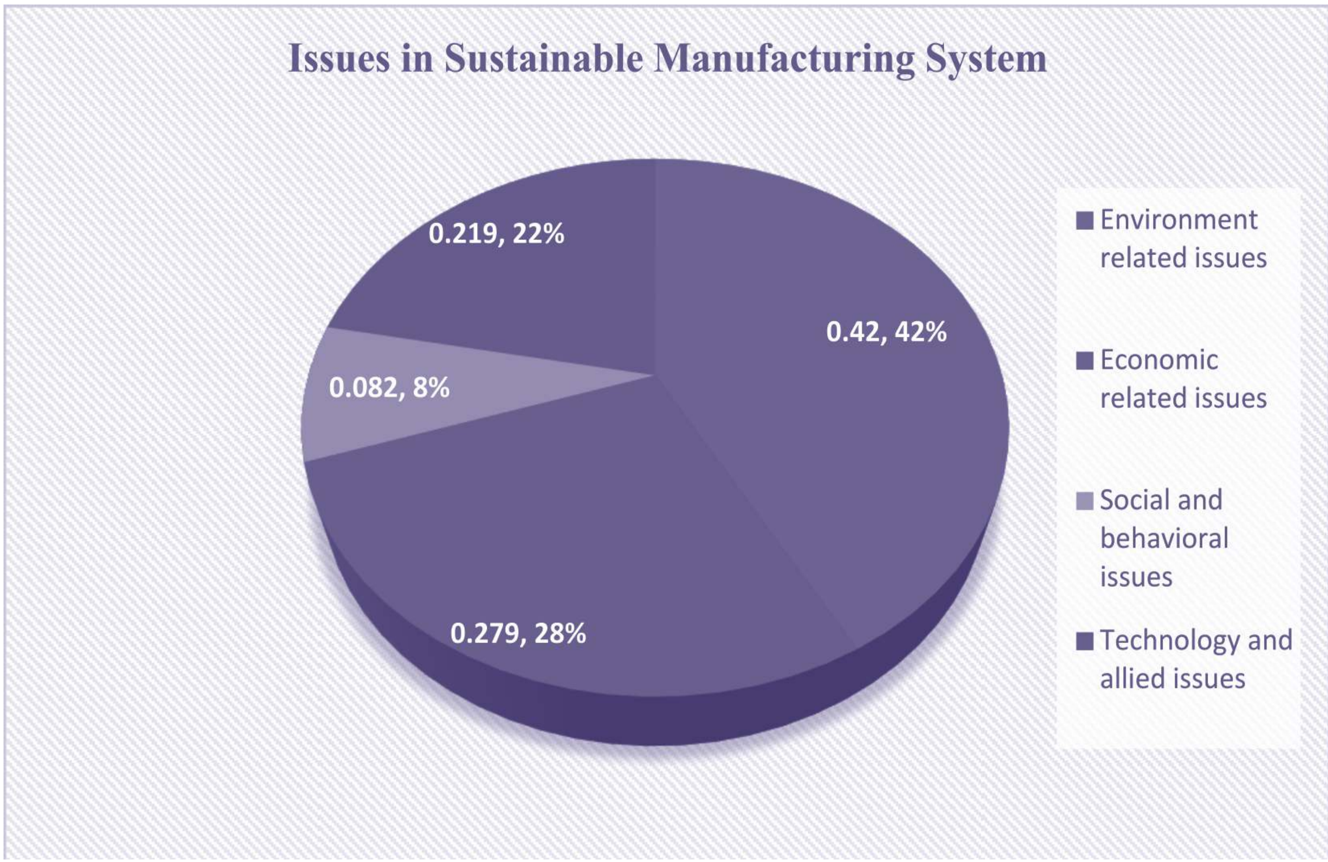


Fig. 1: Priority weights of SMS issues

It is observed from Fig. 1 that environment related issues are ranked I. This indicates that there is an urgent need for controlling waste, emission, pollution and all other elements associated with environment related issues.

Economic related issues (Ranked II) signifies that the associated elements like availability of funds, credit, subsidies and other economic resources are vital for the progress of SMS. Technology and allied issues are ranked III. It signifies that relevant technologies are essential towards improving the manufacturing efficiency. Technological up gradation through R&D and innovation will be supportive towards addressing Technological barriers and allied issues. Moreover, it will help to promote eco-friendly practices which are vital towards SMS.

Social and behavioural issues are ranked IV. This however does not mean that this issue is less critical considering the fact that all manufacturing activities take place in close vicinity to our societal framework. With the increasing public awareness on environment and sustainable issues, business firms have to be more practical, responsible, careful and sensible in carrying out their manufacturing operations. The subsequent article will estimate the priorities for each sub-element linked with the main issues. Table5 illustrates the pair-wise comparison among the environment related elements.

Table 5: Pair-wise comparison matrix for Environment related elements

Environment related elements	E_{11}	E_{12}	E_{13}	E_{14}	E_{15}	E_{16}	E_{17}
E_{11}	1	4	2	3	1/3	6	1
E_{12}		1	1/3	1/2	1/4	2	1/5
E_{13}			1	3	1/4	7	1/3
E_{14}				1	1/5	4	1/3
E_{15}					1	7	2
E_{16}						1	1/5
E_{17}							1

Table 6 represents the result obtained for Environment related elements.

Table 6: Tabulation of results for Environment related elements

CI	RI for n=7	CR= CI/RI	Consistency
0.08403	1.32	0.063657	6.36%

Priority weights for each of the environment related an element has been represented below. These are multiplied by the priority weight of main criteria (Environment related issues) to obtain the Global priority index. This is represented in table 7.

Table 7: Global priority index for environment related elements

Environment related elements	Priority weights (x)	Global priority index (x*0.42)
E_{11}	0.179	0.07518
E_{12}	0.050	0.0210
E_{13}	0.128	0.05376
E_{14}	0.074	0.03108
E_{15}	0.337	0.14154
E_{16}	0.029	0.01218
E_{17}	0.204	0.08568

Similarly, the results for other elements are also obtained. These have been represented below.

Table 8: Tabulation of results for Economic related elements

CI	RI for n=7	CR= CI/RI	Consistency
0.09483	1.32	0.07184	7.184 %

Table 9: Global priority index for Economic related elements

Economic related elements	Priority weights (y)	Global priority index (y*0.279)
E_{21}	0.305	0.085095
E_{22}	0.054	0.015066
E_{23}	0.093	0.025947
E_{24}	0.044	0.012276
E_{25}	0.197	0.054963
E_{26}	0.180	0.05022
E_{27}	0.126	0.035154

Table 10: Tabulation of results for Social and behavioral related elements

CI	RI for n=8	CR= CI/RI	Consistency
0.06287	1.41	0.04458	4.458 %

Table 11: Global priority index for Social and behavioral related elements

Social and behavioral related elements	Priority weights (z)	Global priority index (z*0.082)
E_{31}	0.166	0.046314
E_{32}	0.061	0.017019
E_{33}	0.263	0.073377
E_{34}	0.036	0.010044
E_{35}	0.160	0.04464
E_{36}	0.129	0.035991
E_{37}	0.030	0.00837
E_{38}	0.154	0.042966

Table12: Tabulation of results for Technology and allied elements

CI	RI for n=9	CR= CI/RI	Consistency
0.115622	1.45	0.07973	7.973 %

Table 13: Global priority index for Technology and allied elements

Technology and allied elements	Priority weights (a)	Global priority index (a*0.219)
E_{41}	0.217	0.047523
E_{42}	0.116	0.025404
E_{43}	0.177	0.038763
E_{44}	0.095	0.020805
E_{45}	0.158	0.034602
E_{46}	0.076	0.016644
E_{47}	0.068	0.014892
E_{48}	0.044	0.009636
E_{49}	0.050	0.01095

As obtained from above tables (Table 5- 13), all the 31SMS elements have been arranged based on their Global priority index. This is represented in table 14.

Table 14: Ranking of SMS elements

Elements	Weightage	Ranking
E_{15}	0.14154	1
E_{17}	0.08568	2
E_{21}	0.085095	3
E_{11}	0.07518	4
E_{33}	0.073377	5
E_{25}	0.054963	6
E_{13}	0.05376	7

E_{26}	0.05022	8
E_{41}	0.047523	9
E_{31}	0.046314	10
E_{35}	0.04464	11
E_{38}	0.042966	12
E_{43}	0.038763	13
E_{36}	0.035991	14
E_{27}	0.035154	15
E_{45}	0.034602	16
E_{14}	0.031080	17
E_{23}	0.025947	18
E_{42}	0.025404	19

E_{12}	0.02100	20
E_{44}	0.020805	21
E_{32}	0.017019	22
E_{46}	0.016644	23
E_{22}	0.015066	24
E_{47}	0.014892	25
E_{24}	0.012276	26
E_{16}	0.01218	27
E_{49}	0.01095	28
E_{34}	0.010044	29
E_{48}	0.009636	30
E_{37}	0.00837	31

Ranking of various elements are further displayed in chart shown in Fig. 2.

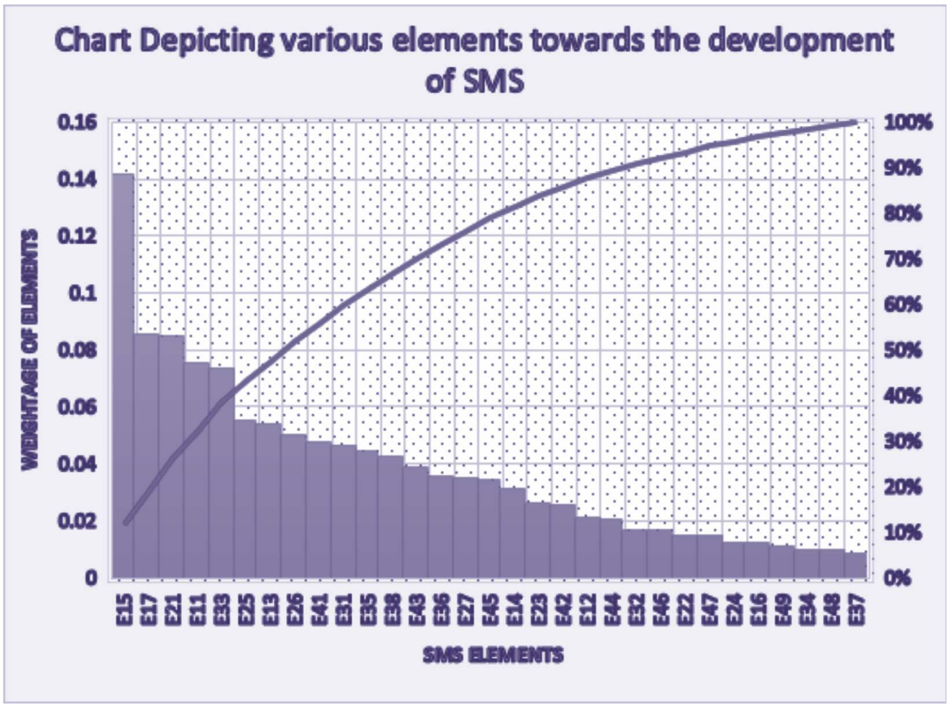


Fig. 2: Chart depicting various elements towards the development of SMS

Fig. 2displaysall 31 elements based on their rankings. Among these elements the top 10 elements are $E_{15,}E_{17,}E_{21,}E_{11,}E_{33,}E_{25,}E_{13,}E_{26,}$ and E41and $E_{31.}$ Out of these, four elements namely E_{11} (Waste management), E13 (Focus on 3 R's Principles), E15 (Environment management systems) and E_{17} (Emission control) are linked to Environment and related issues. Three elements E_{21} (Commercial advantages), E25 (Incentives and subsidies funded by government to promote sustainable technologies), E26(Ease of soft loans and credit facilities by financial institutions) are linked to Economic and related issues. ElementsE_{31} (Vision for long term sustainable development) and E_{33} (Top Management support and commitment) are linked to

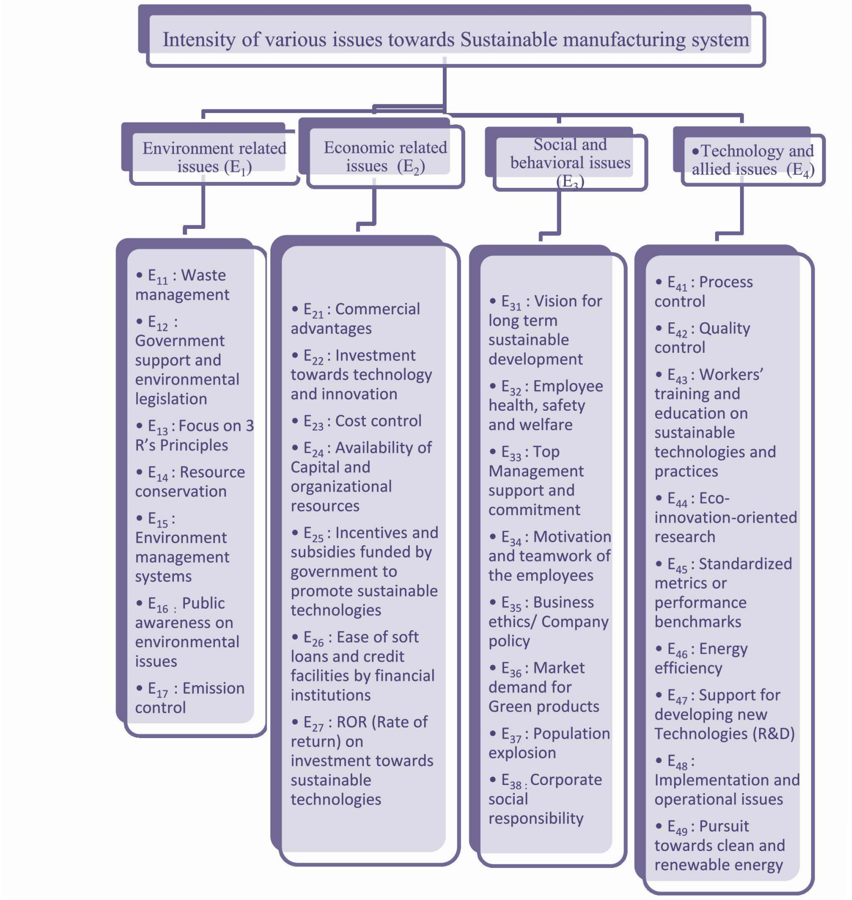
Social and behavioral issues. Element E_{41} (Process control) is linked to Technology and related issues.

The result obtained from AHP analysis must be verified for its authenticity and correctness. Some other MCDM technique can be used for this purpose. The current study proposes touseR^3I technique which is a well-known MCDM technique for this purpose. The succeeding section illustrates the same.

3.3 R^3I (Relative Reliability Risk Index) analysis

R^3I analysis has been used to calculate the intensity of four primary issues. Entropy method has been used for this purpose. The intensity assessment system concerning all issues and sub-elements has been represented in Fig. 3.

Fig. 3: The intensity assessment system towards SMS



3.3.1 Entropy method

Entropy method has been used to carry out the R^3I analysis. Five experts were invited to rate each element associated with the primary issues. The intensity evaluation for each issue has been done using Delphi method (in a scale of 1-5). For each SMS issue the entropy values (e), entropy weights (w) and the intensity values (R) are calculated by adopting the following systematic steps.

Step- I: Formulation of Intensity evaluation matrix (M)

$$M=\begin{bmatrix} m_{11} & m_{12} & m_{13} & & m_{1j} \\ m_{21} & m_{22} & m_{23} & & m_{2j} \\ m_{31} & m_{32} & m_{33} & & m_{3j} \\ & & & & \\ m_{i1} & m_{i2} & m_{i3} & & m_{ij} \end{bmatrix} \quad \text{.........(i)}$$

where j = 1, 2, 3, 4, 5 (Serial no. of experts)
i = Serial no. of elements for each SMS issues
(I = 1- 7 for E_1, 1-7 for E_2, 1-8 for E_3 and 1-9 for E_4)

Step- II: Normalization of Matrix (M^*)

$$M^*=\begin{bmatrix} m'_{11} & m'_{12} & m'_{13} & & m'_{1j} \\ m'_{21} & m'_{22} & m'_{23} & & m'_{2j} \\ m'_{31} & m'_{32} & m'_{33} & & m'_{3j} \\ & & & & \\ m'_{i1} & m'_{i2} & m'_{i3} & & m'_{ij} \end{bmatrix} \quad \text{.........(ii)}$$

where $m'_{ij} = \frac{m_{ij} - \min(m_{ij})}{\max(m_{ij}) - \min(m_{ij})}$

Step- III: Entropy calculation

Entropy $\mathbf{e_i = -K \sum f_{ij} . \ln f_{ij}}$ (f_{ij}. ln = 0 for f_{ij}=0) ....(iii)
where K= 1/ (ln n), (n =No. of experts =5)

and $f_{ij} = \frac{m'_{ij}}{\sum m'_{ij}}$

Entropy weight $\mathbf{w_i} = \frac{\mathbf{1 - e_i}}{\mathbf{m - \sum e_i}}$, (m = i_{max} for each issue) … (iv)

Total intensity (risk) of each issue is calculated as $\mathbf{R = \sum w_i . e_i}$ ……..(v)

The intensity of each issues based on expert assigned values for each sub-element are calculated using the equations (i) to (v). These have been tabulated below.

Table 15: Intensity evaluation for Environment related issues (E_1)

$$M_1 = \begin{bmatrix} 4 & 3 & 4 & 5 & 3 \\ 3 & 2 & 3 & 2 & 2 \\ 3 & 3 & 2 & 2 & 2 \\ 3 & 2 & 2 & 2 & 2 \\ 4 & 3 & 3 & 3 & 3 \\ 3 & 2 & 3 & 2 & 4 \\ 3 & 3 & 4 & 4 & 5 \end{bmatrix} M_1^* = \begin{bmatrix} 0.5 & 0 & 0.5 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0.5 & 0 & 0.5 & 0 & 1 \\ 0 & 0 & 0\ 5 & 0\ 5 & 1 \end{bmatrix}$$

e_1 = (0.64601, 0.43068, 0.43068, 0, 0, 0.64601, 0.64601)
w_1 = (0.08427, 0.13553, 0.13553, 0.23806, 0.23806, 0.08427, 0.08427)

$R_{environment}$ = 0.28006

Table 16: Intensity evaluation for Economic related issues (E_2)

$$M_2 = \begin{bmatrix} 2 & 3 & 2 & 2 & 2 \\ 2 & 3 & 3 & 2 & 4 \\ 2 & 2 & 2 & 3 & 2 \\ 4 & 3 & 3 & 4 & 3 \\ 3 & 3 & 2 & 3 & 2 \\ 3 & 2 & 2 & 3 & 2 \\ 3 & 2 & 3 & 3 & 4 \end{bmatrix} M_2^* = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0.5 & 0.5 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 & 0 \\ 0.5 & 0 & 0.5 & 0.5 & 1 \end{bmatrix}$$

e_2 = (0, 0.64601, 0, 0.43068, 0.68261, 0.43068, 0.82773)
w_2 = (0.25111, 0.08889, 0.25111, 0.14296, 0.0797, 0.14296, 0.04326)
$R_{economic}$ = 0.27078

Table 17: Intensity evaluation for Social and behavioral issues (E_3)

$$M_3 = \begin{bmatrix} 3 & 2 & 3 & 2 & 2 \\ 2 & 2 & 3 & 2 & 2 \\ 4 & 4 & 4 & 5 & 4 \\ 2 & 2 & 3 & 2 & 2 \\ 2 & 2 & 3 & 3 & 3 \\ 3 & 2 & 2 & 2 & 2 \\ 2 & 2 & 1 & 1 & 2 \\ 3 & 3 & 2 & 2 & 2 \end{bmatrix} M_3^* = \begin{bmatrix} 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 0 & 0 & 0 \end{bmatrix}$$

e_3 = (0.43068, 0, 0, 0, 0.68261, 0, 0.68261, 0.43068)

w_3 = (0.09861, 0.17321, 0.17321, 0.17321, 0.05497, 0.17321, 0.05497, 0.09861)

R_{social} = 0.15999

Table 18: Intensity evaluation for Technology and allied issues (E_4)

$$M_4 = \begin{bmatrix} 4 & 3 & 3 & 3 & 3 \\ 2 & 3 & 2 & 2 & 3 \\ 3 & 2 & 3 & 4 & 3 \\ 3 & 2 & 2 & 3 & 2 \\ 2 & 2 & 2 & 2 & 1 \\ 2 & 2 & 3 & 2 & 3 \\ 2 & 2 & 2 & 2 & 3 \\ 3 & 2 & 3 & 3 & 3 \\ 2 & 2 & 2 & 2 & 3 \end{bmatrix} M_4^* = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 \\ 0.5 & 0 & 0.5 & 1 & 0.5 \\ 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

e_4 = (0, 0.43068, 0.82773, 0.43068, 0.86135, 0.43068, 0, 0.86135, 0)
w_4 = (0.19389, 0.11039, 0.0334, 0.11039, 0.02688, 0.11039, 0.19389, 0.02688, 0.19389)
$R_{technology}$ = 0.21658

Based on the above calculations (Table 15-18), the SMS issues have been ranked.
This is given in table 19.

Table 19: Ranking of various SMS issues

S. No.	SMS Issues	Intensity value (R)	Ranking based on Intensity
1	Environment related issues (E_1)	0.28006	I
2	Economic related issues (E_2)	0.27078	II
3	Social and behavioral issues (E_3)	0.15999	IV
4	Technology and allied issues (E_4)	0.21658	III

Based on R^3I analysis, the ranking obtained for the SMS issues are:

E_1 ➡ E_2 ➡ E_4 ➡ E_3

4. RESULT AND DISCUSSION

The result obtained from R^3I analysis conforms the ranking obtained by using AHP analysis. therefore, R^3I analysis validates the result obtained from AHP analysis. Both the analysis hence reveals the key role of Environment related issues (E_1) towards the attainment of Sustainable manufacturing system. Succeeding issues are Economic related issues (E_2), Technology and allied issues (E_4) and lastly the Social and behavioral issues (E_3).

The result highlights that environment and related issues (ranked I) are of paramount importance towards adopting SMS. Therefore, environmental elements like waste management, emission control, recycling practices, resource conservation and other elements need to be suitably addressed. Needful actions towards eco-friendly manufacturing practices will help in progress towards sustainable manufacturing system.

Economic related issues are ranked II. This highlights the fact that without adequate capital and resources, progress towards SMS is not viable. Support and Funding by the government and other agencies will be beneficial towards addressing economic hardships- considered as crucial towards the development of SMS.

Technology and allied issues are ranked III. It is pertinent to highlight that many of the environment and related issues can be appropriately addressed through technological means. Technological barriers can be moderated through technological innovations, R & D initiatives, incorporating suitable training to the workmen and by fixing sub- elements under Technological issues.

The importance of Social and behavioral issues (ranked IV) towards SMS are crucial. This is so because manufacturing systems operate within the social boundaries - the vision, motivation, commitment and teamwork of the society might give immense impetus and motivation towards the attainment of SMS.

4.1 Limitations and directions for future work

Information and data for the current study were collected from experts and industries belonging to one country only (India).This can be treated as the foremost limitation of this research. Future researchers may wish to obtain data from several countries in order to curb this geographical limitation. Although the present research gives a direction towards developing SMS, further research may be carried out to explore the relationships among the various elements or to formulate a model towards SMS. Techniques such as Interpretive Structural Modeling (ISM) can be used for this purpose.

5. CONCLUSION

This paper has come out with a comprehensive methodology towards identifying critical elements for a sustainable manufacturing environment. By using Analytic hierarchy process, priorities of various issues and the associated elements has been obtained. The result obtained through AHP analysis has been correlated using R^3I analysis. The study establishes the relative importance of various issues and their sub- elements towards adopting SMS. The research analysis will be useful for the managers eager to adopt Sustainable manufacturing system in the organizations. Based on inputs from the above analysis, managers can suitably focus on various issues and their sub-elements based on their weightages which might be supportive in comprehending the ultimate objective of developing Sustainable Manufacturing System in the organizations.

REFERENCES

1. *A. Paulraj, "Environmental motivations: a classification scheme and its impact on environmental strategies and practices", Business Strategy and the Environment, vol.18(7), pp. 453-468, 2008.*
2. *B. E. Narkhede, "Linkages in Advanced Manufacturing Strategy: A Literature Review", International Journal of Applied Management Sciences and Engineering, vol. 3, Issue 1, 2016.*
3. *B. B. Gardas, Balkrishna E. Narkhede, and Rakesh D. Raut, "Sustainable Supply Chain Management Review– MCDM approaches", Proceedings of NCIETM 2016 conference, pp. 189-202, 2016.*
4. *Brundtland G H, "Our Common Future", The World Commission on Environment and Development, Oxford University Press, Oxford, UK, 1987.*
5. *Chieh-Yu Lin and Yi- Hui Ho, "An Empirical Study on Logistics services provider, intention to adopt Green Innovations", Journal of Technology, Management and Innovation, vol. 3(1), pp.17-26, 2008.*

6 C. Douligeris and Ian J. Pereira, "Telecommunications quality study using the Analytic Hierarchy Process", IEEE Journal on Selected Areas in Communications, vol. 12(2), pp. 241 – 250, 1994.

7 D. Traian Pele, Emese Lazar, and Alfonso Dufour, "Information Entropy and Measures of Market Risk", Entropy, vol. 19, No. 226, pp. 1-19, 2017.

8 Ge Xiao-meia, and Liu Xiao-junb, "Application of Entropy Measurement in Risk Assessment of the Engineering Project of Construction-agent System", Systems Engineering Procedia, 2011, vol. 1, pp. 244–249.

9 Geir B. Asheim, "Ethical foundations and Economic properties", Policy research working paper: 1302, Sustainability, 1994.

10 G.Miller, Janice Pawloski, and Charles Standridge, "A case study of lean, sustainable manufacturing", JIEM, vol. 3(1), pp.11-32, 2010, ISSN: 2013-0953.

11 G. Johansson and Thomas Magnusson, "The Journal of Sustainable product design", Issue 7, pp. 7-15, 1998, ISSN: 1367-6679.

12. H Zhang and Karl R. Haapala, "Integrating sustainable manufacturing assessment into decision making for a Production work cell", Journal of Cleaner Production, vol. 105, pp. 52-63, 2015.

13 H. W. M. Van Bommel, "A conceptual framework for analyzing sustainability strategies in industrial supply networks from an innovation perspective", Journal of Cleaner Production, vol. 19(8), pp. 895-904, 2011.

14. I. S. Jawahir, "Sustainable Manufacturing: The Driving Force for Innovative Products, Processes and Systems for Next Generation Manufacturing", ISM, www.ncsl.org/Portals/1/Documents/employ/Jawahir-Manuf.pdf.

15 Innovating Clean Energy Technologies in Advanced Manufacturing, Quadrennial Technology Review, 2015, www.energy.gov/sites/prod/files /2016 /05/f31/ QTR 2015 - 6L- Sustainable-Manufacturing. Pdf.

16. J. Petrie, B. Cohen, and M. Stewart, "Decision support frameworks and metrics for sustainable development of minerals and metals", Clean Techn Environ Policy, vol. 9, pp. 133–145, 2007.

17 J. Sarkis, "Benchmarking the greening of business", Benchmarking: An International Journal, vol. 17, Issue 3, 2010.

18 J. Sarkis, "Evaluating Environmentally conscious Business practices", European Journal of Operational research, vol. 107(1), pp. 159-174, 1998.

19 Ji Han, Psyche Fontanos, Kensuke Fukushi, Srikantha Herath, Niko Heeren, Vincenzo Naso, Claudio Cecchi, Peter Edwards, and Kazuhiko Takeuchi, "Innovation for sustainability: toward a sustainable urban future in industrialized cities", Sustain Sci, vol. 7 (Supplement 1), pp. 91–100, 2012.

20. Jose Maria Agudo-Valiente, Concepcion Garces-Ayerbe, and Manuel Salvador- Figueras, "Corporate Social Responsibility Drivers and Barriers according to Managers' Perception; Evidence from Spanish Firms", Sustainability, vol. 9, No. 1821, pp. 1-24, 2017.

21. K. Madan Shankar, P. Udhaya Kumar, and Devika Kannan, "Analyzing the Drivers of Advanced Sustainable Manufacturing System using AHP approach", Sustainability, vol. 8, No. 824, pp. 1-10, 2016, doi:10.3390/su8080824.

22. Karl R. Haapala, Fu Zhao, Jaime Camelio, John W. Sutherland, Steven J. Skerlos, David A. Dornfeld, I.S. Jawahir, Hong Chao Zhang, and Andres F. Clarens, "A review of engineering research in sustainable manufacturing", Proceedings of the ASME 2011 InternationalManufacturing Science and Engineering conference", MSEC 2011- 50300.

23. L. G. Tornatzky and M. Fleischer, "The Process of Technological innovation", Lexington, MA, 1990.

24 Michael Mutingi, Harmony Musiyarira, Charles Mbohwa, and Venkata P. Kommula, "An Analysis of Enablers and Barriers of Sustainable Manufacturing in Southern Africa", WCECS, 2017.

25. Ming Chen, "Sustainable Recycling of Automotive Products in China: Technology and Regulation - Key Manufacturing Technology & Equipment for Energy Saving and Emissions Reduction in Mechanical Equipment Industry", JOM: The Journal of the Minerals, Metals & Materials Society, vol. 58, Issue 8, pp. 23-26, 2006.

26. Ming-Tang Wang, "Use of a Combination of AHP and ISM for Making an Innovative Rescue Caring Design in Landslide Area", Hindawi Publishing Corporation, Mathematical Problems in Engineering, vol. 2015(2), pp. 1-13, Article ID: 401736, 2015

http://dx.doi.org/10.1155/2015/401736.

27. N. Bhanot, P. Venkateswara Rao, and S.G. Deshmukh, "Enablers and Barriers of Sustainable Manufacturing: Results from a Survey of Researchers and Industry Professionals", Procedia CIRP, vol. 29, pp. 562-567, 2015.

28 Our Common Future, Chapter 8: Industry: Producing More With Less, A/42/427: Report of the World Commission on Environment and Development, un-documents.net/ocf-08.htm.

29 S. Gilbert, "Greening supply chain: Enhancing competitiveness through green productivity", Report of the Top Forum on enhancing Competitiveness through Green Productivity held in the Republic of China, 2000, ISBN: 92-833-2290-8.

30 S. L. Tung and S. L. Tang, "A comparison of the Saaty's AHP and modified AHP for right and left eigenvector inconsistency," European Journal of Operational Research, vol. 106, No. 1, pp. 123–128, 1998.

31 S. Luthra, V. Kumar, S. Kumar, and A. Haleem, "Barriers to implement green supply chain management in automobile industry using interpretive structural modeling technique: An Indian perspective", Journal of Industrial Engineering and Management, vol. 4(2), pp. 231-257, 2011.

32 S.Reijonen, "Environmentally friendly consumer: from determinism to emergence", International Journal of Consumer Studies, vol. 35(4), pp. 403-409, 2011.

33 S. Choundhe, P. Khandeshe, and N.R. Rajhans, "Selection of Media using R31 (Entropy, Standard Deviation) and TOPSIS", AEOTIT, 2013.

34 S. K. Patra, Tilak Raj, and B.B. Arora, "An Analysis of Selected Parameters in an Energy Efficient Sustainable Manufacturing System Using AHP", International Journal of Advanced Production and Industrial Engineering, IJAPIE-2017-02-211, vol. 2(2), pp. 1-4, 2017, ISSN: 2455-8419.

35 S. K. Patra, Tilak Raj, and B.B. Arora, "Sustainability Issues in Energy Efficient Manufacturing Systems - A Review", International Journal of Engineering and Manufacturing Science, volume 5, No. 1, pp. 1-8, 2015, ISSN: 2249- 3115.

36. T. L. Saaty, The Analytic Hierarchy Process, McGraw-Hill, NY, USA, 1980.

37 T. L. Saaty, "Decision making with the analytic hierarchy process", Int. J. Services Science, vol. 1, No. 1, pp. 83-98, 2008.

38. V. Ravi and R. Shankar, "Analysis of interactions among the barriers of reverse logistics", International Journal of Technological Forecasting & Social change, vol. 72(8), pp. 1011-1029, 2005.

39. V. Srinivasan, "An Engineer grapples with sustainable manufacturing", Clean Techn Environ Policy, vol. 13, pp. 217–219, 2011.

40 Z. Molamohamadi and N. Ismail, "Developing a New Scheme for Sustainable Manufacturing", International Journal of Materials, Mechanics and Manufacturing, vol. 1, No. 1, 2013.

AUTHORS

Subrata Kumar Patra, M. Tech, G. B. Pant Institute of Technology, New Delhi, Delhi, patrask2005@yahoo.co.in

Dr. Tilak Raj, PhD, Department of Mechanical Engineering, YMCAUST, Faridabad, Delhi, tilakraj64@rediffmail.com

Dr. B.B. Arora, PhD, Department of Mechanical Engineering, Delhi Technological University, Delhi, bbarora@dce.ac.in