Measurement of sustainability index among paper manufacturing plants

IOP Conf. Series: Materials Science and Engineering **263** (2017) 062046 doi:10.1088/1757-899X/263/6/062046

Measurement of sustainability index among paper manufacturing plants

V Sharathkumar Reddy[1], K Jayakrishna[1] and Babu Lal[2]
[1]School of Mechanical Engineering, VIT Univeristy, Vellore-632014, Tamil Nadu, India.
[2]Dire Dawa University, Dire Dawa - 3000, Ethiopia.

E- mail: jayakrishna.k@vit.ac.in

Abstract: The paper manufacturing companies are facing challenges to implement sustainable manufacturing into their products and processes. Paper manufacturing has remarked as an intensive consumer of natural raw materials, energy and a major source of multiple pollutants. Thus, evaluating the sustainable manufacturing in these companies has become a necessity. This paper proposes a set of Performance Indicators (PIs) for evaluating the sustainable manufacturing appropriate to the paper manufacturing companies based on the triple bottom line of sustainability. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), a multi-criteria decision analysis method is applied to prioritize the performance indicators by summarizing the opinions of stakeholders. It is hoped that the proposed PIs enables and assists the paper manufacturing companies to achieve the higher performance in sustainable manufacturing and so as to increase their competitiveness.

1. Introduction

Globally, sustainable manufacturing has become an important issue amongst all manufacturing industries. Achieving sustainable manufacturing is considered as a critical requirement due to strict rules and regulations related to atmosphere, occupational health and safety, declining non-renewable resources, and increasing preference for consumer products which are environmental-friendly [1]. It has been observed that those companies which are adopting sustainable manufacturing practices are achieving better product quality, increased profits, and higher market share [2]. These sustainability practicesseems to be associated positively with competitive outcomes [3]. Hence, developing sustainable manufacturing techniques to companies has been considered as a critical comprehensive concern [4]. Sustainable manufacturing can be defined as the formation of manufactured products that conserve energy, conserve natural resources, and is safe for employees, minimize negative impacts on environment, and economically viable for community and customer [5]. The principle of manufacturing with consideration of sustainability is to reduce energy consumption, emissions, intensity of materials to be used, and also reduction in the creation of undesirable by-products while improving or maintaining, the price of products to organizations and to society [6].According to the definition of sustainable manufacturing, the incorporation of all the three pointers of environmental, economic, and social known as the triple bottom line of sustainable manufacturing to be addressed. Hence, sustainable manufacturing ought to be assessed as for those three pointers. Sustainable manufacturing is unquestionably one of the basic issues for the paper manufacturing industries. Paper, as the most important part of the contemporary world, is a central component of communication media around the world [7]. World-wide, paper is mostly produced from cellulose fibers. Less than twothirds comes from wood, one-third comes from recycled paper and about 5% comes from non-wood sources. According to United Nations Energy Information Administration report Paper and paperboard mills emit over 9 percent of the energy-related carbon in the manufacturing sector [8]. Generally, the paper industries are characterized as an intensive consumer of natural raw materials and fossil fuels, and has remarked as emitters of pollutants [9, 10].

Sustainable manufacturing evaluation has become necessary for paper manufacturing industries, because these industries are one of the concentrated consumers driven on the planet [11]. In this paper, a literature review was done to decide indicators usually utilized as a part of sustainable manufacturing evaluation process. In sustainable manufacturing evaluation, the most commonly used indicators are alluded from World Business Council for Sustainable Development (WBCSD) comprising of huge amounts of paper per MJ, raw material and fuel substitution rates, non-item yield, net CO2 per huge amounts of paper, and occurrence rate. In addition, there are various sustainable manufacturing evaluation indicators proposed by different associations, for example, ISO 14031, Organization for Economic Co-operation and Development (OECD) and Global Reporting Initiative (GRI). This paper proposes an arrangement of Performance Indicator (PIs) for assessing the sustainable manufacturing accepted to be suitable for the paper industry in light of the triple bottom line of sustainability. These performance indicators are used to construct sustainable manufacturing evaluation model. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), a multi-criteria decision analysis method is used to prioritize the performance indicators.

2. Methodology

The study is divided into 3 stages. First, the initial performance indicators (PIs) were derived and identified for sustainable manufacturing evaluation. Secondly, validating the initial PIs to industry practices. In last stage, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is used for sustainable manufacturing performance evaluation of the identified PIs.
Above stages are presented in the upcoming sections.

2.1. PIs Identification

This study begins with identifying performance indicators (PIs) from literature review for the sustainable manufacturing evaluation. In this triple bottom line of sustainability, the economic, environmental and social performance factors are adopted for constructing the initial performance indicators (PIs). Therefore, the initial performance indicators such as economic, environmental factors and social performance factors were divided into eighteen indicators as shown in Table 1.

2.2. Performing industry survey

An industry survey is conducted to validate the initial PIs, in a paper manufacturing company which is located in Karur, Tamil Nadu. Established in 1984, is the first government paper manufacturing plant in Tamil Nadu, to produce Newsprint and Printing & Writing Paper using bagasse, a sugarcane residue, as primary raw material. The Company commenced production with an initial capacity of 90,000 tons per annum (tpa). Over the years, the production capacity has been increased to 2,45,000 tpa and the Company has emerged as the largest bagasse based Paper Mill in the world consuming about one million tons of bagasse every year. The industry completed a Mill Expansion Plan during December 2010 to increase the mill capacity to 4,00,000 tpa. The industry also exports about 1/5th of its production to more than 50 countries. Manufacturing of quality paper for the past two and half decades from bagasse is an index of the company’s technological competence. A strong record in adopting minimum impact best process technology, responsible waste management, reduced pollution load and commitment to the corporate social responsibility makes the company as one of the most environmentally compliant paper mills in the world.

2.3. PIs Rating

The next step is to rate the PIs in the sustainable manufacturing evaluation. In this problem, to evaluate the performance of the PIs, which are rated on a scale ranging from 1 to 10, where1 for highly poor, 5 for moderately fair and 10 for excellent. Based on the above scale, a group of 5 stakeholders of manufacturing and production division were asked to rate the PIs based on their importance in Sustainable manufacturing evaluation in the industry. Information gathered from the stakeholders presented in below table, where mean importance values of the PIs ranged from 0.061 to 0.042 as shown in Table 2.

Table 1. PIs of sustainable manufacturing evaluation

Goal	Sustainability Criteria		Sustainability Indicators	
Measurement of sustainability index among paper manufacturing plants	SC_1	Economic	SI_1	Inventory cost
			SI_2	Labour cost
			SI_3	Material cost
			SI_4	Machining cost
			SI_5	Product delivery
			SI_6	Raw material substitution
	SC_2	Environmental	SI_7	Air emission
			SI_8	Energy consumption
			SI_9	Fuel consumption
			SI_{10}	Material consumption
			SI_{11}	Noise pollution
			SI_{12}	Water utilization
	SC_3	Social	SI_{13}	Accident rate
			SI_{14}	Employee involvement
			SI_{15}	Labour relationship
			SI_{16}	Gender equity
			SI_{17}	Occupational health and safety
			SI_{18}	Training and education

3. Evaluation of sustainable manufacturing performance in the case organization

A sustainable manufacturing performance assessment model for paper industry was evolved based on the proposed performance indicators (PIs). Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methodology was applied in developing the model with decision matrix, normalizing the decision matrix, weighting the normalized decision matrix, computing positive ideal and negative ideal solution, determining separation between ideal solutions and ranking by calculating relative closeness to ideal solution.

3.1. The TOPSIS method

Sections should be numbered with a dot following the number and then separated by a single space:
This study uses the TOPSIS method. The TOPSIS method was initially presented by Yoon and Hwang [12] and Lai, Liu, and Hwang [13]. The TOPSIS method is expressed in a succession of six steps as follows [14] :

Step 1: Calculate the normalized decision matrix. The normalized value r_{ij} is calculated as follows:

$$r_{ij} = x_{ij}\sqrt{\sum_{i-1}^{m} x_{ij}^2} \qquad \mathrm{i} = 1,2 \ldots\ldots\ldots \mathrm{m \ and\ j} = 1,2 \ldots.\mathrm{n} \qquad (1)$$

Step 2: Calculate the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as follows:

$$v_{ij} = r_{ij} \times w_j \qquad \mathrm{i} = 1,2 \ldots\ldots\ldots \mathrm{m \ and\ j} = 1,2 \ldots.\mathrm{n} \qquad (2)$$

Where w_j is the weight of the j^{th} criterion or attribute and$\sum_{j-1}^{n} w_j = 1$.

Step 3: Determine the ideal (A^*) and negative ideal $\left(A^{\#}\right)$ solutions.

$$A^* = \{(max_i v_{ij} | j \in C_b), (min_i v_{ij} | j \in C_c)\} = \{v_j^* | j = 1,2, \ldots.m\} \qquad (3)$$

$$A^{\#} = \{(min_i v_{ij} | j \in C_b), (max_i v_{ij} | j \in C_c)\} = \{v_j^{\#} | j = 1,2, \ldots.m\} \qquad (4)$$

Step 4: Calculate the separation measures using the m-dimensional Euclidean distance. The separation measures of each alternative from the positive ideal solution and the negative ideal solution, respectively, are as follows:

$$S_i^* = \sqrt{\sum_{j=1}^{m}\left(v_{ij} - v_j^*\right)^2}, \qquad \mathrm{j}=1,2,\ldots..\mathrm{m} \qquad (5)$$

$$S_i^{\#} = \sqrt{\sum_{j=1}^{m}\left(v_{ij} - v_j^{\#}\right)^2}, \qquad \mathrm{j}=1,2,\ldots..\mathrm{m} \qquad (6)$$

Step 5: Calculate the relative closeness to the ideal solution. The relative closeness of the alternative $A_i$with respect to A^* is defined as follows:

$$RC_i^* = \frac{S_i^{\#}}{S_i^* + S_i^{\#}}, \qquad i = 1,2, \ldots., m \qquad (7)$$

Step 6: Rank the preference order.

Table 2. Importance values of the PIs.

Indicators of sustainability		**Stakeholders**					**Average**	**Mean**
		SH1	**SH2**	**SH3**	**SH4**	**SH5**		
SI1	Inventory cost	7	8	8	8	9	8.000	0.059
SI2	Labour cost	8	6	8	9	9	8.000	0.059
SI3	Material cost	9	8	9	9	7	8.400	0.062
SI4	Machine cost	7	7	7	8	8	7.400	0.055
SI5	Product delivery	8	8	9	8	8	8.200	0.061
SI6	Raw material substitution	9	8	7	8	6	7.600	0.056
SI7	Air emission	9	7	6	7	8	7.400	0.055
SI8	Energy consumption	8	6	9	8	6	7.400	0.055
SI9	Fuel consumption	7	7	8	6	7	7.000	0.052
SI10	Material consumption	9	7	9	8	7	8.000	0.059
SI11	Noise pollution	8	5	5	6	6	6.000	0.045
SI12	Water utilization	7	8	8	9	8	8.000	0.059
SI13	Accident rate	5	6	5	5	7	5.600	0.042
SI14	Employee involvement	9	7	7	9	7	7.800	0.058
SI15	Labor relationship	8	9	8	7	8	8.000	0.059

Indicators of sustainability		Stakeholders					Average	Mean
		SH1	SH2	SH3	SH4	SH5		
SI16	Gender equity	7	8	7	8	7	7.400	0.055
SI17	Occupational health and safety	6	9	9	7	7	7.600	0.056
SI18	Training and education	5	7	7	8	8	7.000	0.052

4. Case Study results

The use of sections to divide the text of the paper is optional and left as a decision for the author. Table 3 shows the decision matrix after computing the attribute weights. The attribute weights were computed based on the score provided by the stakeholders based on their perception on a scale of 1-10.

Table 3. Decision matrix

Sustainability Indicators		PLANT I	PLANT II	PLANT III
SI1	Inventory cost	7.000	5.800	6.600
SI2	Labour cost	6.400	6.600	6.800
SI3	Material cost	7.000	6.400	7.400
SI4	Machine cost	7.000	7.000	5.600
SI5	Product delivery	7.000	7.800	7.600
SI6	Raw material substitution	6.800	7.200	6.800
SI7	Air emission	6.600	5.800	6.400
SI8	Energy consumption	7.000	7.800	7.000
SI9	Fuel consumption	6.400	7.000	7.200
SI10	Material consumption	6.200	6.000	7.400
SI11	Noise pollution	6.600	6.600	7.600
SI12	Water utilization	7.000	7.600	6.800
SI13	Accident rate	7.400	6.200	6.800
SI14	Employee involvement	7.400	6.200	7.600
SI15	Labour relationship	5.400	7.400	5.800
SI16	Gender equity	6.400	6.600	7.400
SI17	Occupational health and safety	6.200	7.600	6.200
SI18	Training and education	6.600	7.200	7.800

It is necessary to transforms various attribute dimensions into non-dimensional attributes, for comparisons across criteria. For normalizing, each column of decision matrix is divided by root of sum of square of respective columns using Equation 1. Table 4 shows the normalized decision matrix thus formulated.

Weighted normalized decision matrix was formulated by multiplying attributes weight to each rating against each alternative using Equation 2. Table 5 shows the weighted normalized decision matrix formulated.
The positive ideal (A*) and negative ideal (A#) solutions are determined using Equations 3 and 4. The results are shown in Table 6. The separation of each alternative solution is calculated using Equations 6 and 7. The final results are shown in Table 7.

Table 4. Normalized matrix

Sustainability Indicators		Normalized decision matrix		
		PLANT I	PLANT II	PLANT III
SI1	Inventory cost	0.623	0.516	0.588
SI2	Labor cost	0.560	0.577	0.595
SI3	Material cost	0.582	0.532	0.615
SI4	Machine cost	0.615	0.615	0.492
SI5	Product delivery	0.541	0.603	0.587
SI6	Raw material substitution	0.566	0.599	0.566
SI7	Air emission	0.607	0.534	0.589
SI8	Energy consumption	0.555	0.619	0.555
SI9	Fuel consumption	0.537	0.588	0.605
SI10	Material consumption	0.545	0.528	0.651
SI11	Noise pollution	0.548	0.548	0.631
SI12	Water utilization	0.566	0.614	0.550
SI13	Accident rate	0.627	0.525	0.576
SI14	Employee involvement	0.602	0.505	0.619
SI15	Labor relationship	0.498	0.682	0.535
SI16	Gender equity	0.542	0.559	0.627
SI17	Occupational health and safety	0.534	0.655	0.534
SI18	Training and education	0.528	0.576	0.624

Table 5. Weighted Normalized matrix

Sustainability Indicators		Weighted normalize decision matrix		
		PLANT I	PLANT II	PLANT III
SI1	Inventory cost	4.985	4.130	4.700
SI2	Labor cost	4.477	4.617	4.757
SI3	Material cost	4.888	4.469	5.167
SI4	Machine cost	4.554	4.554	3.644
SI5	Product delivery	4.434	4.941	4.814

Sustainability Indicators		Weighted normalize decision matrix		
		PLANT I	PLANT II	PLANT III
SI6	Raw material substitution	4.302	4.555	4.302
SI7	Air emission	4.493	3.948	4.357
SI8	Energy consumption	4.110	4.580	4.110
SI9	Fuel consumption	3.762	4.115	4.232
SI10	Material consumption	4.364	4.223	5.208
SI11	Noise pollution	3.290	3.290	3.788
SI12	Water utilization	4.527	4.915	4.398
SI13	Accident rate	3.509	2.940	3.225
SI14	Employee involvement	4.698	3.936	4.825
SI15	Labor relationship	3.984	5.460	4.279
SI16	Gender equity	4.013	4.138	4.640
SI17	Occupational health and safety	4.061	4.978	4.061
SI18	Training and education	3.696	4.032	4.368

Table 6. Positive and negative ideal solutions

Sustainability Indicators		Positive Ideal Solution (Max)	Negative Ideal Solution (Min)
SI1	Inventory cost	4.985	4.130
SI2	Labor cost	4.757	4.477
SI3	Material cost	5.167	4.469
SI4	Machine cost	4.554	3.644
SI5	Product delivery	4.941	4.434
SI6	Raw material substitution	4.555	4.302
SI7	Air emission	4.493	3.948
SI8	Energy consumption	4.580	4.110
SI9	Fuel consumption	4.232	3.762
SI10	Material consumption	5.208	4.223
SI11	Noise pollution	3.788	3.290
SI12	Water utilization	4.915	4.398
SI13	Accident rate	3.509	2.940
SI14	Employee involvement	4.825	3.936
SI15	Labor relationship	5.460	3.984

Sustainability Indicators		**Positive Ideal Solution (Max)**	**Negative Ideal Solution (Min)**
SI16	Gender equity	4.640	4.013
SI17	Occupational health and safety	4.978	4.061
SI18	Training and education	4.368	3.696

Table 7. Determine separation and relative closeness from/to ideal solutions

Sustainability Indicators	**PLANT I**	**PLANT II**	**PLANT III**
Si*	2.431	2.060	2.108
Si#	1.724	2.220	2.108
Si*+Si#	4.155	4.281	4.217
Si# / Si*+Si#	0.415	0.519	0.500

5. Conclusions

The paper industries are generally high consumer driven industries with huge flow of material and energy from cradle to cradle. Thus, it is essential to evaluate the sustainable manufacturing in this industry. In this work Performance Indicators (PIs) for sustainable manufacturing evaluation in paper industries was identified based on the literature. Based on the survey, three criteria with a total of eighteen indicators are identified as the PIs. An assessment model was then established using TOPSIS methodology. The criteria weights of the PIs were decided by the expert team framed. After computing the attribute weights the decision matrix was formulated, followed by standardization of decision matrix and weighting the standardized decision matrix. The positive ideal and negative ideal solutions were computed to determine the separation between ideal solutions. The plants scores and rank were computed by calculating relative closeness to ideal solution to quantify sustainable manufacturing performance corresponding to the PIs. It was found that, Plant II has achieved the highest overall score (0.519) with a good performance. On the other hand, Plant I has attained a low overall score (0.415) with a reasonable performance (Figure 1).

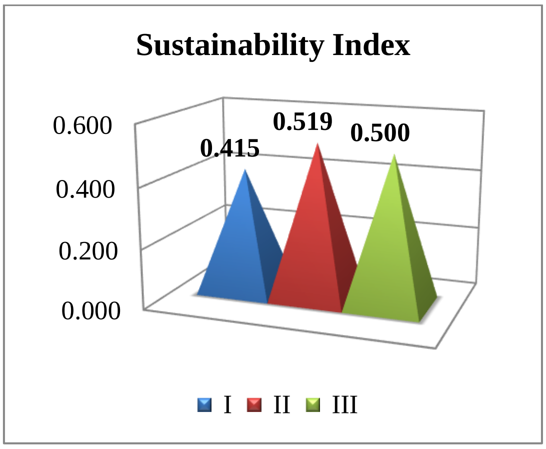

Figure 1. The overall score of plants compared

IOP Conf. Series: Materials Science and Engineering **263** (2017) 062046 doi:10.1088/1757-899X/263/6/062046

Results of the case study conducted were useful in quantifying the sustainability performance of the paper plants. The organization was able to focus more by identifying the weaker areas of sustainability to achieve sustainable performance. The study can further be extended to other industries to check its feasibility of adoption.

6. References

[1] Jayal, A. D., Badurdeen, F., Dillon, O. W., & Jawahir, I. S. (2010). Sustainable manufacturing: Modeling and optimization challenges at the product, process and system levels. CIRP Journal of Manufacturing Science and Technology, **2(3)** 144-152

[2] Nambiar, A. N. (2010, January). Challenges in sustainable manufacturing. In Proceedings of the 2010 international conference on industrial engineering and operations management, Dhaka, Bangladesh, 9-10.

[3] Rusinko, C. (2007). Green manufacturing: an evaluation of environmentally sustainable manufacturing practices and their impact on competitive outcomes. IEEE Transactions on Engineering Management, **54(3)** 445-454

[4] Ijomah, W. L., McMahon, C. A., Hammond, G. P., & Newman, S. T. (2007). Development of design for remanufacturing guidelines to support sustainable manufacturing. Robotics and Computer-Integrated Manufacturing, **23(6)** 712-719

[5] US Department of Commerce. (2009) Sustainable manufacturing initiative. Proceedings of the 2nd Annual Sustainable Manufacturing Summit.

[6] Manufacturing, S. (2009). Eco-Innovation. Framework, Practices and Measurement. Synthesis Report, OECD.

[7] Elhasia, T., Noche, B., & Zhao, L. (2013, March). Simulation of a Sustainable Cement Supply Chain; Proposal Model Review. In Proceedings of World Academy of Science, Engineering and Technology (No. 75, p. 562). World Academy of Science, Engineering and Technology (WASET).

[8] United Nations Environment Program - Division of Early Warning and Assessment. Keeping Track of Our Changing Environment: From Rio to Rio+20 (1992-2012). Report; 2011: p 84.

[9] Hunter, D. (1978). Papermaking: the history and technique of an ancient craft. Courier Corporation.

[10] Pardo, N., Moya, J. A., & Mercier, A. (2011). Prospective on the energy efficiency and CO 2 emissions in the EU cement industry. Energy, **36(5)** 3244-3254

[11] Uson, A. A., López-Sabirón, A. M., Ferreira, G., & Sastresa, E. L. (2013). Uses of alternative fuels and raw materials in the cement industry as sustainable waste management options. Renewable and Sustainable Energy Reviews, **23** 242-260

[12] Hwang, C. L., & Yoon, K. (2012). Multiple attribute decision making: methods and applications a state-of-the-art survey (Vol. 186). Springer Science & Business Media.

[13] Lai, Y. J., Liu, T. Y., & Hwang, C. L. (1994). Topsis for MODM. European Journal of Operational Research, **76(3)** 486-500

[14] Jahanshahloo, G. R., Lotfi, F. H., & Davoodi, A. R. (2009). Extension of TOPSIS for decision-making problems with interval data: Interval efficiency. Mathematical and Computer Modelling, **49(5)** 1137-1142