RESEARCHERID
THOMSON REUTERS

[Thakur * *et al.*, 7(9): September, 2018]
IC™ Value: 3.00

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

INDUSTRIAL SUSTAINABILITY ANALYSIS USING AHP AND INTEGRATED FUZZY AHP PROCESS

Neeraj Singh Thakur*[1], Neha Verma[2] & Manoj Mathew[3]
[*1]Student, Mechanical Department, SSIPMT, Raipur, India
[2&3]Assistant Professor, Mechanical Department, SSIPMT, Raipur, India

DOI: 10.5281/zenodo.1411102

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 environmental factors, waste minimization and 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.

Keywords: Fuzzy, AHP, Sustainability, EWZ.

I. INRTODUCTION

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]. The achievement of sustainable development requires a balanced integration of environment, economic and social objectives, taking into account the needs and concerns of both present and future generations. But the links between the economic, environmental and social dimensions are complex, sometimes involving difficult trade-offs between them, which might seem contradictory in the short term though they should be mutually reinforcing in the long term [2].

Environmental factor and sustainability*:* 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.

It may impact on people's livelihoods. For example, pollution of the sea will affect people who are involved in the fishing and tourism industries.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Thus environmental factors play an important role in today's industrial scenario. To make an industry sustainable to various changes in the industrial working, environment plays an important role. With the proper control of the effects of these environmental factors, the Sustainability of an industry can be further increased.

Waste minimization and sustainability: Waste minimization 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.

Zero defect and sustainability: 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, 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, Zero Defects 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.

Zero defects help reduce the wastage and losses to the industries. With Maintaining zero defect in all possible industrial processes an improvement can be made in the entire industrial working scenario. Thus Zero defects can be considered as an important tool in making an industrial working more sustainable.

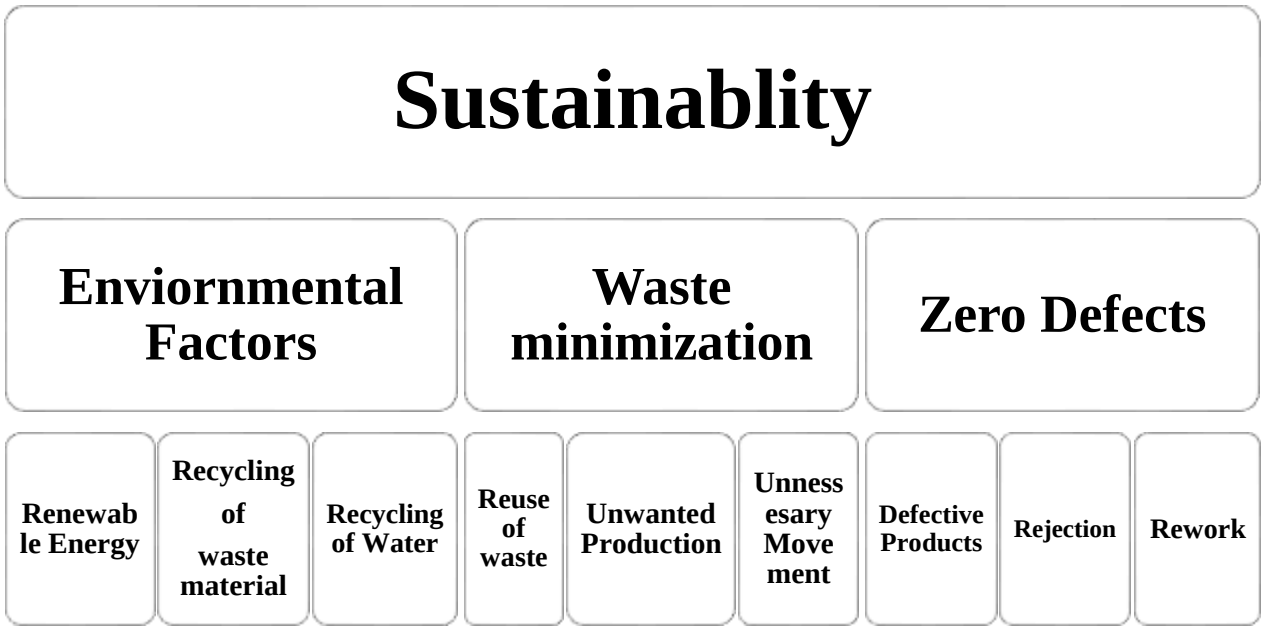

Fig1.1 sustainability flow diagram

II. METHDOLOGY

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

- Analytic hierarchy process
- Fuzzy AHP

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

The analytic hierarchy process: Analytic Hierarchy Process (AHP) is one of multi measures decision-making technique that was originally developed by (Saaty 1980; Saaty 1991) [3]. 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 [4]. 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 [5]. 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 [6].

Consistency of pair-wise comparison matrix **:**
In classical AHP, we consider an *nxn* pair-wise comparison matrix *A* with positive elements such that [7]

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

This matrix is reciprocal if $a_{ij} = \frac{1}{a_{ji}}$ for each $1 \le I, j \le n$. We say that A is consistent if
$a_{ij} * a_{jk} = a_{ik}$, for each $1 \le i, j, k \le n$.

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.
$A_1 = [b_{ij}]$

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

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

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 $A_2 = [w1, w2, w3 \dots \dots \dots \dots wj]^T$ 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:

$$\text{Consistency index} = \frac{Principle\ Eigen\ value - size\ of\ matrix}{size\ of\ matrix - 1} = \frac{\lambda max - n}{n-1}$$

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 Saaty (1980).

Table no. 2.1 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

Fuzzy AHP: Fuzzy Analytic Hierarchy Process (F-AHP) embeds the fuzzy theory to basic Analytic Hierarchy Process (AHP), which was developed by Saaty [7]. 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 [8]. 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 [9]. They defined the triangular membership functions for the pair wise comparisons.

Table no. 2.2 Fuzzy values[10]

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 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.

III. RESULTS AND CALCULATION

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 calculations of one industry using both methods is shown below;

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:

Waste minimization (C1):
Reuse of wastes (C11)
Unwanted production (C12)
Unnecessary movement (C13)

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

	C11	C12	C13	PV
C11	1	3	9	0.649
C12	1/3	1	7	0.294
C13	1/9	1/7	1	0.056

Thus the above-mentioned matrix is the local priority matrix for waste minimization.

Consistency index = $\frac{Principle\ Eigen\ value - size\ of\ matrix}{size\ of\ matrix - 1} = \frac{\lambda max - n}{n-1}$

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…..
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.

Environmental factors (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 waste minimization.
Consistency index = $\frac{Principle\ Eigen\ value - size\ of\ matrix}{size\ of\ matrix - 1} = \frac{\lambda max - n}{n-1}$

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…..
CR=$\frac{0.03}{0.58}$

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

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.

Zero defects (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 zero defects.
Consistency index = $\frac{Principle\ Eigen\ value - size\ of\ matrix}{size\ of\ matrix - 1} = \frac{\lambda max - n}{n-1}$
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…..
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.

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.
Waste minimization (C1)
Environmental effects (C2)
Zero defects (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 = $\frac{Principle\ Eigen\ value - size\ of\ matrix}{size\ of\ matrix - 1} = \frac{\lambda max - n}{n-1}$

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=$\frac{3.08-3}{3-1}$

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

CI = 0.04
CR = $\frac{CI}{RI}$
RI=0.58 for a matrix size of 3×3 from table no…..
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)
Waste minimization	C1×C11+C1×C12+C1×C13	0.719
Environmental factor	C2×C21+C2×C22+C2×C23	0.208
Zero defects	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:

Waste minimization (C1)

Reuse of wastes (C11)
Unwanted production (C12)
Unnecessary production (C13)

	C11	C12	C13	PV
C11	1	3	9	0.649
C12	1/3	1	7	0.294
C13	1/9	1/7	1	0.056

Thus the above-mentioned matrix is the local priority matrix for waste minimization.
Consistency index = $\frac{Principle\ Eigen\ value - size\ of\ matrix}{size\ of\ matrix - 1} = \frac{\lambda max - n}{n-1}$

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…..
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.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

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 also calculated for industry 1.

Environmental factors (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 waste minimization.
Consistency index = $\frac{Principle\ Eigen\ value - size\ of\ matrix}{size\ of\ matrix - 1} = \frac{\lambda max - n}{n-1}$

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…..
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.

Zero defects (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 waste minimization.
Consistency index = $\frac{Principle\ Eigen\ value - size\ of\ matrix}{size\ of\ matrix - 1} = \frac{\lambda max - n}{n-1}$

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;

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

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…..
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;
Waste minimization (C1)
Environmental effects (C2)
Zero defects (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.

FACTORS	OPERATIONS	PRIORITY VECTOR (PV)
Waste minimization	C1×C11+C1×C12+C1×C13	0.800
Environmental factor	C2×C21+C2×C22+C2×C23	0.128
Zero defects	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.

Results
The study of the EWZ factors by Fuzzy based AHP in the consideration of the plant sustainability is being studied. The three factors and its three sub factors 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 sub factors 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.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

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

Industry	Factors	Using ahp tool	Using fuzzy ahp
Industry 1	Waste minimization	0.719	0.800
	Environmental factor	0.208	0.128
	Zero defect	0.059	0.075
Industry 2	Waste minimization	0.482	0.603
	Environmental factor	0.453	0.382
	Zero defect	0.076	0.075
Industry 3	Waste minimization	0.768	0.764
	Environmental factor	0.104	0.117
	Zero defect	0.127	0.180

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

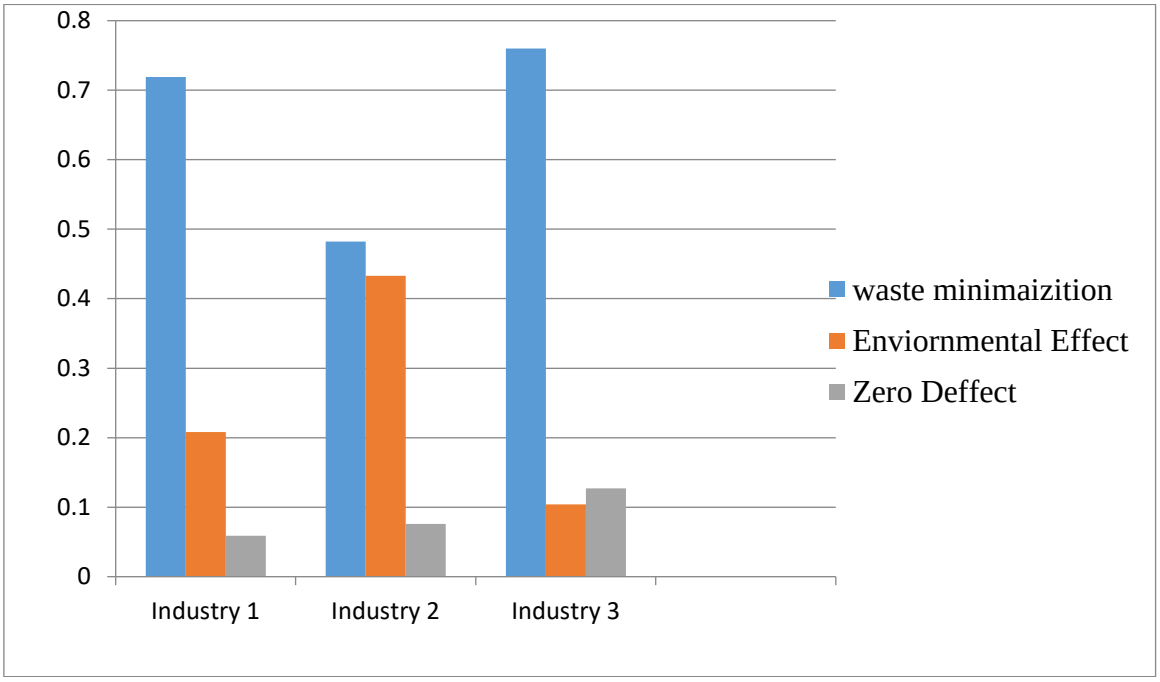

Fig 6.1 graph of priority values using AHP method

Thus it can be seen from the graph that the priority given to waste minimization for all the three industries is the highest amongst all three, where as environmental factors is placed in the second spot for industry 1 and industry 2 while in the industry 3 it is ranked third.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

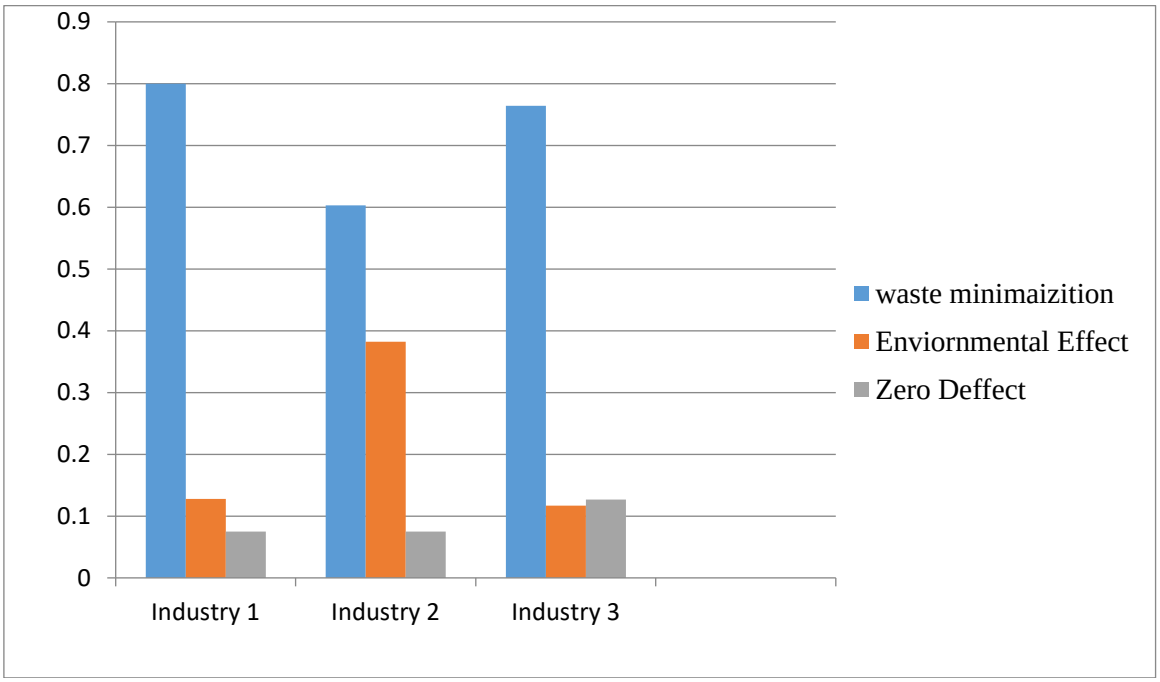

Fig 6.2 graph of priority values using AHP method

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.

IV. CONCLUSION

A case study on three industries is being considered and data is being obtained using a questionnaire regarding a pair wise 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 waste minimization On top of the priority lists followed by environmental factors and zero defect respectively. But the calculations from industry 3 states that waste minimization remains on top followed by Zero defect and environmental factors in the order from top to bottom respectively.

REFERENCES

[1] T. Lu, A. Gupta, A.D. Jayal, F. Badurdeen, S.C. Feng, O.W. Dillon, Jr. , I.S. Jawahir, A framework of product and process metrics for sustainable manufacturing,2010, *8th Global Conference on Sustainable Manufacturing* .

[2] R. Lokuliyane, R.S. Ekanayake, A.K. Kulatunga, P. Jayatilake, Incorporating Green Building Concepts in Manufacturing Plant Design,2012, Proceedings of *ICSBE*, Kandy, Sri Lanka, .

[3] T.L. Saaty , How to make a decision: the analytic hierarchy process, *European journal of operational research, 1900, 48(1),9-2.*

[4] S Thanki, K Govindan, and J Thakkar. An investigation on lean-green implementation practices in Indian SMEs using analytical hierarchy process (AHP) approach, 2016, *Journal of Cleaner Production* 135: 284-298.

[5] V.Darji, and RV.Rao. Application of AHP/EVAMIX method for decision making in the industrial environment, 2013, *American Journal of Operations Research* 3, no. 06: 542.

[6] M Matjaž, V Lovrenčić, B Najjar, and B Gomišček. An application of analytic hierarchy process (AHP) and sensitivity analysis for maintenance policy selection, 2014, *Organizacija* 47, no. 3: 177-188.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

[7] T Saaty Fundamentals of Decision Making and Priority Theory with the AHP. 1994 RWS Publications,Pittsburgh, PA, U.S.A.
[8] H Jayawickrama,, A.Kulatunga, and S. Mathavan. Fuzzy AHP based Plant Sustainability Evaluation Method, 2017, *Procedia Manufacturing* 8 : 571-578.
[9] B Sodhi, and T Prabhakar. A simplified description of Fuzzy TOPSIS, 2012 *arXiv preprint arXiv:1205.5098* .
[10] B Ayhan,A Fuzzy AHP Approach for Supplier Selection Problem: A Case Study in a Gear Motor Company, 2013, *arXiv preprint arXiv:1311.2886*.

CITE AN ARTICLE

Thakur, N. S., Verma, N., & Mathew, M. (2018). INDUSTRIAL SUSTAINABILITY ANALYSIS USING AHP AND INTEGRATED FUZZY AHP PROCESS. *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY*, *7*(9), 134-145.