An Experimental Research in Sustainability Analysis in Industries based on Lean Green and Six Sigma using AHP and Fuzzy AHP

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Abstract—Sustainability is a matter of utmost importance in the industries of all the sectors in the current scenario. Thus a study based on the different factors responsible for the sustainability is done. Hence three factors which affect sustainability are considered they are Green (environmental factors), Lean manufacturing(waste minimization) and Six Sigma (zero defects). Sub factors to all this factors are also selected. These factors and their sub factors are than prioritized by the proportion or percentage to which they affect the sustainability of the organization. These factors are given ratings from the industries and these ratings are further utilized to determine the priority ratios. The prioritization is done by using Fuzzy and Fuzzy AHP processes.

Index Terms—Fuzzy, AHP, Sustainability, Lean manufacturing, Green manufacturing, Six Sigma.

1. INTRODUCTION

Sustainable development has been defined as "the development that meets the needs of the present without compromising the ability of the future generation to meet their own needs". Building on the scientific rationale that the management of natural resources should be consistent with the preservation of its reproductive capacity, this concept has been broadened to incorporate economic, social and environmental concerns. Environmental protection, economic development, and social development are thus the three pillars of sustainable development. The emphasis on the needs of both present and future generations (inter-generation equity) with regard to these three dimensions is a key aspect

*1.1. Green Manufacturing (Environmental factor and sustainability)*F*:* With the coming of the Industrial Revolution, humans were able to advance further into the 21st century. Technology developed rapidly, science became advanced and the manufacturing age came into view. With all of these came one more effect, industrial pollution.

As the factories used to work for definite hours a day, the levels of pollution did not grow considerably. But after the subsequent growth of these factories, the industrial pollution has become a factor of high disturbance.

Any type of pollution which can sketch its immediate source to industrial practices is known as industrial pollution. The majority of the pollution on the planet occurs due to the industries of some kind. Also, industrial pollution has taken on the momentous importance for agencies fighting against environmental degradation. Countries with an increase in the industries are finding it difficult to cope with this kind of pollution.

Industrial pollution can affect the environment in a number of ways:

- It may increase the chances of degradation of human health as this pollutants might get into the water sources hence might degrade water quality.
- It may interfere with natural processes. For example, industrial waste could change local climatic conditions or destroy wildlife habitats.

1.2 Lean manufacturing (Waste minimization and sustainability): Lean manufacturing is the phenomenon which works to reduce the wastes produced in an organization. Hence reducing the losses in the organization in the form of wastes. Thus waste minimization is a positive approach to indirectly increase an organizations profit.

Waste management should be considered as a matter of utmost importance. The waste management requires a significant amount of time and resources; therefore, it is important to understand the benefits of waste minimization and how it can be implemented in all sectors of the economy, in an effective, safe and sustainable manner.

1.3 Six Sigma (Zero defect and sustainability): Six sigma (Zero defects) are referred to as a viewpoint, a state of mind, or a movement that targets to reduce the number of defects in manufactured products and service as much as possible. It does not have different steps to follow or rules to stand by,

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which leaves companies open to customizing how they want it to work for themselves. Hence, a certain product is said to have achieved quality if and when it meets those requirements. However, this should not be confused with higher standards of products. For instance, it'll be unrealistic to say that a basic mobile phone is of low quality compared to the latest iPhone because they both have to meet different quality standards to pass the quality test. Based on this, six sigma means the basic mobile phone is a quality product if it meets the initial requirements set for it. That is, if it can make and take phone calls clearly, send and receive text messages, among other things, then it is only realistic to say it conforms to quality and has (close to) zero defects.

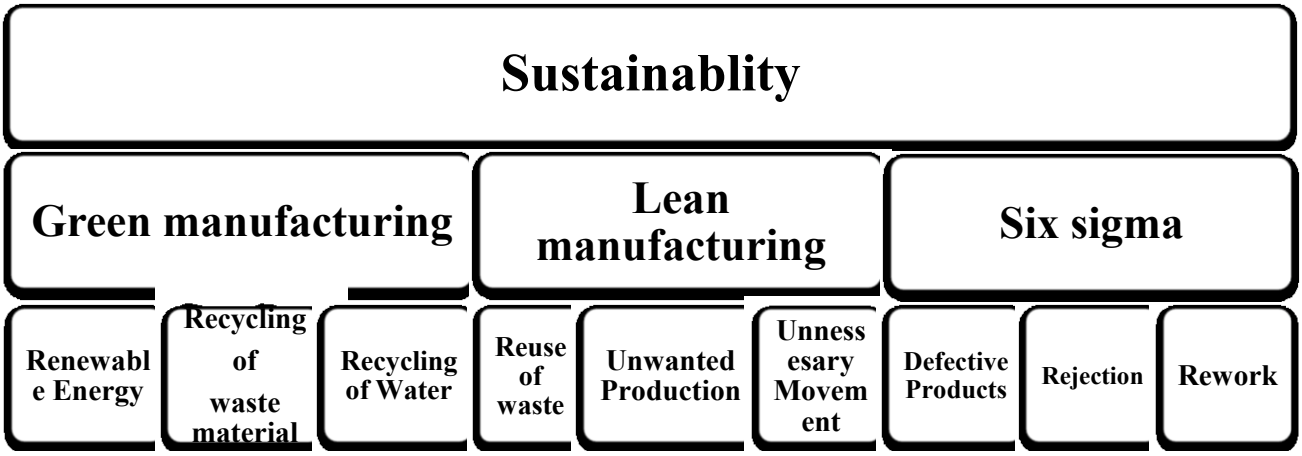

Fig1 sustainability flow diagram

2. Objective of paper

In the field of AHP based case study on the parameters of lean, green and six sigma. Thus the description of the research gaps are as mentioned below:

1. It can be interpreted that till now the many parameters are considered on the individual basis but here in this paper are using three parameters integrated to find out the sustainability.

2. Sustainability prediction using the Fuzzy AHP using the three factors being used has not been done.

3. Comparison between the normal AHP calculation and Fuzzy calculation has not been done.

3. Methodology:

The calculation for the priority vector based on the sustainability for the factors is done by two factors they are as follows:

3.1. Analytic hierarchy process
3.2 Fuzzy AHP

3.1. The analytic hierarchy process: Analytic Hierarchy Process (AHP) is one of multi measures decision-making technique that was originally developed by . In short, it is a technique to derive ratio scales from paired comparisons. The input can be obtained from actual measurements such as price, weight etc., or from subjective opinions such as satisfaction feelings and preference. AHP allow some small inconsistency in judgment because human is not always consistent. The ratio scales are derived from the principal Eigenvectors and the consistency index is derived from the principal Eigen value.

It is a tool used for solving complex decision problems to evaluate many dilemmas in different areas of human requirements, such as political, financial and various others different interests. The AHP provides a comprehensive and rational framework to help managers set priorities and make the best decision when both qualitative and quantitative aspects of a decision need to be considered. In conventional AHP, the pair-wise comparison is established using a scale which converts the human preferences between available alternatives. Even though the discrete scale of AHP has the advantages of simplicity and ease of use, it is not sufficient to take into account the uncertainty associated with the mapping of one's perception to a number. However, due to vagueness and uncertainty in the decision maker's judgment, a crisp, pair-wise comparison with a conventional AHP may be unable to accurately capture the decision maker's judgment .

Consistency of pair-wise comparison matrix.[1]

In classical AHP, we consider an *nxn* pair-wise comparison matrix *A* with positive elements such that [1]

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix}$$

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…… (1)

This matrix is reciprocal if $a_{ij} = \frac{1}{a_{ji}}$ for each 1≤I, j≤n.

We say that A is consistent if

$a_{ij} * a_{jk} = a_{ik}$, for each 1≤i, j, k≤n.

From the geometrical means, the relative normalized weights of each attribute/criterions can be calculated by normalizing the geometrical means of raw in the comparison matrix. This can be presented in Equation (1 & 2) the geometric means method of AHP is explored to find out the relative normalized weights of the criterion due to its simplicity and easiness to find out the maximum Eigen value and to reduce the inconsistency in judgment.

$A_1 = [b_{ij}]$

GM $= [\coprod_{j=1}^{n} bij]^{\frac{1}{M}}$ …… (2)

$A_2 = w_j = \frac{GM}{\sum_{j=1}^{n} GMj}$ ……..(3)

Calculation of matrix A_3 and A_4 such that $A_3 = A_1 \times A_2$ and $A_4 = A_3/A_2$…….. (4)

Where $A_2 = [w1, w2, w3 \ldots\ldots\ldots wj]^T$ and A_i is a decision matrix

Determine the maximum eigen value (λ_{max}) i.e. the average of matrix A_4. Consistency index is evaluated by this equation:

Consistency index $= \frac{PrincipleEigenvalue - sizeofmatrix}{sizeofmatrix - 1}$

$= \frac{\lambda max - n}{n-1}$

Index of consistency for random Judgments, Saaty(1980) defined the consistency ratio (CR) as:

CR $= \frac{CI}{RI}$

Where RI is the average value of CI for random matrices using the given scale [1]

Table no.1 values of RI

M	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

3.2 Fuzzy AHP: Fuzzy Analytic Hierarchy Process (F-AHP) embeds the fuzzy theory to basic Analytic Hierarchy Process (AHP), which was developed by Saaty. AHP is a widely used decision-making tool in various multi-criteria decision-making problems. It takes the pair-wise comparisons of different alternatives with respect to various criteria and provides a decision support tool for multi-criteria decision problems. In a general AHP model, the objective is in the first level, the criteria and sub-criteria are in the second and third levels respectively. Finally, the alternatives are found in the fourth level. Since basic AHP does not include vagueness for personal judgments, it has been improved by benefiting from the fuzzy logic approach. In F-AHP, the pair wise comparisons of both criteria and the alternatives are performed through the linguistic variables, which are represented by triangular numbers. They defined the triangular membership functions for the pair wise comparisons.

Table no.2 Fuzzy values

ASSESSMENT	AHP VALUE	FUZZY NUMBER
Very poor	1	(1,1,3)
Poor	3	(1,3,5)
Moderate	5	(3,5,7)
Good	7	(5,7,9)
Very good	9	(7,9,9)

Based on the above table.2 the AHP values in the matrices are replaced with their corresponding fuzzy triangular matrix values and the priority vector is being calculated by applying fuzzy set theory. The priority vector thus calculated is in the form of the fuzzy triangular value which is then required to be converted to the normal numbers. This is done by using centre of area method. By applying the below-mentioned equation.

$M_{i1} = \frac{lwi + mwi + nwi}{3}$

Thus the de-fuzzified values can be utilized to determine the priorities.

USING AHP TOOLS:

Industry 1

The local priority is being calculated based on the comparisons of the local priority factors. A matrix is being formulated based on the comparisons being made through the questionnaires.

LOCAL PRIORITY:

Lean manufacturing (C1):

Reuse of wastes (C11)

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Unwanted production (C12)
Unnecessary movement (C13)

	C11	C12	C13	PV
C11	1	3	9	0.649
C12	01-Mar	1	7	0.294
C13	01-Sep	01-Jul	1	0.056

Thus the above-mentioned matrix is the local priority matrix for Lean manufacturing.

Consistency index = $\frac{PrincipleEigenvalue-sizeofmatrix}{sizeofmatrix-1}$

$=\frac{\lambda max-n}{n-1}$

Where in the eigen value is calculated using the usual methods to calculate the eigen value.
Thus;
Eigen value = 3.08
And n=3 as the size of matrix used is 3×3;
Hence: CI=$\frac{3.08-3}{3-1}$
CI = 0.04
CR = $\frac{CI}{RI}$
RI=0.58 for a matrix size of 3×3 from table no.1
CR=$\frac{0.04}{0.58}$
CR=0.06
The consistency ratio of the above matrix is found to be less than 0.1, thus the above matrix can be termed as consistent.
The priority vector (PV) in the above matrix is calculated by adding all the columns to formulate a column sum and then dividing each column sums to each of its column cells. This results to a formulation of a new values to each of the cells of the matrix. Than by calculation the row averages of each of the newly calculated cell values leads to the priority vector of each of the sub factors corresponding to them in the local priority matrix.
Similarly, the local priority values for the other two factors are also calculated for industry 1.

Green manufacturing (C2):
Renewable energy (C21)
Recycling of waste material (C22)
Recycling of water (C23)

	C21	C22	C23	PV
C21	1	3	7	0.641
C22	1/3	1	5	0.282
C23	1/7	1/5	1	0.073

Thus the above-mentioned matrix is the local priority matrix for Green manufacturing.

Consistency index = $\frac{PrincipleEigenvalue-sizeofmatrix}{sizeofmatrix-1}$

$=\frac{\lambda max-n}{n-1}$

Where in the eigen value is calculated using the usual methods to calculate the eigen value.
Thus;
Eigen value = 3.06
And n=3 as the size of matrix used is 3×3;
Hence: CI=$\frac{3.06-3}{3-1}$
CI = 0.03
CR = $\frac{CI}{RI}$
RI=0.58 for a matrix size of 3×3 from table no.1
CR=$\frac{0.03}{0.58}$
CR=0.051

The consistency ratio of the above matrix is found to be less than 0.1, thus the above matrix can be termed as consistent.
Hence the priority vector for the matrix can be calculated for the matrix as it is found consistent.

Six sigma (C3):
Defective products (C31)
Rejection rate (C32)
Rework (C33)

	C31	C32	C33	PV
C31	1	3	7	0.641
C32	1/3	1	5	0.282
C33	1/7	1/5	1	0.073

Thus the above-mentioned matrix is the local priority matrix for six sigma.

Consistency index = $\frac{PrincipleEigenvalue-sizeofmatrix}{sizeofmatrix-1}$

$=\frac{\lambda max-n}{n-1}$

Where in the eigen value is calculated using the usual methods to calculate the eigen value.
Thus;
Eigen value = 3.06
And n=3 as the size of matrix used is 3×3;
Hence: CI=$\frac{3.06-3}{3-1}$
CI = 0.03
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Hence the priority vector for the matrix can be calculated for the matrix as it is found consistent.

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Global Priority:
Global priority is the comparisons of the all the global factors. The comparison is made with the help of the questionnaire and hence a pairwise comparison matrix is being prepared to calculate global priority.
Lean manufacturing (C1)
Green manufacturing (C2)
Six sigma (C3)

	C1	C2	C3	PV
C1	1	5	9	0.72
C2	1/5	1	5	0.215
C3	1/9	1/5	1	0.060

Thus the above-mentioned matrix is the local priority matrix for the global priority, which is being formulated on the basis of all the three major factors.
Consistency index = $\frac{PrincipleEigenvalue-sizeofmatrix}{sizeofmatrix-1}$
$=\frac{\lambda max-n}{n-1}$
Where in the eigen value is calculated using the usual methods to calculate the eigen value.
Thus;
Eigen value = 3.08
And n=3 as the size of matrix used is 3×3;
Hence: CI=$\frac{3.08-3}{3-1}$
CI = 0.04
CR = $\frac{CI}{RI}$
RI=0.58 for a matrix size of 3×3 from table no.1
CR=$\frac{0.04}{0.58}$
CR=0.06
The consistency ratio of the above matrix is found to be less than 0.1, thus the above matrix can be termed as consistent.
Thus the priority vector for the major factors for sustainability is being calculated and is termed as global priority.

Aggregate Global Priority Matrix:An aggregate matrix is being prepared which is the aggregate of all the local priorities and the global priorities.

FACTORS	OPERATIONS	PRIORITY VECTOR (PV)
Lean manufacturing	C1×C11+C1×C12+C1×C13	0.719
Green manufacturing	C2×C21+C2×C22+C2×C23	0.208
Six sigma	C3×C31+C3×C32+C3×C33	0.059

USING FUZZY AHP TOOLS:

Industry 1: The local priority is being calculated based on the comparisons of the local priority factors. A matrix is being formulated based on the comparisons being made through the questionnaires.
LOCAL PRIORITY:
Lean manufacturing (C1)
Reuse of wastes (C11)
Unwanted production (C12)
Unnecessary production (C13)

	C11	C12	C13	PV
C11	1	3	9	0.649
C12	01-Mar	1	7	0.294
C13	01-Sep	01-Jul	1	0.056

Thus the above-mentioned matrix is the local priority matrix for Lean manufacturing.

Consistency index = $\frac{PrincipleEigenvalue-sizeofmatrix}{sizeofmatrix-1}$
$=\frac{\lambda max-n}{n-1}$
Where in the eigen value is calculated using the usual methods to calculate the eigen value.
Thus;
Eigen value = 3.08
And n=3 as the size of matrix used is 3×3;
Hence: CI=$\frac{3.08-3}{3-1}$
CI = 0.04
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RI=0.58 for a matrix size of 3×3 from table no.1
CR=$\frac{0.04}{0.58}$
CR=0.06
The consistency ratio of the above matrix is found to be less than 0.1, thus the above matrix can be termed as consistent.
The priority vector (PV) in the above matrix is calculated by adding all the columns to formulate a column sum and then dividing each column sums to each of its column cells. This results to a formulation of a new values to each of the cells of the matrix. Than by calculation the row averages of each of the newly calculated cell values leads to the priority vector of each of the sub factors corresponding to them in the local priority matrix.
Similarly, the local priority values for the other two factors are also calculated for industry 1.
The consistency ratio of the above matrix is less than 0.1 Hence the matrix can be stated as consistent.
Similarly, the local priority values for the other two factors are

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also calculated for industry 1.

Green manufacturing (C2):
Renewable energy (C21)
Recycling of waste material (C22)
Recycling of water (C23)

	C21	C22	C23	PV
C21	1	3	7	0.641
C22	1/3	1	5	0.282
C23	1/7	1/5	1	0.073

Thus the above-mentioned matrix is the local priority matrix for green manufacturing.

Consistency index = $\frac{PrincipleEigenvalue-sizeofmatrix}{sizeofmatrix-1}$
$=\frac{\lambda max-n}{n-1}$
Where in the eigen value is calculated using the usual methods to calculate the eigen value.
Thus;
Eigen value = 3.06
And n=3 as the size of matrix used is 3×3;
Hence: CI=$\frac{3.06-3}{3-1}$
CI = 0.03
CR = $\frac{CI}{RI}$
RI=0.58 for a matrix size of 3×3 from table no.1
CR=$\frac{0.03}{0.58}$
CR=0.051
The consistency ratio of the above matrix is found to be less than 0.1, thus the above matrix can be termed as consistent.

Six sigma (C3):
Defective products (C31)
Rejection rate (C32)
Rework (C33)

	C31	C32	C33	PV
C31	1	3	7	0.641
C32	1/3	1	5	0.282
C33	1/7	1/5	1	0.073

Thus the above-mentioned matrix is the local priority matrix for six sigma manufacturing.

Consistency index = $\frac{PrincipleEigenvalue-sizeofmatrix}{sizeofmatrix-1}$
$=\frac{\lambda max-n}{n-1}$
Where in the eigen value is calculated using the usual methods to calculate the eigen value.
Thus;
Eigen value = 3.08
And n=3 as the size of matrix used is 3×3;
Hence: CI=$\frac{3.08-3}{3-1}$
CI = 0.04
CR = $\frac{CI}{RI}$
RI=0.58 for a matrix size of 3×3 from table no.1
CR=$\frac{0.04}{0.58}$
CR=0.06
The consistency ratio of the above matrix is found to be less than 0.1, thus the above matrix can be termed as consistent.

Fuzzy Global Priority Matrix:
Global priority is the comparisons of the all the global factors. The comparison is made with the help of the questionnaire and hence a pair wise comparison matrix is being prepared to calculate global priority. The values in the global priority matrix are than replaced with their corresponding Fuzzy values to calculate the priority vectors based on the fuzzy AHP method.
Thus all the global factors in considerations to sustainability are given below;
Lean manufacturing (C1)
Green manufacturing (C2)
Six sigma (C3)

	C1	C2	C3	PV	De fuzzy PV
C1	(1,1,3)	(3,5,7)	(7,9,9)	(0.20, 0.723,1.48)	0.801
C2	(1/3,1/5,1/7)	(1,1,3)	(3,5,7)	(0.119,0.215,0.353)	0.229
C3	(1/7,1/9,1/9)	(1/3,1/5,1/7)	(1,1,3)	(0.043,0.061,0.126)	0.076

The above matrix is being prepared by substituting the values of each cells with their corresponding fuzzy values. Thus the calculation for priority vector is done to the Fuzzy global matrix by applying fuzzy operations to all the fuzzy triangular values in each of the cells.

Aggregate Global Priority Matrix:
An aggregate matrix is being prepared which is the aggregate of all the local priorities and the global priorities.

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FACTORS	OPERATIONS	PRIORITY VECTOR (PV)
Lean manufacturing	C1×C11+C1×C12+C1×C13	0.800
Green manufacturing	C2×C21+C2×C22+C2×C23	0.128
Six sigma	C3×C31+C3×C32+C3×C33	0.075

Thus the calculations for priority values for both AHP and Fuzzy AHP methods can be done for all the other two industries using the methods used above.
Hence, similarly the calculations for priority vectors forall the factors using both AHP and Fuzzy AHP for the rest of the industries can be calculated and and can be hence compared.

4.RESULT

The study of the Lean green six sigma factors by Fuzzy based AHP in the consideration of the plant sustainability is being studied. The three factors and its three subfactors are studied in three different industries and hence the industrial data I being evaluated in the form of a matrix. The matrix is thus solved by applying AHP and fuzzy value to it and hence combining the factors and the subfactors can be prioritized keeping in mind the data thus obtained.
This data are calculated for all the three industries for which the calculation is to be done. Thus a graph is being formulated which shows the values by which the corresponding factor is important in the sustainability of the plant.The calculation for the priority vector is initiated by a case study which revolves around a questionnaire to be presented to the experts present in the industries. Hence a questionnaire based on pair wise comparison between factors and also between sub factors is being prepared and is presented to the expert. To which the expert replies with AHP numbers i.e 1,3,5,7,9.
Once the data is being obtained the calculation procedure can be initiated. The calculation is done for three sub factors to each factor which is termed as local priority matrix and also to all the major factors which is termed as global priority matrix.
The calculations for the three industries on the basis of the three factors and its sub factors is done using both AHP and Fuzzy AHP methods.

The results using both AHP and Fuzzy AHP methods is being shown in the below-mentioned table.3

Industry	**Factors**	**Using ahp tool**	**Using fuzzy ahp**
Industry 1	Lean manufacturing	0.719	0.800
	Green manufacturing	0.208	0.128
	Six sigma	0.059	0.075
Industry 2	Lean manufacturing	0.482	0.603
	Green manufacturing	0.453	0.382
	Six sigma	0.076	0.075
Industry 3	Lean manufacturing	0.768	0.764
	Green manufacturing	0.104	0.117
	Six sigma	0.127	0.180

The data obtained from the calculations done using AHP method for the priority vector is being shown graphically below:

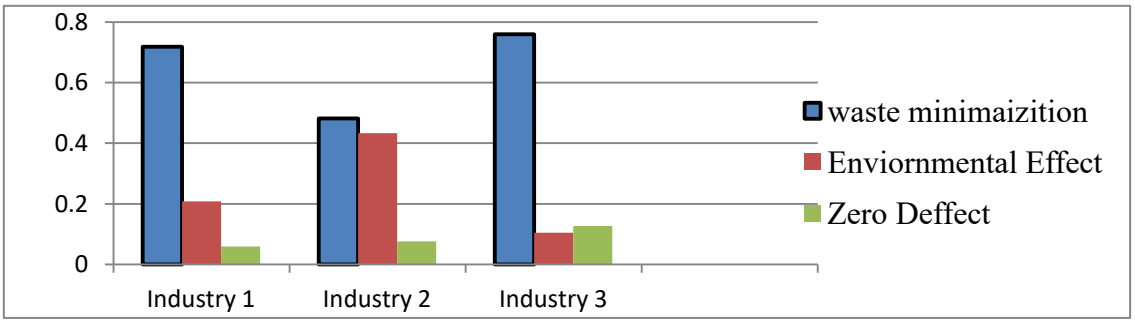

Fig.2 graph of priority values using AHP method

Thus it can be seen from the graph that the priority given to Lean manufacturing for all the three industries is the highest amongst all three, whereasgreen manufacturing is placed in the second spot for industry 1 and industry 2 while in the industry 3 it is ranked third.

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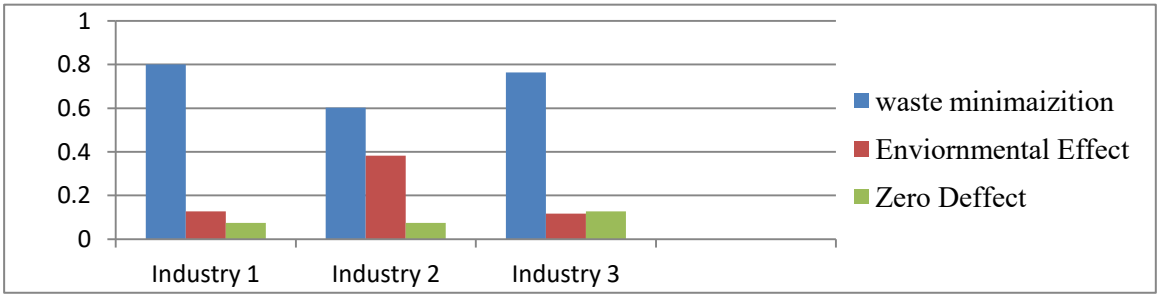

Fig.3 graph of priority values using AHP method

The above graph shows the priority vectors provided by each industry to all the three factors when the calculation is done using Fuzzy AHP process.

5. CONCLUSION:

A case study on three industries is being considered and data is being obtained using a questionnaire regarding a pairwise comparison amongst all the three factors. Hence calculation for the priority of the factors to be considered based on their sustainability is being done with the help of AHP and using FUZZY AHP tools both separately. The data from both the methods reveal that the priority of the three factors results to be the same but the percentage to which they contribute to the sustainability varies by a very small fraction. Thus it can be interpreted from the calculations that calculation from the AHP tool is being verified and found correct by using the FUZZY AHP tool. From the study, it is found that the Industry 1 and Industry 2 rate Lean manufacturing On top of the priority lists followed by green factors and six sigma respectively. But the calculations from industry 3 states that Lean manufacturing remains on top followed by six sigma and green manufacturing in the order from top to bottom respectively.

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