Development of Sustainable Manufacturing Process: A Fuzzy-AHP Approach

[1]Dr. Priyabrata Mohapatra, [2]Sourabh Nanda, [3]Nihar Ranjan Sahoo, [4]Debasis Sahoo
[1,2]School of Mechanical Engineering, KIIT, Bhubaneswar, Odisha, India
[3]Senior Environmental Engineer, Odisha Pollution Control Board, Odisha, India
[4]School of Engineering, MITS, Bhubaneswar, Odisha, India

Abstract

Development of sustainable manufacturing system is a key research area to realise the Sustainable Development Goal of any country. In this research work we have developed a model for development of a sustainable manufacturing process using fuzzy-AHP. The fuzzy-AHP technique is used to determine the effect of various factors affecting the sustainability of a product. The study shows that, adoption of a sustainable manufacturing process is the key factor followed with the design of the product is crucial in determining sustainability of the product.

Keywords

Sustainable Engineering, Sustainable Manufacturing, Fuzzy, AHP.

I. Introduction

In recent times, there is more focus in sustainable engineering in which sustainable manufacturing is one of the key area. Sustainable manufacturing is defined as the manufacturing practices that do not harm the environment during the manufacturing of any product. It emphasizes the use of processes that do not pollute the environment or harm consumers, employees, or other members of the community. Sustainable manufacturing includes recycling, conservation, waste management, water supply, environmental. Sustainable manufacturing emphasis on designing and delivering products that minimize negative effects on the environment through their production, use, and disposal. In the current scenario it is better to make product for environmental as well as economic feasibility for the organizations. Sumit et. al.[2015] have done a crucial issue in present scenario for the manufacturing firms in the development of Sustainable Manufacturing and operations. Green Jr.et. al. [2012] have done the impact of green supply chain management practices on environmental and organizational performance from a manufacturer's point of view within a supply chain environment. Maria et. al. [2016] have explored and evaluated the relationship and links with Green supply chain management practices. Here a framework is developed which provides business practices to evidence suggesting that to beneficial for Green practices and the implementation of Green practices. Govindan et al. [2014] identifies barriers to the implementation of a green supply chain management (Green SCM) based on procurement effectiveness. Mohapatra, et al [2014] states ANP fuzzy based green balanced scorecard has been used within CDM approach to assist in arriving at a consistent, accurate & timely data flow across all cross functional areas of business. Sunil Luthra et. al. 2016 had implemented the sustainable consumption and production is a challenge in supply chain in which an Analytical Hierarchy Process (AHP) is used to evaluate the barriers in adopting sustainable consumption and production initiatives in a supply chain.

II. Problem Statement

The meaning of sustainable development is most comprehensively defined in the Brundtland Report, commonly known as Our Common Future as a development that meet the present need of the society, without compromising the need of the future generation. Sustainable manufacturing, which evolves from the paradigm of the sustainable development defined in Our Common Future, actually means that, it is a manufacturing process, which is economically viable, socially acceptable, and environmentally benign. Several authors have studied various aspects of sustainable manufacturing, and broadly encompass the factors which describes:

- How the product is designed so that its impact (both long-term and short-term) on the environment is minimal?
- Whether the process of manufacturing results in minimal release of pollutants to the environment?
- Is the process of raw material procurement, and the process of manufacturing is lean enough to ensure lean manufacturing.
- Is the supply chain associated with raw material procurement chain, and the reverse supply chain to collect the end of life product has minimum impact on the environment.
- Whether environmentally sound methods are available for safe disposal of the pollutants.

The frame work of the model is show in fig. 1. The details are described as follows:

A. Ecologically sound product design(ESPD)

A sound ecological design of a product ensures that, the product is designed in such a way that it is in synch with the ecology at each stage of its life cycle—input procurement, process of manufacturing, use of the product, and the end of life disposal. Therefore, an ecologically design product demands less of resources for manufacturing the product so that the resources are conserved for the future generation, and impact of the end of life disposal is also minimal. Therefore, ecological product design in the context of sustainable manufacturing can be attributed by (i) specific water consumption (WC), (ii) specific energy consumption (EC), (iii) potential of reuse and recycle, (PR) and (iv) the environmental impact of final disposal (EI).

B. Environmentally Sound Process (ESP)

Pollution potential of a manufacturing process is a key determinant of sustainable manufacturing. Therefore, a sustainable manufacturing process is characterised by minimal release of pollutants to the environment. Usually, a process is chosen for manufacturing a product, with the available technology. When multiple technology for manufacturing process are available, the specific pollution load of a process becomes the criteria of measurement to determine the sustainability of a process. Therefore,(i) water pollutant released per unit of product (WP), (ii) emission of air pollutant per unit of product(AP), and (iii) solid waste generated per unit of product are chosen as the attribute of an environmentally sound manufacturing process(SW).

C. Lean manufacturing(LM)

A lean manufacturing process for a product is characterised by the material, energy it consumes to produce an unit of product, and cost of production to ensure economic viability of the product. In many cases, when the product is not economically viable, even if it is a sustainable product, the economic viability is supplemented with subciides or other forms of economic incentives. Keeping these aspects in mind the attributes for lean manufacturing is determined from the (i) material intensity of the product (MP), (ii) energy intensity of the product (EP), and (iii) cost of production(CP).

D. Green and Reverse Supply Chain Management (GRSCM)

Supply chain plays an important role in product life cycle. A product life-cycle usually consists of input material supply chain, product supply chain and waste recovery supply chain as the reverse supply chain. For a sustainable product design, existence of optimal supply chains covering all the three aspects is essential. Therefore, the following attributes are selected for a sustainable supply chain, (i) fraction of locally available raw material (RM), (ii) ease of material recovery(MR), and (iii) extended producers responsibility to collect end of life product(PR).

E. End of Life Impact (EI)

Impact of end of life disposal on the environment is the least discussed subject, even though the environmental impact of end of life disposal is the maximum. The main concern at the end of life is whether, the product contains any hazardous material that can be environmentally harmful when disposed as waste. Secondly the recovery of material from the waste product is proportional to the embedded value of the waste, and finally availability of sound technology for appropriate treatment of waste. Considering these aspects we attribute this factor as (i) the component of hazardous substance in the product (HS), (ii) value of recovery (VR), and (iii) ease of treatability (ET).

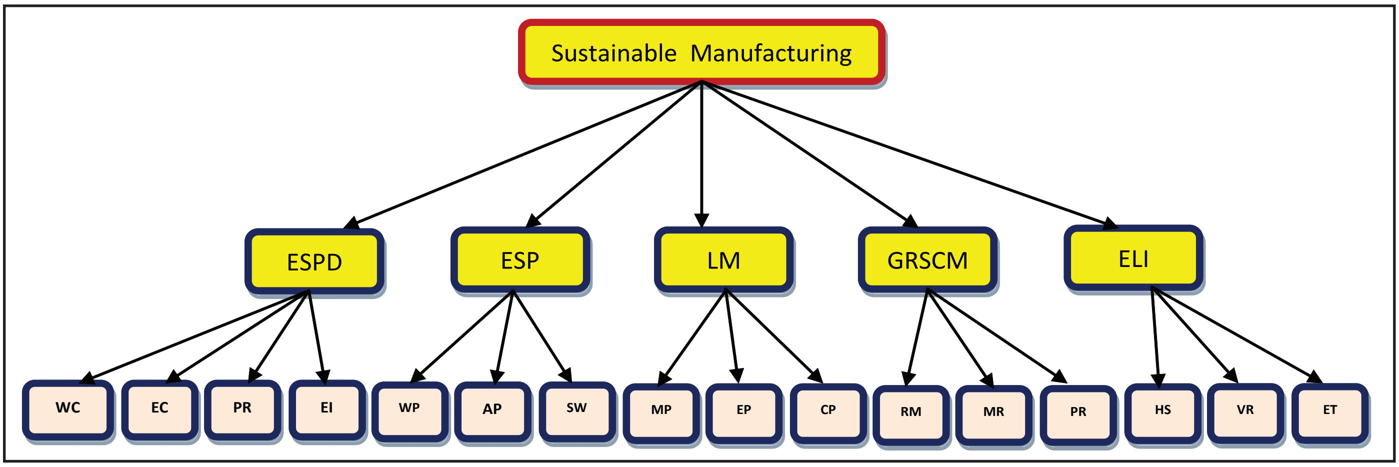


Fig. 1: Frame work of the Model

III. Methodology

In this work, a Fuzzy-AHP is applied and detailed are described as follows.

The Algebraic functions on triangular fuzzy numbers follow the same mathematical rule. The m extent analysis values for each criterion are denoted as follows: (Tiwari et al., 2008)

$N_{oi}^1, N_{oi}^2, ..., N_{oi}^m$ where i = 1,2, ..., n

N_{oi}^j : The triangular fuzzy member (j=1,2,..,3)

N_{oi}^m: The value of extent analysis of ith object for mth goal

The value of fuzzy synthetic extent with respect to ith object is defined as

$$K_i = \sum_{j=1}^{m} N_{oi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} N_{oi}^j \right]^{-1}$$

The value $\sum_{j=1}^{m} N_{oi}^j$ can be found by performing fuzzy addition operation of m extent analysis values from a particular matrix such that

$$\sum_{j=1}^{m} N_{oi}^j = \left(\sum_{j=1}^{m} n1j, \sum_{j=1}^{m} n2j, \sum_{j=1}^{m} n3j \right)$$

The value of $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} N_{oi}^j \right]$ can be obtained by performing the fuzzy addition of N_{oi}^j (j=1,2,..,n) such that

$$\sum_{i=1}^{n} \sum_{j=1}^{m} N_{oi}^j = \left(\sum_{j=1}^{m} n1j, \sum_{j=1}^{m} n2j, \sum_{j=1}^{m} n3j \right)$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} N_{oi}^j \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} n_{3i}}, \frac{1}{\sum_{i=1}^{n} n_{2i}}, \frac{1}{\sum_{i=1}^{n} n_{1i}} \right)$$

The degree of possibility of

$N_1 = (n_{11}, n_{12}, n_{13}) \geq N_2 = (n_{21}, n_{22}, n_{23})$ is defined as the

$$V(N_1 \geq N_2) = \sup_{x \geq y} \left[\min \left(\mu N_1(x), \mu N_2(x) \right) \right]$$

When a pair(x,y) exist such that $x \geq y$ and $\mu N_1(x)$ = $\mu N_2(x)$ =1, then we have $V(N_1 \geq N_2)=1$. The N1 and N2 are the convex fuzzy numbers so

$$V(N_1 \geq N_2) = 1 \quad if \; n_{11} \geq n_{21}$$

$V(N_1 \geq N_2) = hgt(N_1 \cap N_2) = \mu N_1(d)$

Where d is the ordinate point of the highest intersection point D between μN_1 and μN_2

When $N_1 = (n_{11}, n_{12}, n_{13})$ and $N_2 = (n_{21}, n_{22}, n_{23})$, then ordinate of D is calculated by

$$V(N_1 \geq N_2) = hgt(N_1 \cap N_2) = \frac{n_{11} - n_{23}}{(n_{22} - n_{23}) - (n_{12} - n_{11})}$$

For the comparison of N1 and N2, both values of $V(N_1 \geq N_2)$ and $V(N_2 \geq N_1)$ are required.

The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy number N_i (i=1,2,..k) can be defined as

$$V(N \geq N_1, N_2, ..., N_k) =$$
$$V[(N \geq N_1) and (N \geq N_2) and (N \geq N_k)]$$
$$= \min V(N \geq N_1), i = 1, 2, ..., k$$
$$if\ m(P_i) = \min V(K_i \geq K_k)$$

For k=1,2,3...k, $k \neq i$, then the weighted vector is given by

$$W_P = (m(P_1), m(P_1), ..., m(P_n))^T$$

$where\ P_i (i = 1, 2, 3, .., n)$ are n elements.

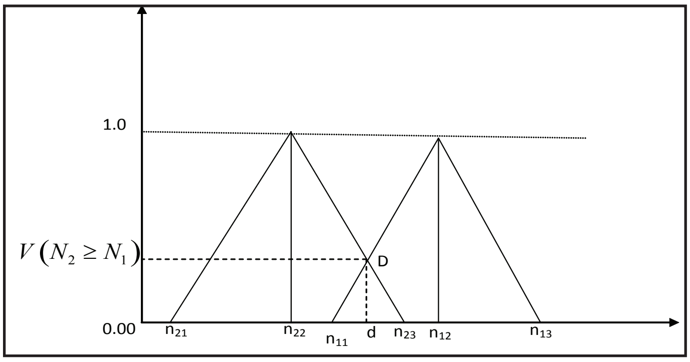
After normalizing Wp, we get the normalized weight vectors $W = (w(P_1), w(P_2), ..., w(P_n))^T$.

The proposed AHP model:

Step 1: First we consider all construct, sub construct and sub-sub-sub construct for Sustainable Selection.

Step 2: By using Fuzzy Mapping function, the weights are calculated.

Step 3: The weight are calculated on each pairwise matrix.



Step 4: Global priority are calculated

Step 5: Calculation Of Overall weight

The overall weight is calculated by the product of the global weight of critical factor and the weight of sub-factor which are belong to the main parameter. Based on the overall weight of sub-parameters, the ranking is done to adapt the critical sub-parameters.

Overall weight = global weight* weight of sub-parameters.

IV. Calculation of Weight for the Criteria

Table 1: Pair-wise Matrix for Ecologically Sound Product Design (ESPD)

ESPD	WC	EC	PR	EI	Weight
WC	1,1,1	5,7,8	.153,.2,.25	.138,.166,.208	0.112
EC	.125,.142,.2	1,1,1	5,6,7	5.6,7,8.4	0.49
PR	4,5,6.5	.142,.166,.2	1,1,1	.166,.2,.25	0.008
EI	4.8,6,7.2	.119,.142,.178	4,5,6	1,1,1	0.390

The weights are calculated using Fuzzy Mapping function.

F1=(1+5+ .153+ .138, 1+7+ .2+.166, 1+8+ .25+ .208) = (6.291, 8.366, 9.458)

Similarly

F2= (11.725, 14.142, 16.6)

F3= (5.308, 6.366, 7.95)

F4= (9.919, 12.142, 14.378)

K1= (6.291, 8.366, 9.458) (48.386, 41.016, 33.243)-1 = (0.130, 0.204, 0.284)

Where 33.243 = 6.291+11.725+5.308+9.919

Similarly

K2= (0.242, 0.344, 0.499)

K3= (0.109, 0.155, 0.239)

K4= (0.2040.296, 0.432)

Here we see that V (K2 ≥K1) =1 if n11> n22, Then we get the final value of weights after normalizing. Normalizing these value we get the final result are (0.112, 0.49, 0.008, 0.39).

Similarly, the normalizing weights of different criteria are calculated (Table 2, 3, 4, 5).

The overall weights of individual factors are shown in Table 8.

Table 2: Pair-wise Matrix of Environmentally Sound Process (ESP)

ESP	WP	AP	SW	Weight
WP	1,1,1	3.6,5,6.3	0.121,0.166,0.217	0.29
AP	0.158,0.2,0.277	1,1,1	4.8,6,7.2	0.356
SW	4.6,6,8.2	0.142,0.166,0.208	1,1,1	0.354

Table 3: Pair-wise Matrix of Lean Manufacturing (LM)

LM	MP	EP	CP	Weight
MP	1,1,1	6.5,8,9	0.135,0.166,0.181	0.56
EP	0.111,0.125,0.153	1,1,1	3,4,5	0.074
CP	5.5,6,7.4	0.2,0.25,0.33	1,1,1	0.366

Table 4: Pair-Wise Matrix of Green and Reverse Supply Chain Management (GRSCM)

GRSCM	RM	MR	PR	Weight
RM	1,1,1	1.5,2,3	2,3,4	0.693
MR	0.333,0.5, 0.666	1,1,1	0.666,1,2	0.207
PR	0.25,0.33,0.5	0.5,1,1.5	1,1,1	0.1

Table 5: Pair-wise matrix of End of life impact (ELI)

ELI	HS	VR	ET	Weight
HS	1,1,1	3,4,5	0.25,0.333,0.4	0.349
VR	0.2,0.25,0.333	1,1,1	4.5,5,6	0.468
ET	2.5,3,4	0.166,0.2,0.222	1,1,1	0.183

Table 6: Global Weight Calculation

	ESPD	ESP	LM	GRSCM	ELI	Weight
ESPD	1,1,1	0.166,0.2,0.222	6.2,7,8	0.142,0.166,0.2	4.6,6,7.2	0.274
ESP	4.5,5,6	1,1,1	0.111,0.125,0.156	4,5,6	6,7,8	0.434
LM	0.125,0.142,0.161	6.4,8,9	1,1,1	0.2,0.25,0.285	0.138,0.166,0.208	0.04
GRSCM	5,6,7	0.166,0.2,0.25	3.5,4,5	1,1,1	0.2,0.25,0.333	0.127
ELI	0.138,0.166,0.217	0.125,0.142,0.166	4.8,6,7.2	3,4,5	1,1,1	0.125

Table 7: Overall Weight Calculation

Critical factors	Global weight	Sub parameters	Weight	overall weight
Ecologically sound product design(ESPD)	0.274	Water consumption(WC)	0.112	0.030688
		Energy consumption(EC)	0.49	0.13426
		Potential of reuse and recycle, (PR)	0.008	0.002192
		Environmental impact of final disposal(EI)	0.390	0.10686
Environmentally sound process(ESP)	0.434	Water pollutant(WP)	0.29	0.12586
		Air pollutant(AP)	0.356	0.154504
		Solid waste(SW)	0.354	0.153636
Lean manufacturing(LM)	0.04	Material intensity of the product(MP)	0.56	0.0224
		Energy intensity of the product(EP)	0.074	0.00296
		Cost of production(CP)	0.366	0.01464
Green and reverse supply chain management(GRSCM)	0.127	Available raw material(RM)	0.693	0.088011
		Material recovery(MR)	0.207	0.026289
		End of life product(PR)	0.1	0.0127
End of life impact (EI)	0.125	Hazardous substance in the product(HS)	0.349	0.043625
		Value of Recovery(VR)	0.468	0.0585
		Ease of treatability(ET)	0.183	0.022875

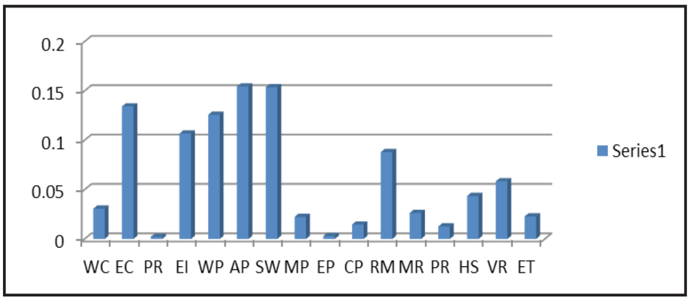


Fig. 3: Overall Weight of Sub-factors.

V. Conclusion

The results obtained from the study indicate that, the environmental soundness of the process adopted to produce the product is the most important factor of sustainability. This factor is derived from the pollution potential of the manufacturing process which is shown in Table 7 and Fig. 3. The impact of water, air and solid waste pollution has been assigned nearly equal weight in this case, which can vary widely depending upon the product. Nevertheless, this factor remains most critical for sustainability of a product. The next factor that is second in the list of criticality is the product design. For this factor, energy consumption plays a crucial role, keeping in mind that the source of energy is not from a sustainable source like renewables. However, other attributes like water consumption and potential for recycling are also important attributes of this factor. The impact of supply-chain and the end of life impact seem to have similar weights, indicating their importance, but impact is limited primarily because these activities are exogenous to the core manufacturing process. However, the study did not envisage any significant impact on account of lean manufacturing practice.

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Dr. Priyabrata Mohapatra received the B Tech degree from the Department of Manufacturing Science and Engineering, UCE Burla and M Tech from the Department of Mechanical Engineering with Production Engineering as a specialisation from National Institute of Technology, Rourkela. He has done his PhD in the Department of Industrial Engineering Management of Indian Institute of Technology, Kharagpur. His current research interests are reconfigurable manufacturing system, intelligent manufacturing systems, integration of process planning and scheduling in manufacturing, supply chain management. and production planning and control.

Sourabh Nanda has completed his M.Tech degree from School of Mechanical Engineering, KIIT University. His research interests are supply chain management, intelligent manufacturing systems, multivariate analysis, process planning & scheduling, production & operation management.

Prof. Debasis Sahoo received his B.E. degree in Mechanical Engineering from Biju Patnaik University & Technology, Odissa, India, in 2005, the M.Tech degree in industrial Engineering & Management from College of Engineering and Technology, Bhubaneswar, Odisha, India in 2009. He is a principal of MITS School of Engineering, Bhubaneswar, Odisha. His research interests include Supply Chain Management.

Eng. N. R. Sahoo had received his B.E degree in Mechanical Engg in U.C.E Burla and M.Tech in IIT Roorkee. He is perusing Ph.D in the Department of Industrial and Systems Engineering, IIT Kharagpur. He is currently working in Senior Environmental Engineer, Odissa Pollution Control Board, Odisha.