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PRIORITIZATION OF OVERALL SUSTAINABILITY FACTORS OF CLOUD MANUFACTURING THROUGH AHP AND FUZZY AHP APPROACH

Summary. In this global competitive environment, with the recent advancement in information and communication technologies, the industries are adopting new strategies to sustain. Cloud manufacturing is a new technology that utilizes data analytics for better decision-making resulting in more productive, cost, and energy-efficient operations. Increasing awareness towards a clean environment and optimum utilization of resources in manufacturing motivate us to study cloud manufacturing in the context of sustainability. Therefore, a significant number of social, environmental, and economic factors of cloud manufacturing are identified through literature review, and experts' opinions and prioritization of these factors are obtained through the AHP and Fuzzy AHP methods. As per the final results obtained, "Efficient use of resources" is the most significant factor for the adoption of cloud manufacturing process and "Remote material monitoring" is the least significant factor amongst all the factors taken under consideration. The results are found to be consistent and accurate as per the value of consistency ratio. And the percentage obtained for social, environmental, and economic factors proves the cloud manufacturing process to be a sustainable manufacturing process.

Keywords: Cloud manufacturing, economic factors, social factors environmental factors, AHP, Fuzzy AHP

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1. INTRODUCTION

Manufacturing industries are undergoing a dynamic change due to the vital role played by collaboration, cost effectiveness, innovation, and scalability, pay to use service and sustainability [1]. Increase in usage of the internet has led to the flow of ideas which has shifted the manufacturing paradigm from being production-oriented to service-oriented or customer orientation [2,3]. The recent advancement in technology, especially in the field of electronics, computers and networking have a great impact on manufacturing. Usage of high-speed Internet, Big data, IoT (Internet of Things), Cloud computing has influenced manufacturing and has also led to the evolution of a new class of manufacturing known as Cloud manufacturing. Cloud manufacturing is an integration of manufacturing, cloud computing, networking, internet, big data, IoT, etc. to have economical and efficient manufacturing [4].

Alessandro Simeone et al. performed a case study of sheet metal industry applied the cloud manufacturing model and found out the increased resource utilization [5]. Yingfeng et al. worked on dynamic optimization scheduling in cloud manufacturing, which minimizes the energy consumption, increases the efficiency of system and thereby reduces the total costs [6]. Tin Chen exclusively calculated the cost-effectiveness of the model with fuzzy method. [7]. Sicheng Liu et al. implemented cloud manufacturing model in 3D printing and applied game theory in scheduling which reduces the overall cost and increases the efficiency of system as compared to earlier traditional method since cloud manufacturing efficiency and cost-effectiveness is studied in many papers proves the economic violability of the model, but few dealt with social and environmental factors. This gap provides the motivation to identify the overall factors that contribute to adoption of the model, thus presenting the wholesome impact of the model.

The use of RFIDs and dynamic scheduling for transportation of raw material and delivery leads to optimization of routing, resulting in lower incurred costs and therefore reduced environmental impact. To determine the percentage of social, environmental, and economic factors, calculations were performed.

To conduct research, a rigorous literature review on tile cloud manufacturing was conducted, which helped identify the relevant factors. That was followed by a survey to gather input from experts. Then these inputs were gathered in AHP and Fuzzy AHP to get the weightage of the factors, and successively a comparison was made between the results for validation.

The contribution of the paper is as follows: Since there are only a limited number of studies on the overall factors in context of cloud manufacturing, all three factors, i.e., social, environmental, and economic factors have been discussed in the context of cloud manufacturing. A total of 19 overall factors, including sustainability factors, have been identified in this study. The identified factors are as follows: Conducive social network**;** Human comfort; Human effort; Human health; Human safety; Remote material monitoring; Fuel reduction; Waste reduction; Efficient machine usage; Environment advices; Instant usage and planning; Detection of natural disaster; Reduction in carbon footprints; Dynamic flexibility; efficiently using resources; Instant Usage/Pay-as-use; Less Cost incurred; Less Inventory and Optimization. With the help of AHP model, prioritization of the aforementioned factors is obtained. By assigning weights and performing pairwise comparisons, the model allows us to identify the most influential factors as well as the least influential factors in the context of cloud manufacturing adoption.

2. LITERATURE REVIEW

In this section, all the factors that affect the adoption of cloud manufacturing viz. social, environmental, and economic are studied and listed in the table. The objective of the study is to prioritize all factors of cloud manufacturing for understanding the three layers of the hierarchical approach used shown in the Figure1 and conclude whether it approaches sustainability with the result obtained. To reach the main objective the literature review is performed related to social, environmental and economic factors of cloud manufacturing.

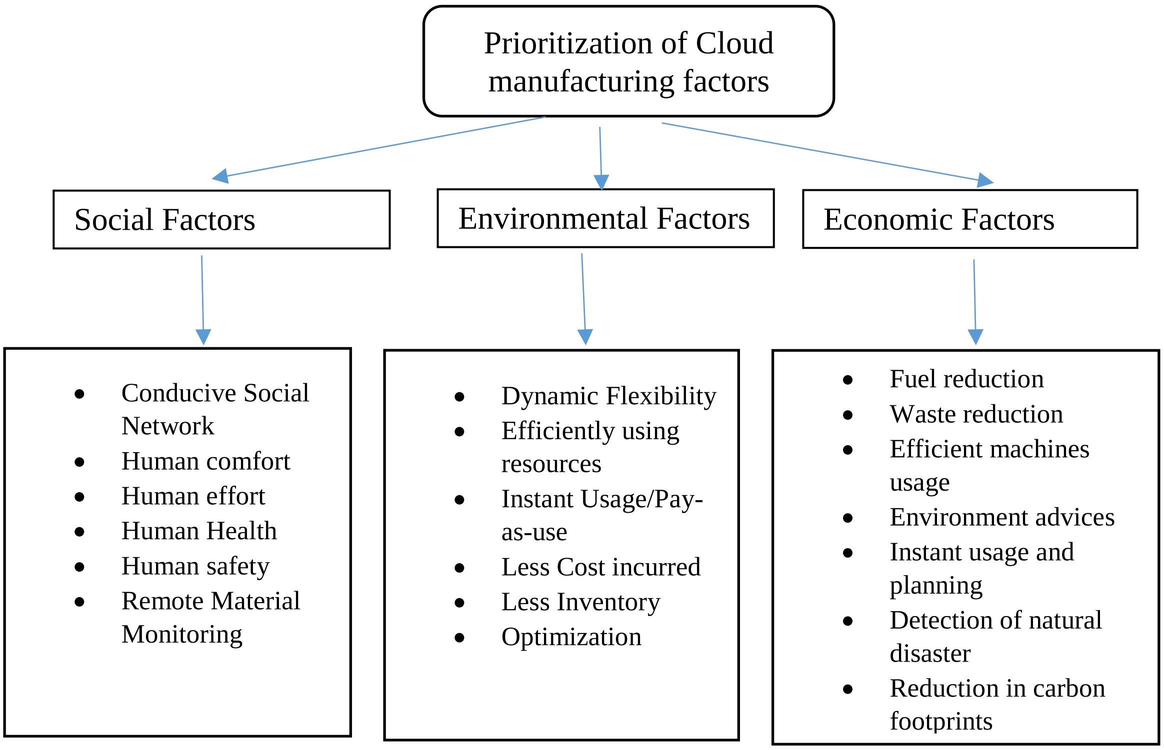

Fig. 1. Hierarchy of factors

2.1. Social Factors

1. Conducive Social Network: Sharing of ideas and knowledge about cloud platform leads to better understanding and innovation [8]. Worthy advice from renowned researchers and experts is easily accessible. Information about the environment can be accessed through social networking sites like International Institute for sustainable development (IISD, iisd.org), United Nations Sustainable Development (un.org), and sustainable communities online (sustainable. org). These websites, supported further with online groups for discussion, display events or conferences to be held on the latest issues on sustainability. They provide the platform for individuals to express their views through blogs. [9].
2. Human comfort: the increased usage of the Internet of things (lsuch as RFIDs), networking, and monitoring, has provided flexibility to human resource to work from anywhere, anytime leading to greater comfort for individuals. [10].
3. Human effort: better solutions provided online with high-speed Internet reduce human effort and calculations. [11, 12].

4. Human Health: Reduced Noise level and dust-free environment. Author Fabio Gregori [13] has performed the experiment with a real cloud manufacturing model and found that noise dust level is reduced in the production area.
5. Human safety: The opportunity to have fully automated manufacturing and continuous feedback process leads to an increase in human safety. Author Fabio Gregori [13] has performed the experiment with a real cloud manufacturing model and has found increased human safety and health.
6. Remote Material Monitoring: Monitoring of material by humans through RFIDs has become easy and dynamic. RFIDs are used for automatic identification of hard resources, which is particularly useful in supply chain management (SCM) for monitoring logistics [15].

Table 1 is used to list all the social factors of cloud manufacturing discussed above for convenience in reading and for usage in the mathematical section. It indicates all the factors related to human that fall under the social aspect of sustainability.

Tab. 1

Social factors for sustainable Cloud manufacturing

S.No	Social factors	Reference
S_1	Conducive Social Network	[8.9]
S_2	Human comfort	[10]
S_3	Human effort	[11,12]
S_4	Human Health	[13]
S_5	Human safety	[13]
S_6	Remote Material Monitoring	[15]

2.2. Environmental Factors

1. Fuel reduction: Optimized transportation route for material movements reduces fuel consumption. Consequently, it results in an environment-friendly method. The centralized pooling and management help in energy saving and emission reduction [15].
2. Waste reduction: Dynamic planning in cloud manufacturing enables a reduction in scrap and waste. An example provided by the author [8] explores the utilization of waste through CMfg, specifically focusing on the pyrolysis of oil.
3. Efficient machine usage: Access to high-standard, fully automated machines that consume less energy results in reduced waste. In the discussion section of the article (14, 15), it is highlighted that the application of the cloud manufacturing model led to increased resource utilization and decreased development and management costs in CA-2. A report released by the China Software Testing Centre, referring to CMfg projects in China, states that there has been a 5% increase, equivalent to a cost saving of 10 million RMB.

4. Environment advice: Expert advice regarding the environment is readily available. Websites like International Institute for Sustainable Development (IISD, iisd.org), United Nations Sustainable Development (un.org) provide the latest information on sustainability, including current rules and regulations. Individual and group advice options can be obtained through these sites. [9].
5. Instant usage and planning: Use when required and prior dynamic scheduling would finally lead to less scrap and better utilization of resources [4].
6. Detection of natural disaster: Cloud computing infrastructure helps in the early detection of any kind of environmental disaster with the help of different types of sensors and RFIDs [16] attached to products at a remote location aid in the early detection of environmental disasters. This information can then be utilized to make informed decisions [9].
7. Reduction in carbon footprints: Computation and data analysis in manufacturing contribute to the reduction of carbon footprints. Akshat Singh [17] conducted an experiment highlighting how cloud manufacturing can effectively reduce carbon footprints in the beef supply chain.

Table 2 is used to list all environmental factors of the cloud manufacturing discussed above. Here all the factors related to environment which come under the environmental part of sustainability are listed

Tab. 2

Environmental factors for sustainable Cloud manufacturing

S.No	**Environmental factors**	**Reference**
En_1/S_7	Fuel reduction	[15]
En_2/S_8	Waste reduction	[8]
En_3/S_9	Efficient machines usage	[14,15]
En_4/S_10	Environment advices	[9]
En_5/S_11	Instant usage and planning	[4]
En_6/S_12	Detection of natural disaster	[9,16]
En_7/_S_13	Reduction in carbon footprints	[17]

2.3 Economic Factors

1. Dynamic Flexibility: The ability to make adjustments and alterations at any time in the manufacturing process can lead to cost and time savings. CMfg has provided this flexibility [18], allowing for changes in manufacturing based on the current market situation [19].

Another example of the flexibility of CMfg model is provided by sheet metal forming operation [20] which allows for greater flexibility during operation.

2. Efficient use of resources: Optimized algorithms at every stage reduce the total cost incurred in the product. The centralized pooling and management help in energy saving and emission reduction [14, 15, 21]. The author [22] conducted an experiment on the manufacturing model, specifically focusing on wafer production. Runtime energy consumption data provided by software was analyzed to improve overall energy efficiency in production.
3. Instant Usage/Pay-as-use: Using services when needed provides an economic advantage. Users can get the services online and pay only for the time they use, known as "pay and go" [23] which automatically reduces costs.
4. Less Cost incurred: Fixed cost of product manufacturing is reduced to almost zero. For SMEs, financing a project is the prime concern. Cloud manufacturing provides manufacturing units and production facilities through a cloud platform, eliminating the need to purchase manufacturing units or land. The pay-as-per-use model further reduces fixed costs for SMEs, effectively bringing them close to zero.
5. Less Inventory: Less WIP Inventory and Inventory maintenance become easy. [24].
6. Optimization: Optimized transportation route for material movement results in less money incurred in the indirect cost of the product, finally saving the money. AI techniques enable intelligent processing and decision-making [15].

Table 3 is used to list all economic factors of the cloud manufacturing discussed above. Here all the factors related to cost which come under the economic part of sustainability are listed.

Tab. 3

Economic factors for sustainable Cloud manufacturing

S.No	**Economic factors**	**Reference**
Ec_1/S_14	Dynamic Flexibility	[18,19]
Ec_2/S_15	Efficiently using resources	[14,15,21,22]
Ec_3/S_16	Instant Usage/Pay-as-use	[23]
Ec_4/S_17	Less Cost incurred	
Ec_5/S_18	Less Inventory	[24]
Ec_6/S_19	Optimization	[15]

3. RESEARCH METHODOLOGY

The cloud manufacturing concept is still very new so finding experts in this field is difficult. Even then, a total of 24 experts from industry and academics (8 Industrialists, 8 mechanical engineering academicians, 4 computer science academicians, and 4 industrial engineering academicians) were identified. After discussion, a total of 19 factors were finalized. Detailed questionnaires (Appendix-1) were sent to these experts for filling. After collecting all the questionnaires an average is obtained to get the final average pairwise matrix. Then applied two approaches AHP and Fuzzy AHP to obtain the weights and ranks of factors. Finally, consistency ratio is obtained through the AHP approach and comparison are done among AHP and Fuzzy AHP results for accuracy and validation of results. Figure 2 is a flowchart showing how the research is conducted from the initial step of finding the related articles on cloud manufacturing on google scholar and Scopus database to segregate the relevant concern papers. Then identify the factors with the inputs from experts and further apply the mathematical tool AHP and Fuzzy AHP for ranking these factors. Finally, a comparison of results was obtained and validated.

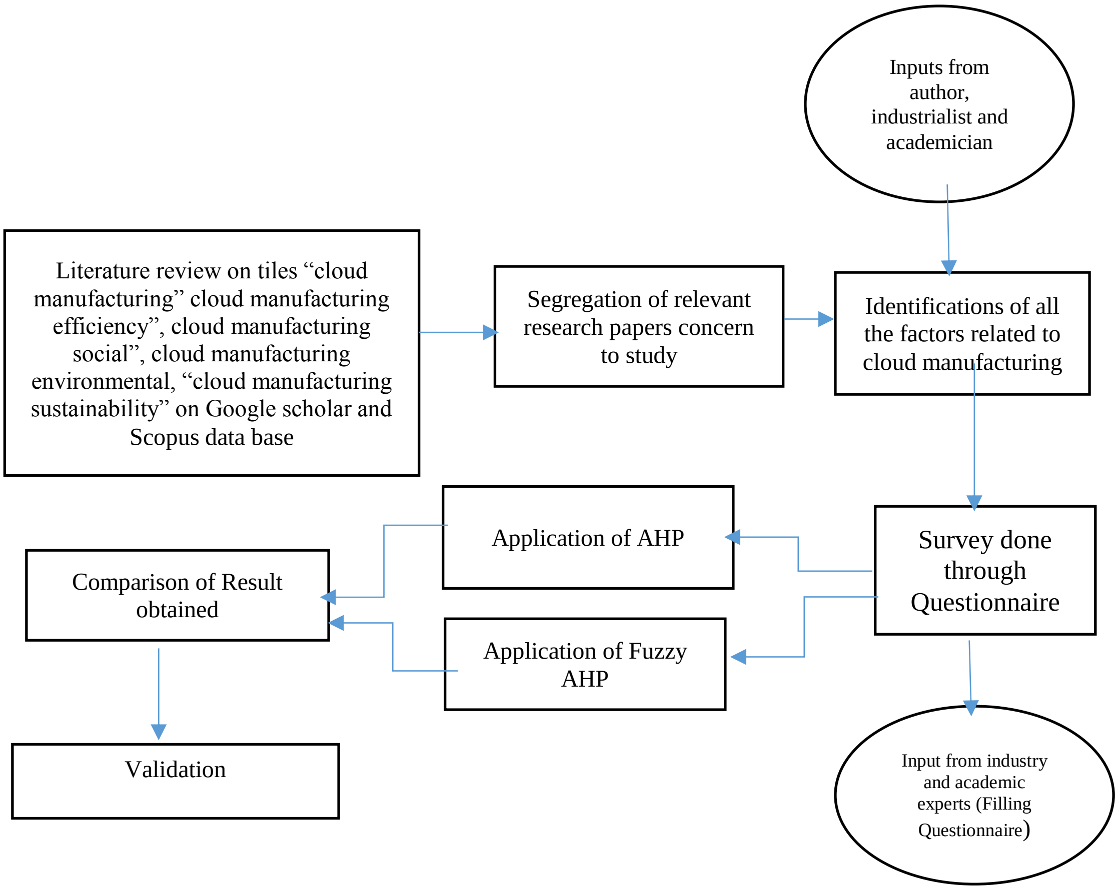

Fig 2. Research methodology flowchart

3.1. AHP process

AHP is one of the MCDM method developed by Saaty [25] .AHP can be applied to many sectors in the industry for selection, decision-making, and prioritization. Hu [26] used a selection of manufacturers in cloud manufacturing. Sevinc [28] applied to difficulties that SMEs facing in transition to Industry 4.0. Mian [29] applied SWOT-AHP to quantify and rank the opportunities and challenges for sustainability education in Industry 4.0. Prioritization of challenges to Industry 4.0 for the supply chain is obtained with the help of AHP [30]. In this article, the Analytic Hierarchy Process (AHP), one of the popular MCDM techniques, is used to prioritize the sustainability factors in the context of cloud manufacturing. To gauge whether the results obtained are robust and consistent enough, a consistency ratio is obtained for the validation. For the stepwise application of the method, the sequential procedure is given below.

Steps followed to apply AHP approach are as follows:

Step 1: Develop a structural hierarchy.

Step 2: Develop pairwise comparison matrix.

Assuming n attributes, a pairwise comparison of attribute i with attribute j a square matrix is obtained.

$$Aij= \begin{bmatrix} a_{11} \ldots\ldots\ldots a_{1j} \ldots\ldots\ldots\ldots a_{1n} \\ a_{i1} \ldots\ldots\ldots\ldots a_{ij} \ldots\ldots\ldots\ldots a_{1j} \\ a_{n1} \ldots\ldots\ldots a_{nj} \ldots\ldots\ldots .a_{nn} \\ \\ \\ \end{bmatrix}$$

Step 3: Develop normalised decision matrix.

$$cij= aij / \sum_{j=1}^{n} aij \qquad (1)$$

where i=1,2,3,4……. n and j=1,2,3,4…………. n

Step 4: Develop normalised decision matrix

$$w_i = \sum_{j=1}^{n} cij \quad \text{where } i=1,2,3,4\ldots\ldots N \qquad (2)$$

Step 5: Calculate eigenvector & row matrix

$$E = N^{th}\text{rootvalue} / N^{th}\text{rootvalue}$$

$$\text{Row matrix} = \sum_{j=1}^{n} aij * ej1 \qquad (3)$$

Step 6: Calculate the maximum eigenvalue, λ_{max}

$$\lambda_{max} = \text{Rowmatrix} / E \qquad (4)$$

Step 7: Obtain the consistency index (CI) & consistency ratio (CR).

$$CI = (\lambda_{max} - n) / (n-1) \qquad (5)$$

$$CR = CI / RI \qquad (6)$$

Tab. 4

Random Index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.85	0.9	1.12	1.24	1.32	1.41	1.45	1.51

Where n & RI denote the order of matrix & Randomly Generated Consistency Index respectively.

3.2. Fuzzy AHP process

Fuzzy AHP can be applied to many sectors in the industry for selection, decision-making, and prioritization. Usama Awan et al. used it to prioritize quantum computing challenges in software industry [31]. Mustafa et al. applied fuzzy AHP and DEA approach for evaluation of operational efficiencies of Turkish airports [32]. Esra et al. used AHP approach for risk assessment of renewable energy investment [33]. In this paper Fuzzy Analytic Hierarchy Process (FAHP), is used to prioritize the sustainability factors in the context of cloud manufacturing. Steps for procedure are given below.

Step 1: Develop a pairwise comparison matrix

In matrix below $\overbrace{bij}^{p}$ preference of p_{th} decision maker for i_{th} criterion over j_{th} criterion via fuzzy triangular numbers. For example, $\overbrace{bi1}^{p}$ =(2,3,4) means input data is 3 and is conerted to (2,3,4) with fuzzy triangular scale using the Table 5.

Tab. 5

Fuzzy scale of relative importance

	Scale of relative importance	Fuzzy scale of relative importance
Equal importance	1	(1,1,1)
Moderate importance	3	(2,3,4)
Strong importance	5	(4,5,6)
Very strong importance	7	(5,6,7)
Extreme importance	9	(7,8,9)

$$\overbrace{Aij} = \left[\begin{matrix} \overbrace{b11}^{p} \ldots\ldots \overbrace{b1j}^{p} \ldots\ldots\ldots \overbrace{b1n}^{p} \\ \overbrace{bi1}^{p} \ldots\ldots \overbrace{bij}^{p} \ldots\ldots\ldots \overbrace{b1j}^{p} \\ \overbrace{bn1}^{p} \ldots\ldots \overbrace{bnj}^{p} \ldots\ldots .\overbrace{bnn}^{p} \end{matrix} \right]$$

Step 2: If there is more than one decision maker than convert to single triangular fuzzy number by taking average of all to get final pairwise matrix below.

$$\overbrace{bij} = \textstyle\sum_{p=1}^{p} \overbrace{b11}^{p} /\mathrm{p} \tag{7}$$

$$Aij = \left[\begin{matrix} \overbrace{b11} \ldots\ldots \overbrace{b1j} \ldots\ldots\ldots \overbrace{b1n} \\ \overbrace{bi1} \ldots\ldots \overbrace{bij} \ldots\ldots\ldots \overbrace{b1j} \\ \overbrace{bn1} \ldots\ldots \overbrace{bnj} \ldots\ldots .\overbrace{bnn} \end{matrix} \right]$$

Step 4: Geometric mean fuzzy values of each criteria is calculated.

$$si = \left(\prod_{j-1}^{n} \widetilde{bij}\right)^{1/n} \qquad (8)$$

Where i= 1, 2, 3…n.

Step 5: Find the fuzzy weights of criterion W_i.

$$w_i = s_i \text{ x } (s_1 \text{ x } s_2 \text{ x } s_3 \ldots\ldots s_n)^{-1} \qquad (9)$$

$Wi = (lw_i, mw_i, uw_i)$

Step 6: Defuzzification of weight obtained.

$$Mi = (lw_i + , mw_i + uw_i) / 3 \qquad (10)$$

4. RESULTS OBTAINED AND DISCUSSION

In this section, we discuss the prioritization of overall factors and the consistency of results obtained. Consistency Ratio is obtained for the validation of the result. After averaging all the individual matrices obtained from experts, a final Average pairwise comparison matrix is obtained followed by the procedure of the AHP and Fuzzy AHP approach given in section 3. Microsoft Excel tool is used for all matrices calculations to obtain error-free, precise, and accurate results.

After the Average Pairwise Comparison Matrix is obtained for factors as shown in Table 6 normalization is done to get the Normalised Decision Matrix (Table 7). And further steps are followed as per AHP approach to obtain a Weighted Normalised decision matrix (Table 8) for weights of factors. Finally, ranking is done based on weights obtained. (Table 9).

As per the final results obtained Efficient use of resources (S_15) has the highest positive value therefore it is the most significant factor. Instant usage/Pay-as-use(S-16), Reduction in carbon footprints (S_13), and Optimization (S_19) secured the 2nd, 3rd and 4th ranks in the category as per their weights obtained. Dynamic Flexibility (S_14), Less Cost incurred (S_17), Efficient machine usage (S_9), Fuel reduction (S_7), Human safety (S_5) secured 5th, 6th, 7th, 8th and 9th ranks as per the weights obtained. With the minor difference in weights Instant usage and planning (S_11), Human comfort (S_2), Human effort (S_3), Detection of human disaster (S_12) obtained 14th 15th 16th, and 17th ranks. Remote material monitoring (S_6) factor obtained the lowest weight and ranks last, indicating its least significance among all the factors. The ranking is shown in Table 9. Pie chart shown in figure 3 depicts weights obtained of factors and figure 4 shows the bar chart of rank for AHP approach.

Table 10 is used to calculate the Consistency ratio. The obtained value of λmax (Table 9) and Random Index (Table 4) is finally used to calculate the value of Consistency Ratio (CR). The obtained value of CR is .084 which is less than .10 highlighting that the results obtained is accurate and consistent.

Tab. 6

Average Pairwise Comparison Matrix – part 1

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_10	S_11	S_12	S_13
S_1	1	0.33	0.33	0.33	0.33	3	0.33	0.33	0.2	0.33	0.33	1	0.33

S_2	3	1	1	0.33	0.33	3	0.33	0.33	0.2	0.33	1	3	0.33
S_3	3	1	1	0.33	0.33	3	0.33	0.33	0.2	0.33	1	3	0.33
S_4	3	3	3	1	1	3	0.33	0.33	0.2	0.33	1	3	1
S_5	3	3	3	1	1	3	1	1	1	1	1	3	1
S_6	0.33	0.33	0.33	0.33	0.33	1	0.33	0.33	0.33	0.33	0.33	1	0.33
S_7	3	3	3	3	1	3	1	1	0.33	3	3	3	1
S_8	3	3	3	3	1	3	1	1	0.33	3	1	1	0.33
S_9	5	5	5	5	1	3	3	3	1	3	3	3	1
S_10	3	3	3	3	1	3	0.33	0.33	0.33	1	1	1	0.33
S_11	3	1	1	1	1	3	0.33	1	0.33	1	1	1	0.33
S_12	1	0.33	0.33	0.33	0.33	1	0.33	1	0.33	1	1	1	0.33
S_13	3	3	3	1	1	3	1	3	1	3	3	3	1
S_14	5	5	5	3	3	5	3	3	3	5	5	5	0.33
S_15	7	7	7	5	5	7	5	5	5	7	7	7	0.2
S_16	5	5	5	3	3	5	5	5	5	5	5	5	0.33
S_17	5	5	5	3	3	5	3	3	3	3	3	3	0.33
S_18	3	3	3	1	1	1	1	1	0.33	1	1	1	0.33
S_19	3	3	3	3	3	5	3	3	3	3	3	3	3

Tab. 6

Average Pairwise Comparison Matrix – part 2

	S_14	S_15	S_16	S_17	S_18	S_19
S_1	0.2	0.142	0.2	0.2	0.33	0.33
S_2	0.2	0.142	0.2	0.2	0.33	0.33
S_3	0.2	0.142	0.2	0.2	0.33	0.33
S_4	0.33	0.2	0.33	0.33	1	0.33
S_5	0.33	0.2	0.33	0.33	1	0.33
S_6	0.2	0.142	0.2	0.2	1	0.2
S_7	0.33	0.2	0.2	0.33	1	0.33
S_8	0.33	0.2	0.2	0.33	1	0.33

S_9	0.33	0.2	0.2	0.33	3	0.33
S_10	0.2	0.142	0.2	0.33	1	0.33
S_11	0.2	0.142	0.2	0.33	1	0.33
S_12	0.2	0.142	0.2	0.33	1	0.33
S_13	3	5	3	3	3	0.33
S_14	1	1	0.33	1	3	1
S_15	1	1	1	1	3	1
S_16	3	1	1	1	3	1
S_17	1	1	1	1	3	1
S_18	0.33	0.33	0.2	0.33	1	0.33
S_19	1	1	1	1	3	1

Tab. 7

Normalized decision matrix – part 1

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_10	S_11	S_12	S_13
S_1	0.02	0.01	0.01	0.01	0.01	0.05	0.01	0.01	0.01	0.01	0.01	0.02	0.03
S_2	0.05	0.02	0.02	0.01	0.01	0.05	0.01	0.01	0.01	0.01	0.02	0.06	0.03
S_3	0.05	0.02	0.02	0.01	0.01	0.05	0.01	0.01	0.01	0.01	0.02	0.06	0.03
S_4	0.05	0.05	0.05	0.03	0.04	0.05	0.01	0.01	0.01	0.01	0.02	0.06	0.08
S_5	0.05	0.05	0.05	0.03	0.04	0.05	0.03	0.03	0.04	0.02	0.02	0.06	0.08
S_6	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.03
S_7	0.05	0.05	0.05	0.08	0.04	0.05	0.03	0.03	0.01	0.07	0.07	0.06	0.08
S_8	0.05	0.05	0.05	0.08	0.04	0.05	0.03	0.03	0.01	0.07	0.02	0.02	0.03
S_9	0.08	0.09	0.09	0.13	0.04	0.05	0.1	0.09	0.04	0.07	0.07	0.06	0.08
S_10	0.05	0.05	0.05	0.08	0.04	0.05	0.01	0.01	0.01	0.02	0.02	0.02	0.03
S_11	0.05	0.02	0.02	0.03	0.04	0.05	0.01	0.03	0.01	0.02	0.02	0.02	0.03
S_12	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.03	0.01	0.02	0.02	0.02	0.03
S_13	0.05	0.05	0.05	0.03	0.04	0.05	0.03	0.09	0.04	0.07	0.07	0.06	0.08
S_14	0.08	0.09	0.09	0.08	0.11	0.08	0.1	0.09	0.12	0.12	0.12	0.1	0.03
S_15	0.11	0.13	0.13	0.13	0.18	0.11	0.17	0.15	0.2	0.17	0.17	0.14	0.02

S_16	0.08	0.09	0.09	0.08	0.11	0.08	0.17	0.15	0.2	0.12	0.12	0.1	0.03
S_17	0.08	0.09	0.09	0.08	0.11	0.08	0.1	0.09	0.12	0.07	0.07	0.06	0.03
S_18	0.05	0.05	0.05	0.03	0.04	0.02	0.03	0.03	0.01	0.02	0.02	0.02	0.03
S_19	0.05	0.05	0.05	0.08	0.11	0.08	0.1	0.09	0.12	0.07	0.07	0.06	0.25

Tab. 7

Nomalized decision matrix – part 2

	S_14	S_15	S_16	S_17	S_18	S_19
S_1	0.01	0.01	0.02	0.02	0.01	0.03
S_2	0.01	0.01	0.02	0.02	0.01	0.03
S_3	0.01	0.01	0.02	0.02	0.01	0.03
S_4	0.02	0.02	0.03	0.03	0.01	0.03
S_5	0.02	0.02	0.03	0.03	0.01	0.03
S_6	0.01	0.01	0.02	0.02	0.01	0.02
S_7	0.02	0.02	0.02	0.03	0.01	0.03
S_8	0.02	0.02	0.02	0.03	0.01	0.03
S_9	0.02	0.02	0.02	0.03	0.01	0.03
S_10	0.01	0.01	0.02	0.03	0.01	0.03
S_11	0.01	0.01	0.02	0.03	0.01	0.03
S_12	0.01	0.01	0.02	0.03	0.01	0.03
S_13	0.22	0.41	0.29	0.25	0.01	0.03
S_14	0.07	0.08	0.03	0.08	0.03	0.11
S_15	0.07	0.08	0.1	0.08	0.03	0.11
S_16	0.22	0.08	0.1	0.08	0.03	0.11
S_17	0.07	0.08	0.1	0.08	0.03	0.11
S_18	0.02	0.03	0.02	0.03	0.01	0.03
S_19	0.07	0.08	0.1	0.08	0.03	0.11

Tab. 8

Weighted normalised decision matrix

	W	WV
S_1	0.308	0.016
S_2	0.420	0.021
S_3	0.420	0.021
S_4	0.679	0.032
S_5	0.799	0.037
S_6	0.287	0.013
S_7	0.916	0.043
S_8	0.763	0.035
S_9	1.347	0.059
S_10	0.633	0.030

S_11	0.511	0.024
S_12	0.379	0.018
S_13	2.332	0.102
S_14	1.858	0.085
S_15	2.610	0.120
S_16	2.372	0.107
S_17	1.784	0.081
S_18	0.631	0.029
S_19	1.940	0.087

Tab. 9

Ranking matrix

	Weight	Rank
S_1	0.016	18
S_2	0.021	15
S_3	0.021	16
S_4	0.032	11
S_5	0.037	9
S_6	0.013	19
S_7	0.043	8
S_8	0.035	10
S_9	0.059	7
S_10	0.030	12
S_11	0.024	14
S_12	0.018	17
S_13	0.102	3
S_14	0.085	5
S_15	0.120	1
S_16	0.107	2
S_17	0.081	6
S_18	0.029	13
S_19	0.087	4

Tab. 10.

For Calculation of Consistency

	W	WV	R=W/WV
S_1	0.308	0.016	19.72
S_2	0.420	0.021	19.54
S_3	0.420	0.021	19.54
S_4	0.679	0.032	20.95
S_5	0.799	0.037	21.47
S_6	0.287	0.013	22.58
S_7	0.916	0.043	21.31
S_8	0.763	0.035	21.51
S_9	1.347	0.059	22.67

S_10	0.633	0.030	21.14
S_11	0.511	0.024	20.93
S_12	0.379	0.018	21.60
S_13	2.332	0.102	22.83
S_14	1.858	0.085	21.84
S_15	2.610	0.120	21.79
S_16	2.372	0.107	22.10
S_17	1.784	0.081	21.91
S_18	0.631	0.029	21.72
S_19	1.940	0.087	22.18

$\Lambda max = 21.42$ RI = 1.59
CI = (21.42-19) / 18 = .134 CR = .134 / 1.59 = .084

In above values obtained. λmax is the eigen value of the final matrix obtained from Tab.10. RI is a random index which is obtained from Tab. 4 as the number of factors is 19 so corresponding to number to value 1.59 is taken for calculation. CI is Consistency index which is obtained by applying equation 5. Finally, CR is the ratio of consistency index to random index which signifies how much observed value and calculated value are related, and by applying equation 6 and its came out to.084 which means observed value is very close to calculated value so the result obtained is accurate

Figure 3 below shows the different weights of factors obtained by the AHP process Efficiently using resources (S_15) got the highest, 0.120 and Remote material monitoring (S_6) got the least, 0.013. From figure 3 also shows that he percentage of social, environmental, and economical factors of the sustainability are 15%, 32% and 51% respectively. Figure 4 shows the rank of the factors obtained through AHP where Efficiently using resources (S_15) got the 1st and Remote material monitoring (S_6) got the 19th.

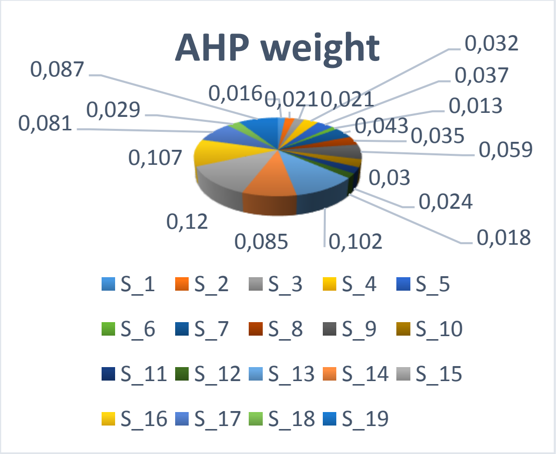

Fig. 3. AHP weight obtained

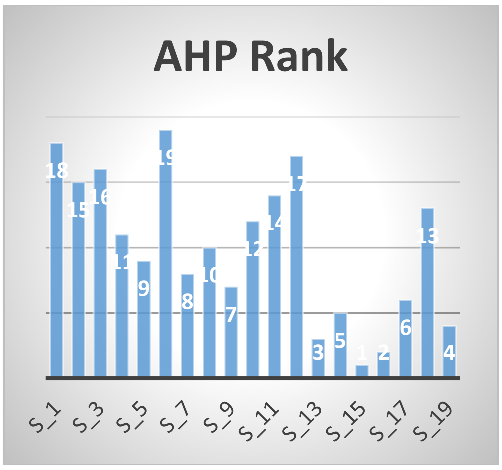

Fig. 4. AHP rank obtained

After the Average Pairwise Comparison Matrix is obtained for factors, the fuzzification of each cell in the matrix is done to obtain the Fuzzified Average Pairwise Comparison Matrix as shown in Table 11. Then step 4 of section 3.2 is used to calculate the fuzzified geometric mean value subsequently fuzzy weight are obtained shown in Table 12. And finally, defuzzication of weight done to obtained weight and rank of factors. (Table 13).

As per the final results obtained Efficient use of resources (S_15) has the highest positive value therefore it is the most significant factor. Instant usage/Pay-as-use(S-16), Optimization (S_19), and Dynamic Flexibility (S_14), secured the 2nd, 3rd and 4th ranks in the category as per their weights obtained. Less Cost incurred (S_17), Reduction in carbon footprints (S_13), Efficient machine usage (S_9), Fuel reduction (S_7), Human safety (S_5) secured 5th, 6th, 7th, 8th and 9th ranks as per the weights obtained. With the minor difference in weights Instant usage and planning (S_11), Human effort (S_3), Human comfort (S_2), Detection of human disaster (S_12) obtained 14th 15th 16th, and 17th ranks. Remote material monitoring (S_6) factor obtained the lowest weight and ranks last, indicating its least significance among all the factors. The ranking is shown in Table 13. Pie chart shown in figure 5 depicts weights obtained of factors and figure 6 shows the bar chart of rank for AHP approach.

Tab. 11

Fuzzified average pairwise comparison matrix – part 1

	S_1	S_2	S_3	S_4	S_5	S_6
S_1	(1,1,1)	(.26,.34,.48)	(.27,.34,.49)	(.26,.34,.48)	(.25,.4,.5)	(2,3,4)
S_2	(2,3,4)	(1,1,1)	(1,1,1)	(.27,.34,.49)	(.24,.33,.47)	(2,3,4)
S_3	(2,3,4)	(1,1,1)	(1,1,1)	(.24,.33,.47)	(.26,.34,.48)	(2,3,4)
S_4	(2,3,4	(2,3,4)	(2,3,4)	(1,1,1)	(1,1,1)	(2,3,4)
S_5	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(1,1,1)	(2,3,4)
S_6	(.27,.34,.49)	(.25,.34,.47)	(.27,.34,.49)	(.24,.33,.47)	(.26,.34,.48)	(1,1,1)
S_7	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(2,3,4)
S_8	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(2,3,4)
S_9	(4,5,6)	(4,5,6)	(4,5,6)	(4,5,6)	(1,1,1)	(2,3,4)
S_10	(2,3,4)	(2.3.4)	(2,3,4)	(2,3,4)	(1,1,1)	(2,3,4)
S_11	(2,3,4)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(2,3,4)
S_12	(1,1,1)	(.25,.4,.5)	(.27,.34,.49)	(.26,.34,.48)	(.26,.34,.48)	(1,1,1)
S_13	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(1,1,1)	(2,3,4)
S_14	(4,5,6)	(4,5,6)	(4,5,6)	(2,3,4)	(2,3,4)	(4,5,6)
S_15	(6,7,8)	(6,7,8)	(6,7,8)	(4,5,6)	(4,5,6)	(6,7,8)
S_16	(4,5,6)	(4,5,6)	(4,5,6)	(2,3,4)	(2,3,4)	(4,5,6)
S_17	(4,5,6)	(4,5,6)	(4,5,6)	(2,3,4)	(2,3,4)	(2,3,4)
S_18	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(1,1,1)	(1,1,1)
S_19	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(4,5,6)

Tab. 11

fuzzified average pairwise comparison matrix – part 2

	S_7	S_8	S_9	S_10	S_11	S_12	S_13
S_1	(.27,.34,.49)	(.24,.33,.47)	(.1,.33,.47)	(.25,.4,.5)	(.24,.33,.47)	(1,1,1)	(.25,.4,.5)
S_2	(.26,.34,.48)	(.24,.33,.47)	(.16,.2,.24)	(.24,.33,.47)	(1,1,1)	(2,3,4)	(.25,.34,.47)
S_3	(.25,.34,.47)	(.25,.4,.5)	(.17,.2,.24)	(.26,.34,.48)	(1,1,1)	(2,3,4)	(.24,.33,.47)

S_4	(.27,.34,.49)	(.25,.34,.47)	(.16,.2,.24)	(.25,.34,.47)	(1,1,1)	(2,3,4)	(1,1,1)
S_5	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(2,3,4)	(1,1,1)
S_6	(.26,.34,.48)	(.27,.34,.49)	(.24,.33,.47)	(.27,.34,.49)	(.25,.34,.47)	(1,1,1)	(.24,.33,.47)
S_7	(1,1,1)	(1,1,1)	(.25,.34,.47)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)
S_8	(1,1,1)	(1,1,1)	(.26,.34,.48)	(2,3,4)	(1,1,1)	(1,1,1)	(.24,.33,.47)
S_9	(2,3,4)	(2,3,4)	(1,1,1)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)
S_10	(.26,.34,.48)	(.24,.33,.47)	(.24,.33,.47)	(1,1,1)	(1,1,1)	(1,1,1)	(.26,.34,.48)
S_11	(.27,.34,.49)	(1,1,1)	(.27,.34,.49)	(1,1,1)	(1,1,1)	(1,1,1)	(.24,.33,.47)
S_12	(.27,.34,.49)	(1,1,1)	(.26,.34,.48)	(1,1,1)	(1,1,1)	(1,1,1)	(.27,.34,.49)
S_13	(1,1,1)	(2,3,4)	(1,1,1)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)
S_14	(2,3,4)	(2,3,4)	(2.3.4)	(4,5,6)	(4,5,6)	(4,5,6)	(.24,.33,.47)
S_15	(4,5,6)	(4,5,6)	(4,5,6)	(6,7,8)	(6,7,8)	(6,7,8)	(.16,.2,.24)
S_16	(4,5,6)	(4,5,6)	(4,5,6)	(4,5,6)	(4,5,6)	(4,5,6)	(.25,.4,.5)
S_17	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(.25,.34,.47)
S_18	(1,1,1)	(1,1,1)	(.27,.34,.49)	(1,1,1)	(1,1,1)	(1,1,1)	(.25,.4,.5)
S_19	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)

Tab. 11

Fuzzified average pairwise comparison matrix – part 3

	S_14	S_15	S_16	S_17	S_18	S_19
S_1	(.16,.2,.25)	(.12,.14,.17)	(.16,.2,.25)	(.17,.2,.24)	(.12,.14,.16)	(.25,.34,.49)
S_2	(.17,.2,.24)	(.13,.14,.16)	(.17,.2,.24)	(.16,.2,.25)	(.26,.34,.48)	(.27,.34,.49)
S_3	(.16,.2,.24)	(.12,.15,.16)	(.16,.2,.24)	(.16,.2,.24)	(.27,.34,.49)	(.26,.34,.48)
S_4	(.25,.34,.47)	(.17,.2,.24)	(.26,.34,.48)	(.26,.34,.48)	(1,1,1)	(.27,.34,.49)
S_5	(.25,.4,.5)	(.16,.2,.24)	(.25,.34,.47)	(.24,.33,.47)	(1,1,1)	(.24,.33,.47)
S_6	(.16,.2,.24)	(.12,.15,.16)	(.16,.2,.24)	(.16,.2,.24)	(1,1,1)	(.16,.2,.25)
S_7	(.25,.34,.47)	(.17,.2,.24)	(.17,.2,.24)	(.25,.34,.47)	(1,1,1)	(.27,.34,.49)
S_8	(.25,.4,.5)	(.16,.2,.25)	(.16,.2,.25)	(.26,.34,.48)	(1,1,1)	(.24,.33,.47)

S_9	(.27,.34,.49)	(.16,.2,.24)	(.17,.2,.24)	(.24,.33,.47)	(2,3,4)	(.26,.34,.48)
S_10	(.16,.2,.25)	(.12,.14,.17)	(.16,.2,.24)	(.25,.34,.47)	(1,1,1)	(.24,.33,.47)
S_11	(.17,.2,.24)	(.13,.14,.16)	(.17,.2,.24)	(.25,.4,.5)	(1,1,1)	(.26,.34,.48)
S_12	(.16,.2,.25)	(.13,.14,.17)	(.16,.2,.24)	(.24,.33,.47)	(1,1,1)	(.25,.4,.5)
S_13	(2,3,4)	(4,5,6)	(2,3,4)	(2,3,4)	(2,3,4)	(.24,.33,.47)
S_14	(1,1,1)	(1,1,1)	(.25,.34,.47)	(1,1,1)	(2,3,4)	(1,1,1)
S_15	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(2,3,4)	(1,1,1)
S_16	(2,3,4)	(1,1,1)	(1,1,1)	(1,1,1)	(2,3,4)	(1,1,1)
S_17	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(2,3,4)	(1,1,1)
S_18	(.27,.34,.49)	(.25,.34,.47)	(.16,.2,.24)	(.25,.34,.47)	(1,1,1)	(.26,.34,.48)
S_19	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(2,3,4)	(1,1,1)

Tab. 12

Fuzzified geometric mean and fuzzy weight

	Fuzzy geometric mean	Fuzzy weight	Weight	Normalized weight
S_1	(.27,.37,.47)	(.009,.015,.025)	0.0164	0.0156
S_2	(.39,.49,.62)	(.013,.020,.032)	0.0218	0.0207
S_3	(.38,.49,.62)	(.013,.020,.032)	0.0218	0.0208
S_4	(.61,.76,.95)	(.021,.031,.049)	0.0336	0.0320
S_5	.81,.98,1.14)	(.028,.040,.059)	0.0424	0.0404
S_6	(.28,.34,.44)	(.010,.014,.023)	0.0155	0.0148
S_7	(.84,1.07,1.31)	(.028,.044,.068)	0.0468	0.0446
S_8	(.72,.91,1.1)	(.024,.037,.057)	0.0396	0.0377
S_9	(1.1.5,1.49,1.85)	(.039,.061,.096)	0.0654	0.0623
S_10	(.57,.72,.89)	(.020,.030,.047)	0.0319	0.0304
S_11	(.57,.65,.75)	(.019,.027,.039)	0.0283	0.0270
S_12	(.39,.47,.56)	(.013,.019,.029)	0.0206	0.0196
S_13	1.54,2.04,2.51)	(.052,.084,.130)	0.0887	0.0845
S_14	(1.78,2.26,2.74)	(.060,.093,.142)	0.0984	0.0937
S_15	(2.59,3.0,3.39)	(.088,.123,.176)	0.1292	0.1231
S_16	(2.21,2.77,3.27)	(.075,.113,.170)	0.1195	0.1138
S_17	(1.66,2.15,2.61)	(.056,.088,.136)	0.0935	0.0890
S_18	(.66,.79,.92)	(.023,.032,.048)	0.0342	0.0326
S_19	(1.72,2.28,2.8)	(.058,.094,.146)	0.0993	0.0945

Tab. 13

Defuzzified weight and rank

	Weight	Rank(Fuzzy AHP)
S_1	0.0156	18
S_2	0.0207	16
S_3	0.0208	15
S_4	0.0320	12
S_5	0.0404	9
S_6	0.0148	19
S_7	0.0446	8
S_8	0.0377	10
S_9	0.0623	7
S_10	0.0304	13
S_11	0.0270	14
S_12	0.0196	17
S_13	0.0845	6
S_14	0.0937	4
S_15	0.1231	1
S_16	0.1138	2
S_17	0.0890	5
S_18	0.0326	11
S_19	0.0945	3

Figure 5 below shows the different weights of factors obtained by the Fuzzy AHP process. Efficiently using resources (S_15) obtained the highest weight of 0.1231, while Remote material monitoring (S_6) got the lowest weight of 0.0148. Figure 5 also illustrates that the percentage of social, environmental, and economic factors in the sustainability is 15%, 30% and 55% respectively. Figure 6 presents the ranking of the factors obtained through Fuzzy AHP, where Efficiently using resources (S_15) got the 1st rank and Remote material monitoring (S_6) got the 19th rank.

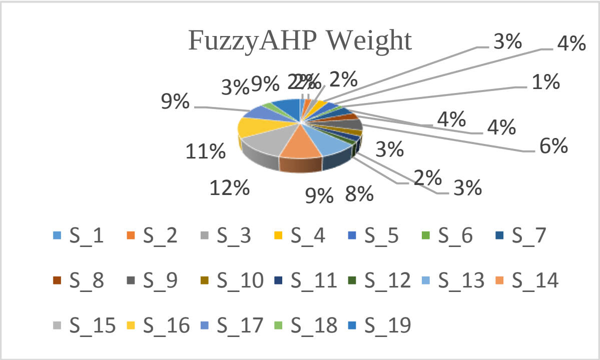

Fig. 5. Fuzzy AHP weight obtained

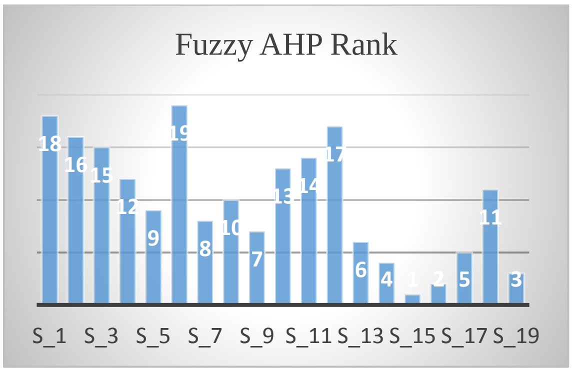

Fig. 6. Fuzzy AHP rank obtained

The ranking obtained from AHP is compared with the ranking of Fuzzy AHP and finds that there is a slight difference in the ranking of factors, as shown in Table 13. The accuracy of the result is confirmed, since the results obtained from both cases are almost identical. Even coincident lines in figure 6 predict the similarity between the results from AHP and Fuzzy AHP.

Tab. 14

Comparison of ranks of AHP and Fuzzy AHP

Factor	AHP rank	Fuzzy AHP rank
S_1	18	18
S_2	15	16
S_3	16	15
S_4	11	12
S_5	9	9
S_6	19	19
S_7	8	8
S_8	10	10
S_9	7	7
S_10	12	13
S_11	14	14
S_12	17	17
S_13	3	6
S_14	5	4
S_15	1	1
S_16	2	2
S_17	6	5
S_18	13	11
S_19	4	3

Figure 6 below shows the comparison of the rank obtained from two different processes, AHP and Fuzzy AHP. It can be inferred from the chart that the lines are just coinciding, meaning that ranks obtained are almost the same, which further implores the accuracy of the result.

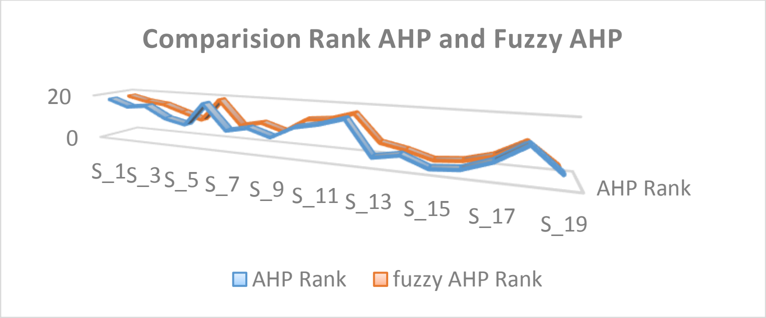

Fig. 6. Comparison of AHP and Fuzzy AHP rank obtained

5. CONCLUSION

This paper focuses on the various factors related to the adoption of cloud manufacturing. Through input from industry experts and academics, a total of 19 factors have been identified: The conducive social network, Human comfort, Human effort, Human health, Human safety, Remote material monitoring, Fuel reduction, Waste reduction, Efficient machine usage, Environment advices, Instant usage and planning, Detection of natural disaster, Reduction in carbon footprints, Dynamic flexibility, Efficiently using resources, Instant usage/Pay-as-use, Less cost incurred, Less inventory, and Optimization. The AHP approach is employed to calculate the weights for these sustainability factors and determine their ranking. To ensure the accuracy of the results, a comparison is conducted between the outcomes obtained from AHP and Fuzzy AHP. This validation process ensures the robustness and consistency of the findings. Results show, Efficient use of resources (S_15) as the most significant and Remote material monitoring (S_6) as the least significant factor in the context of adoption cloud manufacturing. Other factors Instant Usage/Pay-as-use (S_16) and Reduction in carbon footprints (S_13) footprints also play a very important role in choosing cloud manufacturing as a manufacturing process. Furthermore, the consistency ratio value is calculated for validation, accuracy, and consistency of the results and as the value of CR is .084 which less than .1 shows that the results obtained are accurate and consistent. The percentage obtained as 15%, 32%, and 51% for social, environmental, and economic factors of sustainability respectively, proves that cloud manufacturing is a sustainable manufacturing process. To summarize, we obtained a ranking of all factors influencing cloud manufacturing adoption and identified the most significant ones. The percentage obtained for social, environmental, and economic factors of sustainability concludes that cloud manufacturing is a sustainable manufacturing process.

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SURVEY QUESTIONNAIRE

You are supposed to compare the two factors at a time (i.e., in a pair). The scores of comparisons are 1, 3, 5,7, and 9. Scores are assigned accordingly

Equal importance	1
Moderate importance	3
Strong importance	5
Very strong importance	7
Extreme importance	9

For example: If you are comparing sustainability factor (S_1) of a row with the sustainability factor (S_2) of the column and assigned value **5** means that factor S_1 is of strong importance than opportunity S_2

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9
S_1	1								
S_2		1							
S_3			1						
S_4				1					
S_5					1				

S_6						1			
S_7							1		
S_8								1	
S_9									1
S_10									
S_11									
S_12									
S_13									
S_14									
S_15									
S_16									
S_17									
S_18									
S_19									

	S_10	S_11	S_12	S_13	S_14	S_15	S_16	S_17	S_18	S_19
S_1										
S_2										
S_3										
S_4										
S_5										
S_6										
S_7										
S_8										
S_9										
S_10	1									
S_11		1								
S_12			1							
S_13				1						
S_14					1					
S_15						1				
S_16							1			
S_17								1		
S_18									1	
S_19										1

S.No	**Overall factors for cloud manufacturing**
S_1	Conducive social network
S_2	Human comfort
S_3	Human effort

S_4	Human health
S_5	Human safety
S_6	Remote material monitoring
S_7	Fuel reduction
S_8	Waste reduction
S_9	Efficient machines usage
S_10	Environment advices
S_11	Instant usage and planning
S_12	Detection of natural disaster
S_13	Reduction in carbon footprints
S_14	Dynamic flexibility
S_15	Efficiently using resource
S_16	Instant usage / pay-as-use
S_17	Less cost incurred
S_18	Less inventory
S_19	Optimization

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