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Research Article

Selection of Additive Manufacturing Machine Using Analytical Hierarchy Process

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3D printing or additive manufacturing (AM) is considered to be the most important technology among the emerging technologies. 3D printing technology is considered as an alternative to the conventional manufacturer machine traditionally used in the manufacturing sector. 3D printing technology is generally classified into seven types. Each type of 3D printing technology has its separate own uniqueness (i.e., operation, material usage, and no wastage). The price of a manufactured item includes all its costs. The most important of these is to take into account the price of the machine being manufactured and the features of the machine. Moreover, the price of the product produced in AM will depend on all the costs required to produce it. Then, it is possible to reduce the cost of the product by choosing the AMM that has significant features and the right price. Therefore, this paper aims to solve a decision-making problem from the AMM selection by using one of the multicriteria decision-making (MCDM) tools, i.e., analytical hierarchy process (AHP). This paper outcome is meant to meet the expectation of end-users. As an initial step, the Micro, Small, and Medium Enterprise (MSME) company gets quotations from some AM companies to choose a type of AM machine known FDM for its structure product and doll product. The first step is to select the most appropriate machines based on cost, size/volume, extruder type, and weight of the machine. Criteria for AHP are derived from decision-makers. Also, in AHP, the pair-wise matrix is obtained from the decision-makers by answering the standard Saaty's scale criteria questions. In this paper, such a selection method is explored. The outcome of this paper may vary depending on the expectations of the decision-makers. The end of this paper helps to choose the AMM with the right price and features to suit the decision-makers.

1. Introduction

AM is a method of converting a digital file into an STL file or suitable file format (OBJ, VRML, etc) and producing the products layer by layer directly [1]. From this, we can easily produce even the most rigorous geometric materials. According to previous literature [2], the selection process is a major issue in fields such as defense and manufacturing that involves the decision-making of end-user [3]. Therefore, choosing the right AMM in the production cycle or integrated design product can be very difficult. The raw materials used in 3D printing are in the form of filament or powder or resins (metal, polymer, and plastic) [4, 5]. Each AM process has an individual separate feature of its own. Before choosing an AM machine, we should know the preference of the machine buyer as well. Moreover, qualitative data play a vital role in maintaining performance in this competitive environment. At this time, everyone needs decision-making tools with qualitative and quantitative data as well. The choice of the decision-maker and the right machine, however, involves a psychological and mathematical factor. This paper combines the two features mentioned above to help the MSME company select a suitable and highly user-friendly AMM. This paper covers the attitudes and techniques of many researchers according to literature review as some of the remaining key features. This is followed by a description of how problem identification and methodology reach the research objective. The initial stage screening process started with the project engineer who selects the machine. Then, the AHP method was applied. The criteria and alternatives were chosen according to the decision of the buyer of AMM. Finally, the recommended MCDM technique will be verified by a case study.

2. Literature Survey

2.1. 3D Printing or Additive Manufacturing. AM is able to make the most complex geometric properties of production materials during production and produce materials with low mass and low waste. AM requires very low material cost, and the AM separate feature includes options for selecting the process parameter. 3D printing or additive manufacturing has recently attracted the attention of all major sectors. AM is considered to be in a situation that creates the most severe crisis for the traditional production system of conventional manufacturing (CM). AM is better at producing geometrical rigorous material structures compared to conventional manufacturing. AM is also very good at completely rejecting the integrated assembly in CM and preparing materials directly layer by layer. Some of the most challenging factors in AM are the price of the products, the availability of the products, the high production rate, the cost especially in making the prototype, and some difficult real-time operational tests. However, the price of the AM prototype is slightly lower than CM and it provides minimizing production time for prototype manufacturing [6, 7].

The designs in AM mode can be countered very precisely when compared to CM [8]. Ramola et al. [9] conducted research on selecting customized processes in the healthcare industry. Kokotsaki et al. [10] improved a method for selecting processes in the production of new materials and spare parts in AM. The best AMM can be selected through a systematic review because this is a good solution to avoid AMM failure. It will also help increase AMM's productivity. Sophisticated art-minded review by Rashid [11] and Petrovic et al. [12] explored the points such as additive manufacturing benefits of the use of fewer raw materials such as powder particles to create products during its production and the lack of tools in selecting processes as defects indicates a lack of business opportunity. As a third industrial revolution, AM stocks are registering [13] through multisector prototype jewelry making. Manufacturing lead time and time to market are an advantage of the AM industry, as described by Pham and Gault [14] through research comparing various rapid prototype technologies. Bak [15] points out that AM has the advantage of not using tools during production, which is beneficial for exploring from different angles. It also leads to mass production. Roa and Padmanabhan [16] explained in their research how to select RP processes using graph theory and matrix approach with various alterations. Xu et al. [17] outlined comparing the genetic models to select the right process in rapid prototypes with build cost, build time, and surface roughness. The Masood and Soo [18] research concludes that the rule-based expectation system will solve AM's process selection problems in industry and education. The RP processes are researched according to the topic's method with parameters such as strength of build material, accuracy, prototype, cost, elongation, and build time [19]. Kim and Oh [20] explored roughness, accuracy, speed, material cost, and mechanical properties on a quantitative basis. Moreover, research has also explored that AMMs consume only slightly less raw materials. Research by Jones [21] and Ramalinga [22] has shown that 3D printing provides the highest accuracy and lowest material wastage in the field of orthodontist's application and multimodel 3D face recognition. Research reports by Taufik and Jain [23], Gay et al. [24], and Vlasea et al. [25] explain that the structure of AMMs has an impact on mechanical properties and is essential for maintaining mechanical properties. The MCDM technique is used to provide the perfect solution to the latest multiple-choice issues that have more than one alternative and criteria [4]. Below are the benefits and uses of MCDM with the help of the literature of previous researchers.

2.2. MCDM. Choosing the best alternative from many alternatives is known as the decision-making process. The most important goal of MCDM is to choose the appropriate alternative [26, 27]. The process that involves criteria and alternative and includes the decision-maker opinion to state the solution is known as MCDM [28]. MCDM plays a very important role in operation research, and it helps decision-makers in a very tough decision-making situation with many alternatives and criteria [29]. The MCDM has different kinds of decision-making tools such as AHP, FAHP, TOPSIS, and COPRAS [30]. FAHP and TOPSIS [31] and DEMATEL methods are widely used in the AM industry [32]. MCDM plays a significant role in the field of Supply Chain Management (SCM) [33], management science system engineering [34], sustainability [35], planning and product development evaluation, and strategic management [36, 37]. MCDM has also enhanced FTOPSIS and FMEA risk evaluation [38]. MCDM is also used in FTOPSIS layout planning [39]. Each MCDM system is unique; from this, AHP was created in 1970 by Thomas L. Saaty. It also has a 0–9 AHP system as Saaty scale. This scale provides a solution to the inconsistency pair-wise comparison [40].

2.3. Analytical Hierarchy Process. Complex analytical problems are solved by the analytical hierarchy process, and it is a more suitable one on the multicriteria decision-making approach. The objective of AHP has a conflict of decision-making and actual requirements. The AHP is having different phases such as difficult decision-making problems into a hierarchy and increasing the criteria weight that helps alternative priorities [41, 42]. Jose Eugenio Leal explored the AHP and introduced the new AHP-Express tool that is suggested to advanced formulas for minimizing the steps of the traditional AHP method [43]. The AHP includes the following steps involved to find the best alternative by using the previous literature data [44–47].

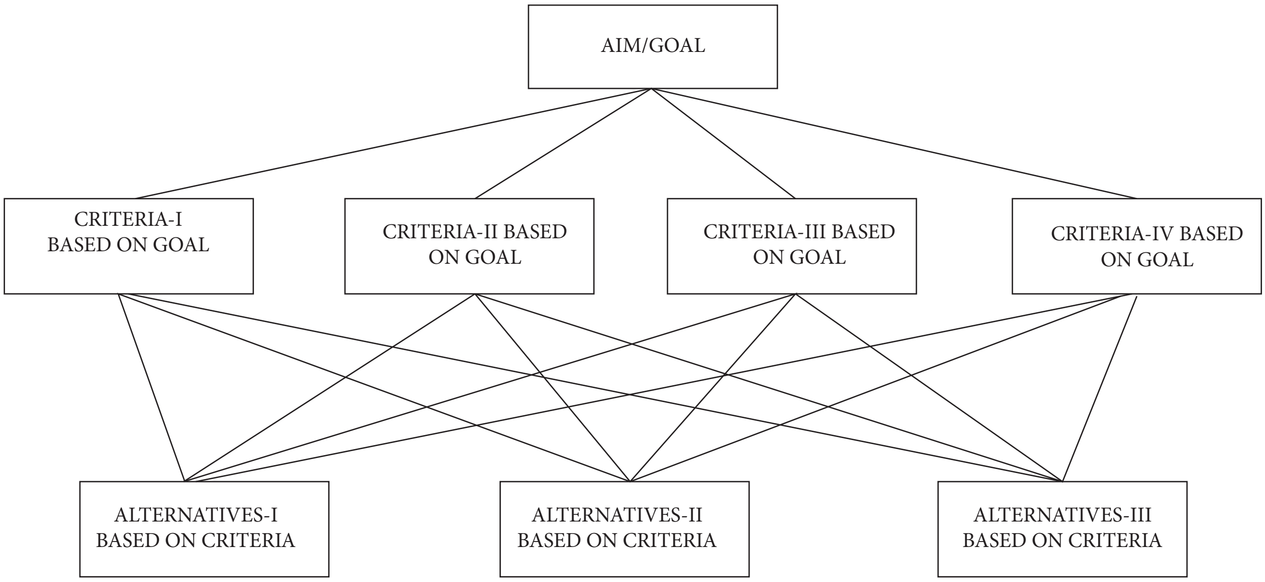

Figure 1: Hierarchical structure of AHP.

2.3.1. Step-I. Figure 1 shows the hierarchical structure for novel problem. It consists of level-I as aim or goal, level-II as criteria based on aim or goal, and level III as an alternative based on criteria.

2.3.2. Step-II. To form the pair-wise matrix for calculating the criteria weight after stage-I, collect the decision-maker expectation by detailed questions about criteria and alternative priorities with the help of a scale of relative alternatives (Saaty scale) (Table 1).

2.3.3. Step-III. Solve the pair-wise matrix to obtain the criteria weight and weight sum value. Moreover, find the consistency index by using the following formula:

$$\text{consistency index, C.I} = \left(\frac{\lambda\text{max} - \text{n}}{n - 1}\right), \quad (1)$$

where λmax = (sum of ratio of weight sum value and criteria weight/number of criteria) and and n = number of criteria.

2.3.4. Step-IV. To find the consistency ratio by using the following formula and standard table:

$$C.R = \left(\frac{C.I}{RI}\right), \quad (2)$$

where C.I = consistency index (found from the previous step) and RI = random index (Table 2).

2.3.5. Step-V. To check whether the consistency ratio is not greater than 0.10: if the consistency ratio is greater than 0.10, then regenerate the criteria. Moreover, tabulate the criteria and criteria weight obtained.

Table 1: Scale of relative alternatives (Saaty scale) [4].

Scale of relative alternatives	
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
1/3, 1/5, 1/7, 1/9	Values for inverse comparison

Table 2: Random index.

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

2.3.6. Step-VI. To form the pair-wise matrix for calculating each alternative criterion weight based on each criterion.

2.3.7. Step-VII. Finally, form the decision matrix and give the rank based on the priority value.

3. Problem Description

The ease of manufacture of geometrical complex products and its low production cost make AM useable in many fields. However, researchers are using optimization tools or techniques to increase the accuracy and other properties of AM. The goal of this research is to enable an MSME company to select the best FDM for doll manufacturing and prototype production on a current basis.

3.1. Problem Identification. AM falls into seven categories [8], according to previous researchers, and each type is unique. Moreover, the AM attracts different applications such as medical, defense, jewelry making, and

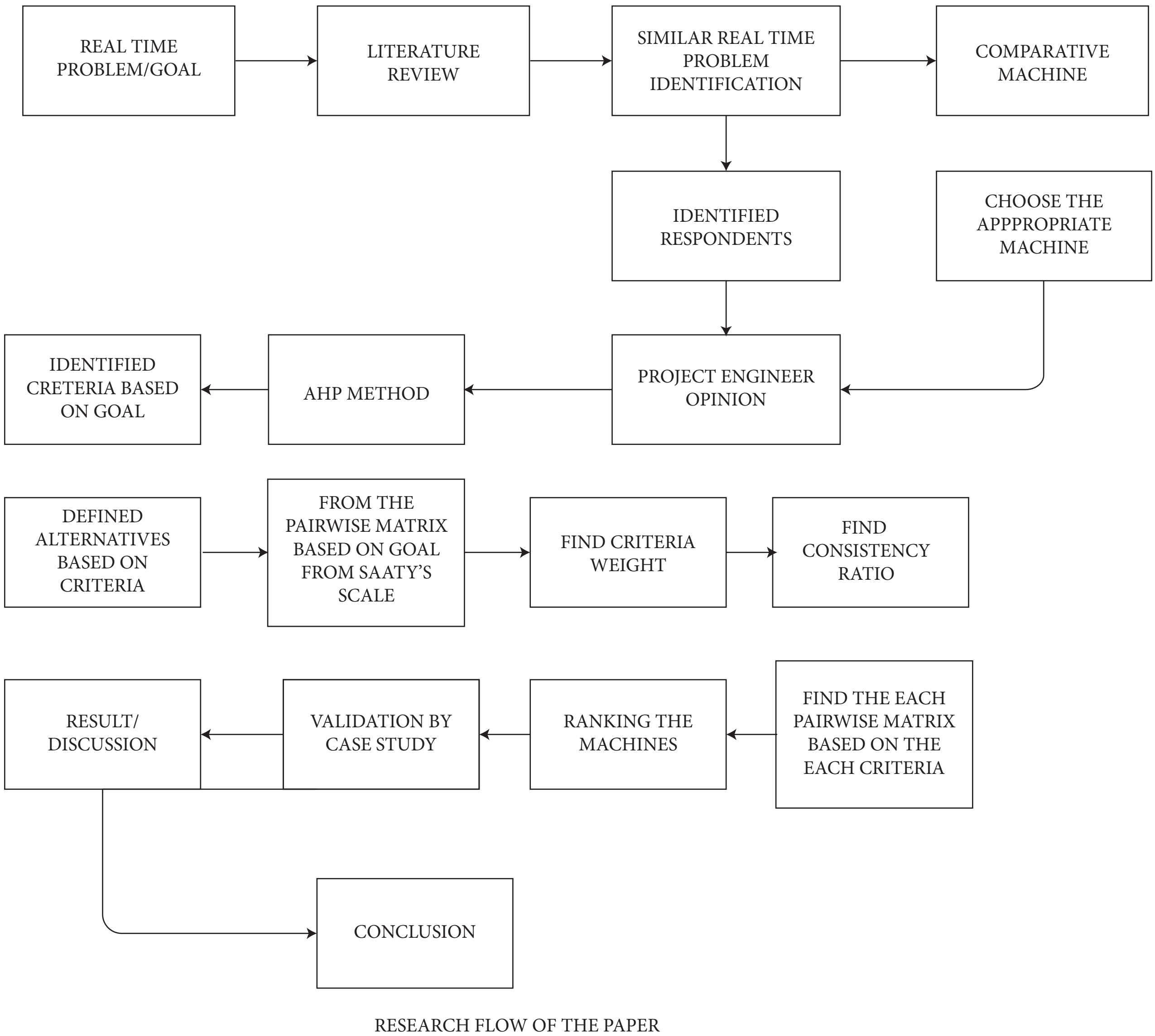

Figure 2: Research flow of the paper.

construction. Although AM has many advantages, its production cost increases due to the following factors compared to the traditional production method. Most manufacturers do not use AM for some of these reasons. Each AM machine has its own separate production material and production costs. These factors cannot be changed for any reason. However, it is possible to reduce the cost of the final product by choosing the most suitable and reasonably priced AM machine for production. Moreover, this will also help increase productivity and possibly choose inexpensive alternative production material or technology. Moreover, this will also help increase productivity and as well as possible to choosing inexpensive alternative production material or technology. But the choice of the selector to use the machine is AM technically and particularly, FDM-based machines such as WANHAO Duplicator 4s, Flash Forge Creator Pro, and Makerbot Replicator Plus companies. Hence, the purpose of this paper is to help MSME to choose a very suitable machine from an FDM machine of three different companies. Hence, the purpose of this paper is to help MSME choose a very suitable machine from an FDM machine of three different companies.

3.2. Research Methodology. This research paper aims to help select the appropriate AM machine based on the respondent's needs. Moreover, this research is to consider and compare several criteria based on the decision-makers' prescribed machines. Further such comparison is to be conducted by the MCDM technique which is a component of the operation research. In particular, the Analytical Hierarchy Process (AHP) technique is used to select the best option. The most important objective of this research paper is to understand the needs of MSME company and to help them choose the right machine by comparing the machines

Table 3: Technical specifications of selected companies.

Properties/brand	WANHAO Duplicator 4s	Flashforge Creator Pro	The MakerBot Replicator+
Extruder type	Dual	Dual Extruder W/2 Spools	Smart extruder
Filament size	1.75 mm dedicated	1.75 mm dedicated	1.75 mm dedicated
Layer capability	0.1 mm–0.5 mm	0.1 mm–0.4 mm	0.1 mm–0.4 mm
Build volume	225 mm × 145 mm × 150 mm	227 mm × 148 mm x150 mm	280 mm × 195 mm × 165 mm
Filament capabilities	ABS, PLA, PVA, NYLON, HIPS, and other common filaments	Works with ABS and PLA	ABS and PLA
Software	ReplicatorG (open source)	Open source	Open source
Warranty	1 year limited warranty	1 year limited warranty	6 months
Frame color	Black steel exoframe	Black steel exoframe	Black steel exoframe
Temperature	60–90o̲°F ambient/32–90°F storage	60–90°F ambient/32–90°F storage	60–90°F ambient/32–90°F storage
Electrical input	AC 100–240 V	AC 240 V	AC 240 V
Power requirement	6.25 a/s	6.25 a/s	6.25 a/s
Net weight	11.5/19.5 kg	14.5–21 kg	23 kg
Chassis	Stainless steel	Metal frame structure	PC ABS with powder-coated steel reinforcement
Body	DPP panel	Acrylic covers	Aluminum
Build platform	Al heating plate/Si glass	Optimized build platform	Grip surface
Bearing	Wear resistance, oil infused bronze	Wear resistance	Wear resistance
Motor used	1.8″ step angle	1.8″ step angle	1.8″ step angle
Connectivity	USB/SD card	USB/SD card	USB/SD card

of WANHAO Duplicator 4s, Flashforge Creator Pro, and MakerBot Replicator Plus companies with the best FDM machine for their preferred doll and prototype product. Figure 2 illustrates the entire research flow, and this research begins with the literature survey. The latest trends in AM, methods of selecting machines, etc. are exploring, and the AHP method is used here. The purpose of this research is finalized, and the work of research begins. According to the AHP method, based on the Saaty scale 0–9 points, the research problem is answered and solved by Google Form questions. Finally, the recommended result is further verified by a case study.

4. Selection and Data Collection

4.1. Selection of 3D Printing Machine. There are many FDM-based 3D printing machines available in the market. From those, WANHAO Duplicator 4s, Flashforge Creator Pro, and MakerBot Replicator Plus FDM machines are prescribed by the decision-makers. This is because MSME has the ability to receive immediate sales and services from these companies. In addition, MSME has a large number of branches, offices, and spare part stores of FDM machines near the company. All of these are key factors in making a mark on the machine or invention market. For example, Maruti Suzuki have branches in all cities in India. The Maruti Suzuki car company in India holds the first rank by its sales and service [48]. Hence, the decision-maker WANHAO Duplicator 4s, Flashforge Creator Pro, and MakerBot Replicator Plus machines would be perfect for them. Table 3 provides a comparison of the machines mentioned above.

4.2. Screening Process. This screening process allows choosing the right machine from the decision-maker's preferred machines. Questions are asked and answered by experts in the field (additive manufacturing machine user), research students, and industrial project managers through Google Form. This Google Form has been sent to more than 200 industry experts. It received 113 significant responses. Of these, 37.2% of research scholars, 42.8% of project engineers, 2.7% of project managers, 2% of professors, and 2% of entrepreneurs answered, and all the questions and answers can be found below. Figures 3–12 explore respondents of this research, such as the working field, designation, city, 3D printing importance on their field, FDM importance of their field, and consumer satisfaction level by 3D printing, 3D printer experience, operation, and material used in their AM field.

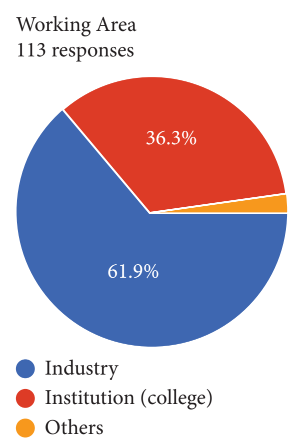

Figure 3: Working area of respondents (additive manufacturing machine user).

Figure 3 shows that 61.9 percent of respondents point to AM sector-based industries, 36.3 percent to research colleges, and the rest to other AM-based industries. Figure 4

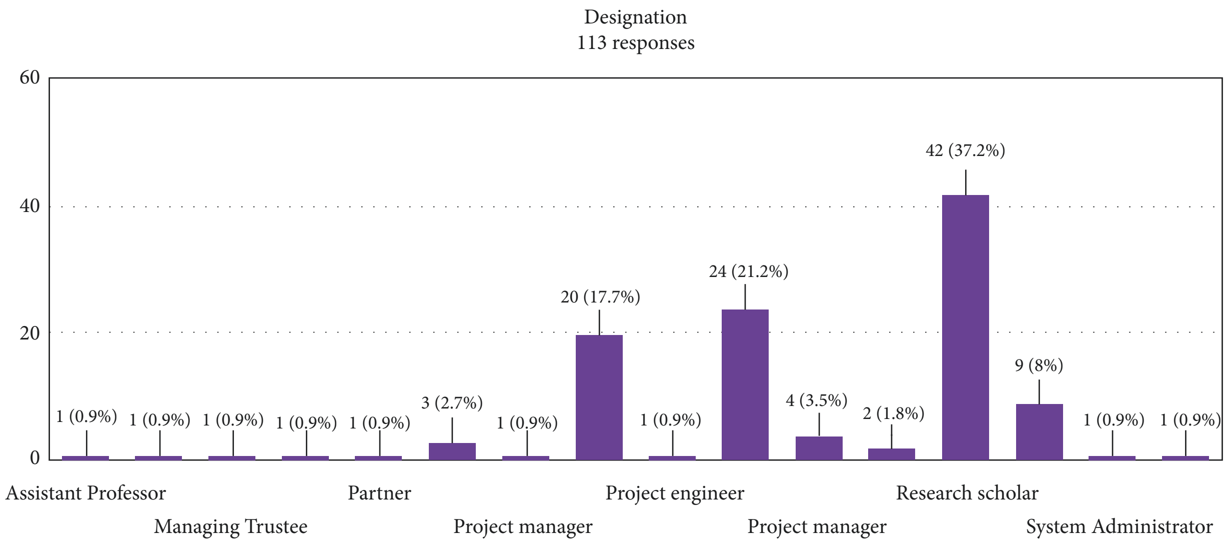

Figure 4: Designation of respondents (additive manufacturing machine user).

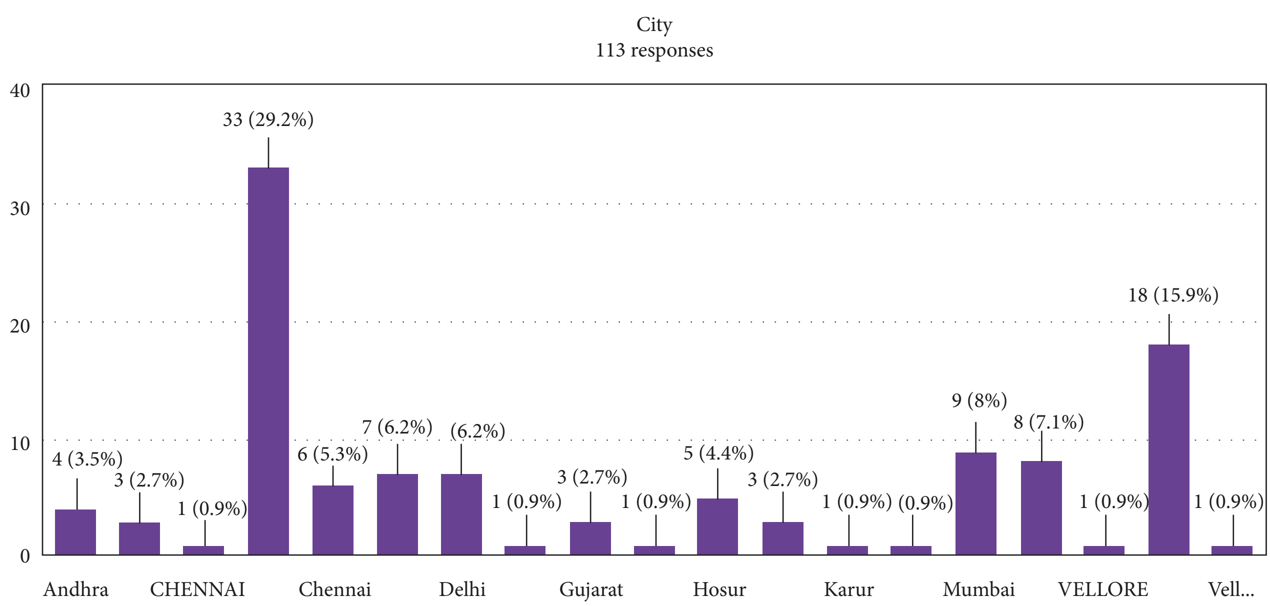

Figure 5: City of respondents (additive manufacturing machine user).

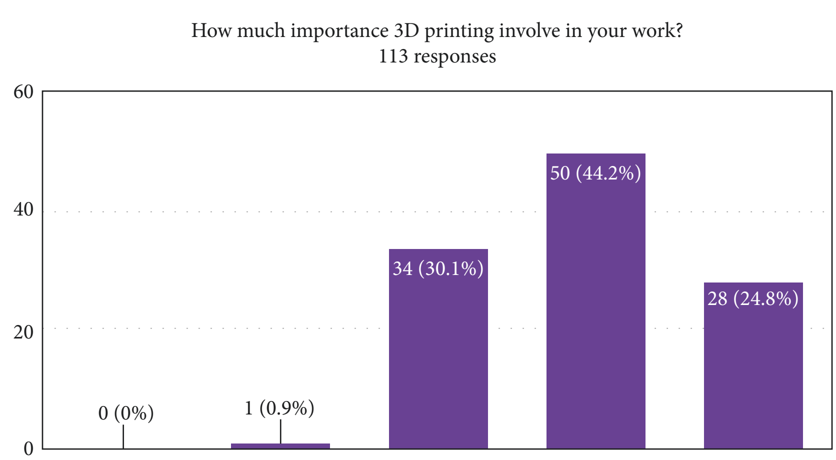

Figure 6: 3D printing importance in respondent's (additive manufacturing machine user) field.

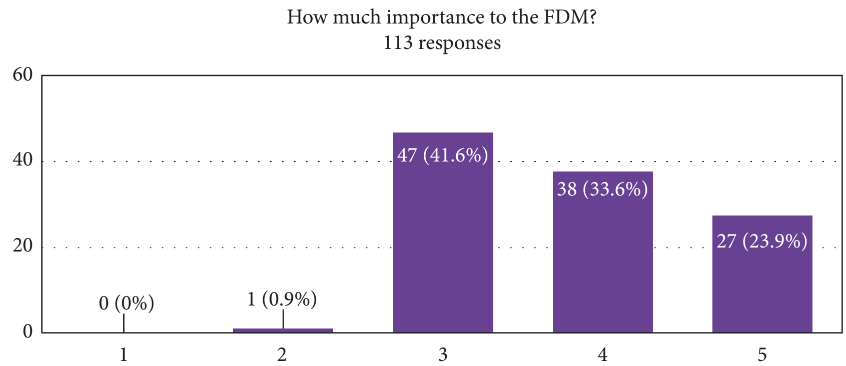

Figure 7: FDM importance in respondents (additive manufacturing machine user) field.

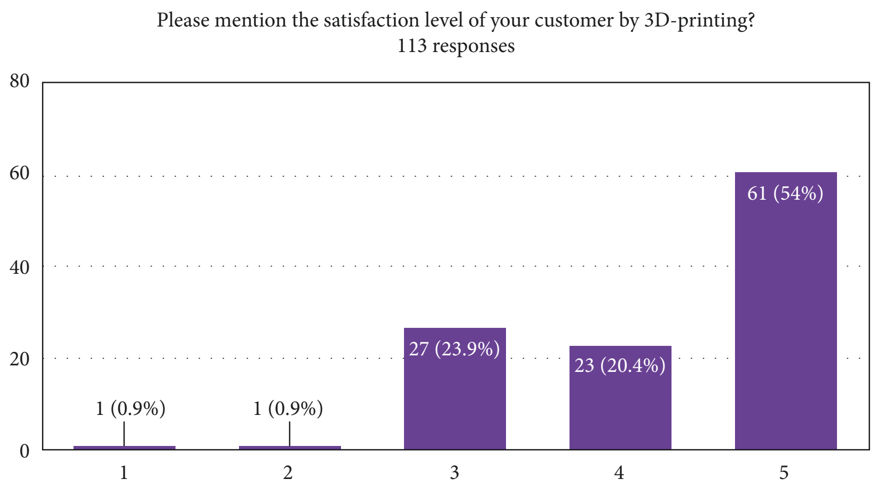

Figure 8: Respondent's (additive manufacturing machine user) consumer satisfaction level by 3D printing.

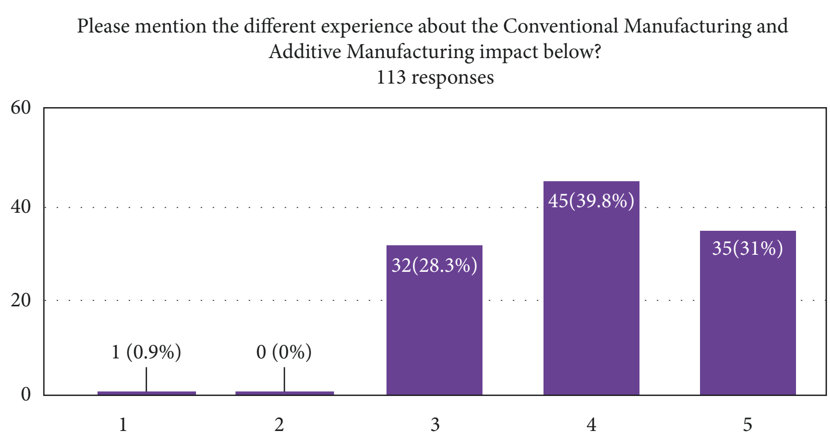

Figure 9: Additive manufacturing importance over conventional manufacturing.

shows the working designation of the respondents, and it is discussed above.

Figure 5 shows the city of respondents; from this, around 40% of respondents live in Chennai, 9.8% of respondents live in Mumbai, 2.7% percent in Gujarat, and the rest of them live in other places of India. Figure 6 shows that AM involves the respondents' work. This figure ensures all the respondents are working in the field of AM.

Figure 7 shows the FDM application specifically in the respondent's field because the novel problem in this paper is to select the best FDM. From this figure, we can see that more than 47% of respondents use the FDM in their field. Moreover, Figure 8 shows the FDM application satisfaction level of respondent's consumer. From this figure, by FDM, 54% of respondent's consumers are more satisfied with the final product.

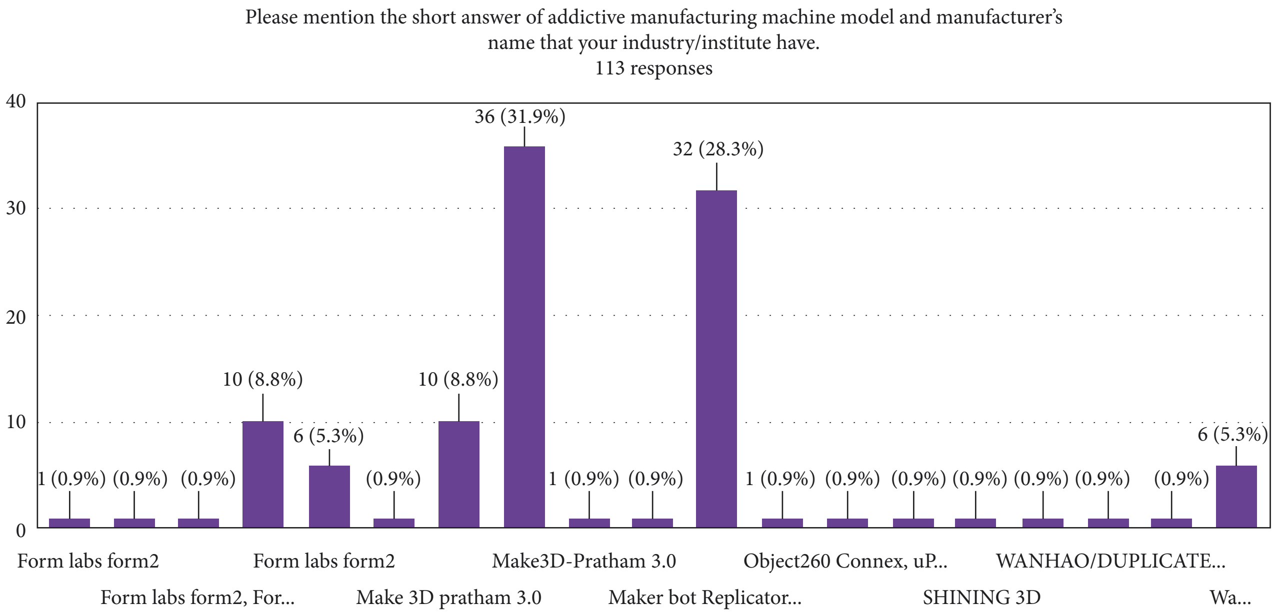

Figure 10: Respondents' (additive manufacturing machine user) AMM and their brand.

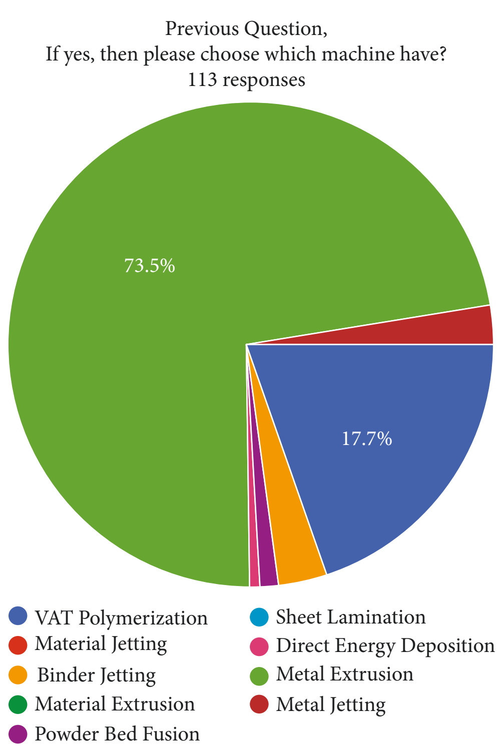

Figure 11: Respondents' (additive manufacturing machine user) operation in AM.

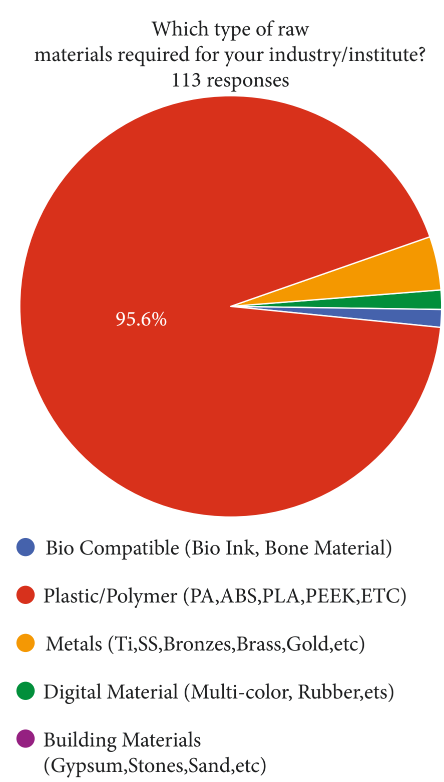

Figure 12: Respondents' (additive manufacturing machine user) operation AM material.

Figure 9 shows the changes or differences between the experience in the field of conventional manufacturing and additive manufacturing. Most of the respondents mentioned 3–5 impact points. Figure 10 indicates the respondents' AMM brands involved in their works.

AM falls into seven categories [6]; the respondents' specific application shown in Figures 11 and 12 indicates the respondents' operation raw materials in their fields. From Figures 11 and 12, we can see that 73.5735 percent of respondents used the material extrusion process and 95.6 percent of respondents used the plastic/polymer raw material in AM (Table 3).

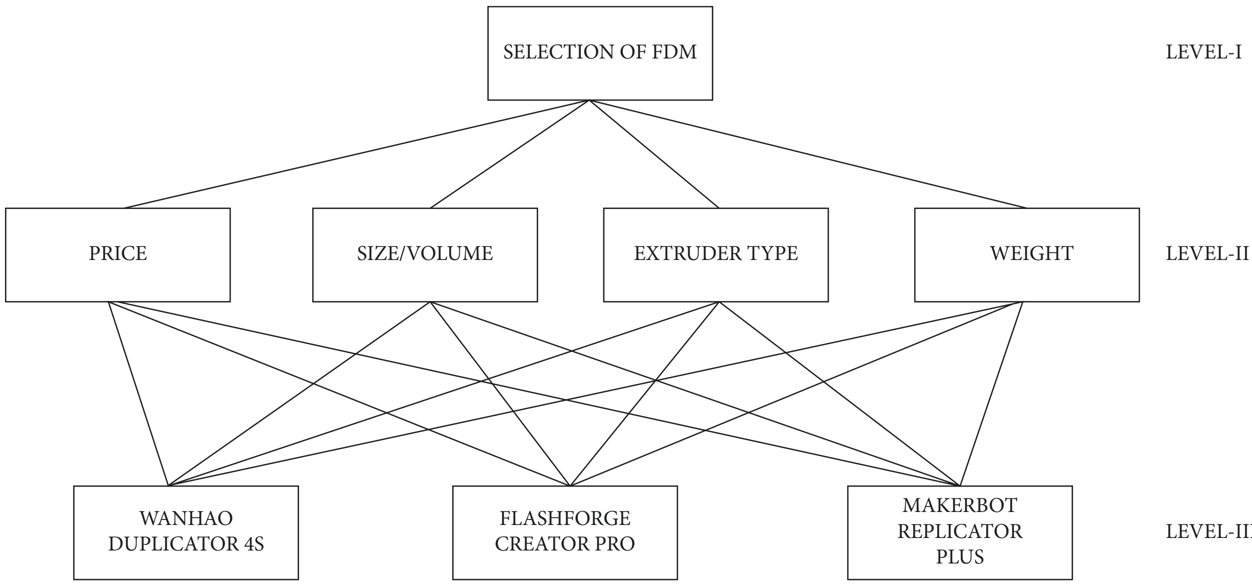

Figure 13: Hierarchical structure of novel problem.

Table 4: Pair-wise matrix.

Based on aim	Price	Size/volume	Extruder type	Weight
Price	1	3	4	6
Size/volume	1/3	1	1/2	3
Extruder type	1/4	2	1	3
Weight	1/6	1/3	1/3	1

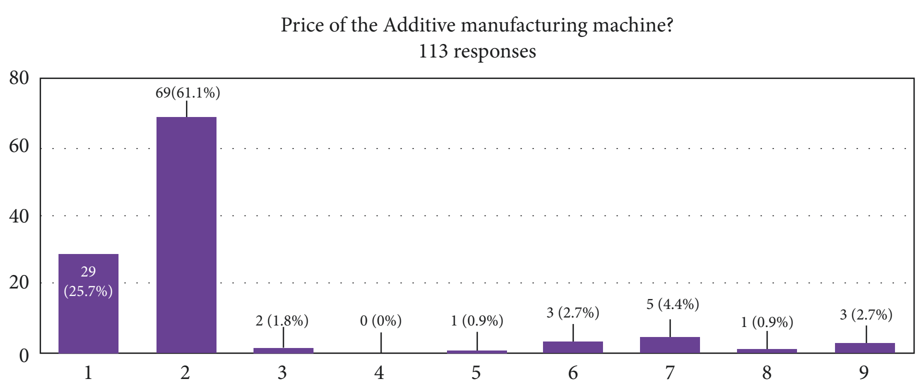

Figure 14: Importance of the price of the AM machines.

4.3. Machine Selection Using AHP. The AHP has included different steps to find the best alternative, and it is discussed in Section 2.3. In Step I, the AHP network diagram is drawn and classified into three levels as shown in Figure 13. From level I, the aim of the novel problem to solve in this paper is selection of FDM machine, and level II is the criteria based on the aim such as price, size/volume, extruder type, and weight of the machine. The following steps are used to select the appropriate machine.

4.3.1. Step-I. Finally, in level III, alternatives are based on the criteria, namely, WANHAO Duplicator 4s, Flashforge Creator Pro, and MakerBot Replicator Plus. In criteria, the price of the machines quoted by the FDM companies is as follows: INR 46000 for WANHAO Duplicator 4s, INR 44000 for Flashforge Creator Pro, and INR 144000 for MakerBot Replicator Plus.

4.3.2. Step-II. Table 4 shows the pair-wise matrix formed by the questions asked to the respondents (additive manufacturing machine user) and their responses.

Figure 14 represents the importance of the price of the AM machines. The price of the machine has most of the respondents (additive manufacturing machine user) take 1-2 importance from the Saaty scale. These represent equal importance from the scale of relative alternatives.

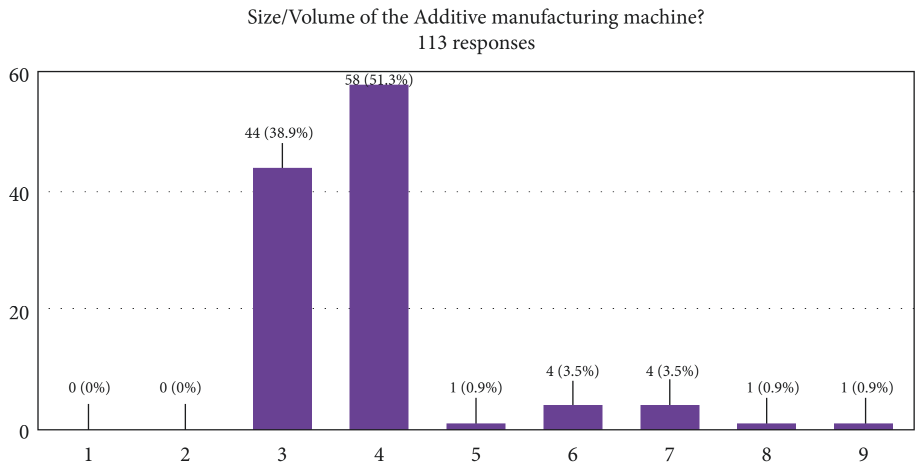

Figure 15: Importance about size/volume of the AM machines.

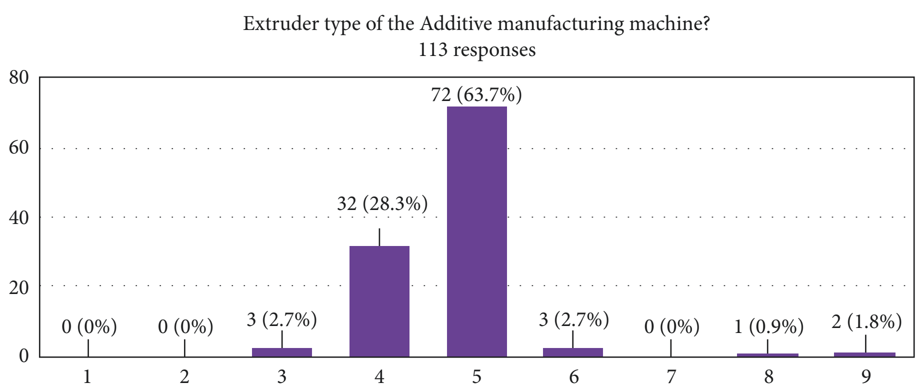

Figure 16: Importance about extruder type of the AM machines.

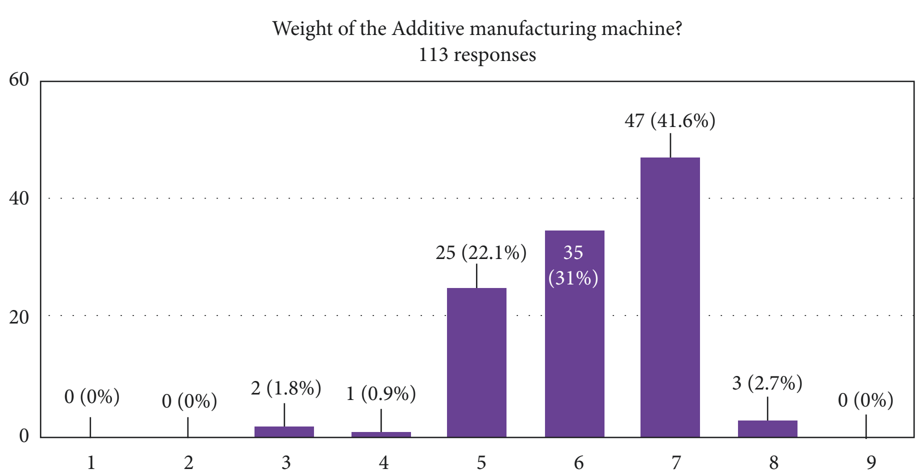

Figure 17: Importance about weight of the AM machines.

Figures 14–17 show the resultant data from the respondents (additive manufacturing machine user). Figure 15 shows the 3-4 importance for size/volume from the Saaty scale, Figure 16 represents the 4-5 importance for extruder type, and Figure 17 represents 5-7 importance for the weight of AM from the Saaty scale.

From these figures, the pair-wise matrix values are taken from the range of respondents' (additive manufacturing machine user) response.

The above pair-wise matrix formed by the Saaty scale from the respondents' (additive manufacturing machine user) data is used to solve for further criteria weight

Table 5: Pair-wise matrix with criteria weight.

Based on aim	Price	Size/volume	Extruder type	Weight	Criteria weight
Price	1	3	4	6	0.55
Size/volume	0.33	1	0.5	3	0.17
Extruder type	0.25	2	1	3	0.22
Weight	0.17	0.33	0.33	1	0.0703
Sum value	1.75	6.33	5.83	13	1.01

Table 6: Pair-wise matrix with weighted sum value.

Based on aim	Price × criteria weight	Size/volume × criteria weight	Extruder type × criteria weight	Weight × criteria weight	Weighted sum value
Price	**0.55**	0.51	0.88	0.4215	**2.36**
Size/volume	0.182	**0.17**	0.11	0.210	**0.672**
Extruder type	0.14	0.34	**0.22**	0.210	**0.91**
Weight	0.094	0.056	0.0726	**0.0703**	**0.292**

formation process. In this pair-wise matrix, the data of the first row are placed based on respondents' (additive manufacturing machine user) opinion based on the Saaty scale and the second row compares the data from the first row. Finally, third-row data are similar to the data of the first row and the second row.

4.3.3. Step-III. Table 5 shows the pair-wise matrix solved by the following procedure to obtain the criteria weight:

(i) To take the sum of column on each criterion
(ii) Each importance value is divided by the total sum of column
(iii) Finally, the sum of row value represents the weight of each criterion

4.3.4. Step-IV. This step is to find the weighted sum value. The weighted sum value is essential to find the consistency ratio and is obtained by multiplying the criteria weight into each criterion importance value. Thus, the matrix is shown in Table 6.

The ratio in Table 7 is found for calculating the $\lambda_{\max}$ value. The ratio is obtained by dividing the weight sum value of each criterion by criteria weight of each criterion.

To find the ratio value of Weighted Sum Value to Criteria Weight,

$\lambda_{\max}$ is found by using the following formula:

$$\lambda_{\max} = \left(\frac{4.29 + 3.95 + 4.13 + 4.17}{4}\right) = 4.135. \tag{3}$$

$\lambda_{\max}$ is obtained by the sum of column of ratio value divided by the number of criteria.

The consistency index (C.I) is obtained by using the following formula:

Table 7: Pair-wise matrix with ratio.

Based on aim	Criteria weight	Weighted sum value	Ratio
Price	0.55	2.36	4.29
Size/volume	0.17	0.672	3.95
Extruder type	0.22	0.91	4.13
Weight	0.0703	0.292	4.17

Table 8: Random index.

N	1	2	3	4	5	6	7	8	9	10
R.I	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 9: Criteria and criteria weight.

Criteria	Criteria weight
Price	0.55
Size/volume	0.17
Extruder type	0.22
Weight	0.0703

$$\begin{aligned} C.I &= \left(\frac{\lambda\max - \mathrm{n}}{n-1}\right), \\ C.I &= \left(\frac{4.135-4}{4-1}\right), \\ C.I &= 0.045. \end{aligned} \tag{4}$$

4.3.5. Step-V. The consistency ratio (C.R) is obtained by using the following formula:

$$C.R = \left(\frac{C.I}{RI}\right). \tag{5}$$

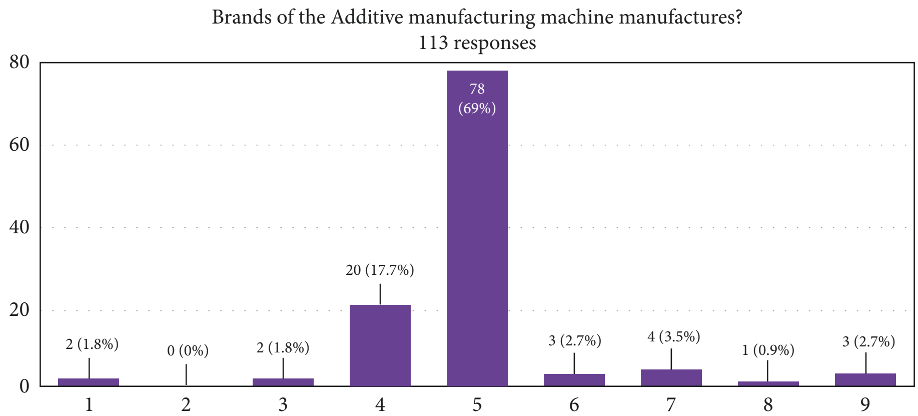

Figure 18: Respondents' importance about the brands of AM.

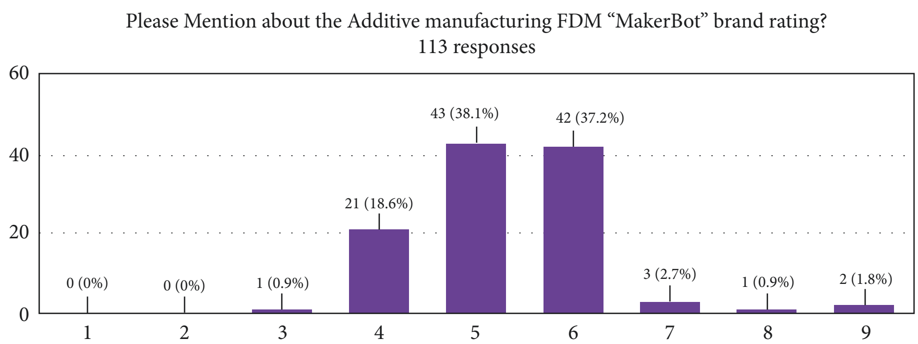

Figure 19: Respondents' importance about the MakerBot brand in AM.

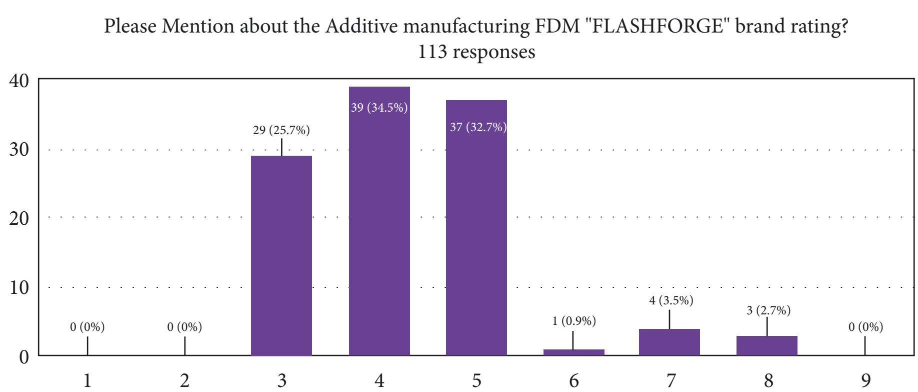

Figure 20: Respondents' importance about the Flashforge brand in AM.

Here, the R.I (random index) values are shown in Table 8. The consistency ratio value is obtained as follows:

$$C.R = \left(\frac{0.045}{0.90}\right),$$
$$C.R = 0.05, \quad (6)$$

$$C.R = 0.05 < 0.10. \quad (7)$$

Hence, the consistency ratio is reasonable and the criteria are acceptable.

Table 9 indicates each criterion weightage, and from this, the price has the most weightage of four criteria.

4.3.6. Step-VI. This step is to form the pair-wise matrix for calculating each alternative criterion weight based on each criterion.

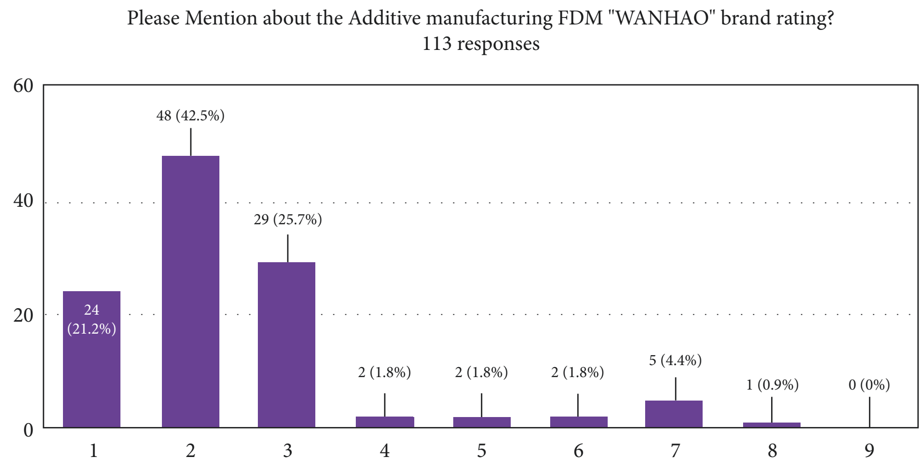

Figure 21: Respondents' importance about the WANHAO brand in AM.

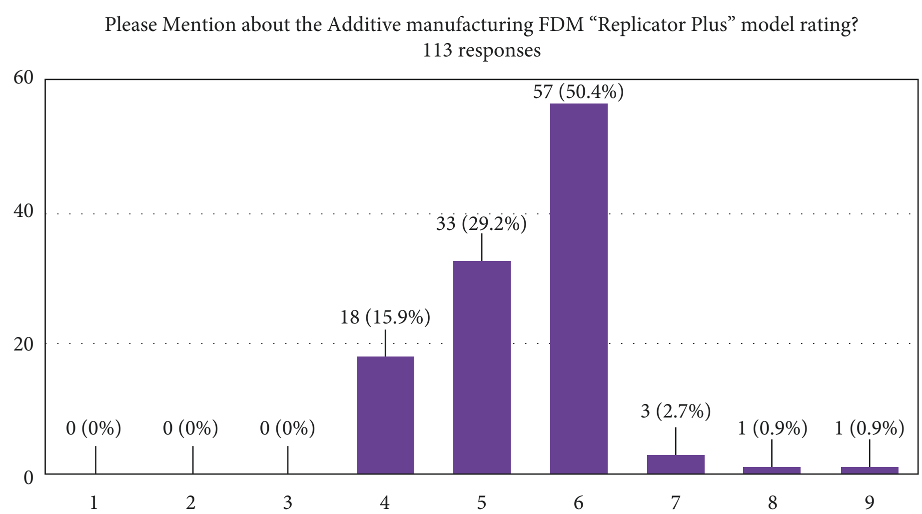

Figure 22: Respondents' importance about the Replicator Plus in AM.

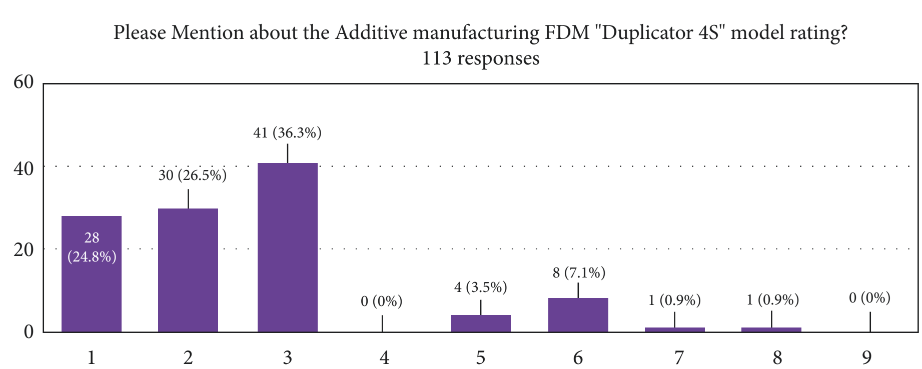

Figure 23: Respondents' importance about Duplicator 4s in AM.

Figures 18–24 represent the importance of brands and alternatives of this paper based on the standard Saaty scale. Figure 18 shows that the respondents give strong importance to the AMM brands. Moreover, Figure 19 shows the strong importance given to the MakerBot brand.

Figure 19 indicates the respondents (additive manufacturing machine user) give strong or very strong importance to the "MakerBot" brand, and Figure 20 shows the strong importance to the "Flashforge" brand.

Figure 21 indicates the respondents' (additive manufacturing machine user) opinion about the WANHAO

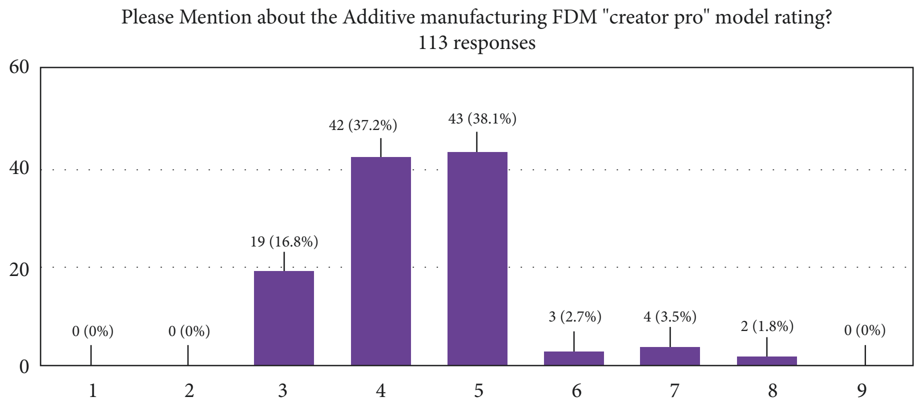

Figure 24: Respondents' importance about the Creator Pro in AM.

Table 10: Pair-wise matrix based on criterion 1.

Based on criterion 1	WANHAO Duplicator 4s	Flashforge Creator Pro	MakerBot Replicator Plus
WANHAO Duplicator 4s	1	4	5
Flashforge Creator Pro	1/4	1	1/7
MakerBot Replicator Plus	1/5	7	1

Table 11: Pair-wise matrix with total sum value of each alternative.

Based on criterion 1	WANHAO Duplicator 4s	Flashforge Creator Pro	MakerBot Replicator Plus
WANHAO Duplicator 4s	1	4	5
Flashforge Creator Pro	0.25	1	0.142
MakerBot Replicator Plus	0.2	7	1
Total sum value of column	1.45	12	6.142

brand in field of AM. The respondents (additive manufacturing machine user) give the equal importance to the WANHAO brand. The points are based on the standard Saaty scale.

Figure 22 indicates the very strong importance to the MakerBot Replicator Plus model from the respondents' (additive manufacturing machine user) responses.

Figure 23 shows the respondents' (additive manufacturing machine user) give equal importance to the "WANHAO Duplicator 4s" model. From the standard Saaty scale, 86 percent of respondents give 1–3 importance for the "WANHAO Duplicator 4s" model.

Figure 24 indicates the respondents (additive manufacturing machine user) give strong importance to the Flashforge Creator Pro model.

Based on respondents' (additive manufacturing machine user) data, the WANHAO Duplicator 4s has 1–3 importance, Flashforge Creator Pro has 3–5 importance, and the MakerBot Replicator Plus has 4–6 importance from the standard Saaty scale. Using these data, the following pair-wise matrix has been formed based on each criterion. Then, each priority value has been

Table 12: Pair-wise matrix with priority I values.

Based on criterion 1	WANHAO Duplicator 4s	Flashforge Creator Pro	MakerBot replicator plus	Priority I
WANHAO Duplicator 4s	0.689	0.33	0.814	0.611
Flashforge Creator Pro	0.172	0.083	0.023	0.093
MakerBot Replicator Plus	0.137	0.583	0.163	0.294

Table 13: Pair-wise matrix with criterion II.

Based on criterion II	WANHAO Duplicator 4s	Flashforge Creator Pro	MakerBot Replicator Plus
WANHAO Duplicator 4s	**1**	5	4
Flashforge Creator Pro	1/5	**1**	1/3
MakerBot Replicator Plus	1/4	3	**1**

Table 14: Pair-wise matrix with total sum value.

Based on criterion II	WANHAO Duplicator 4s	Flashforge Creator Pro	MakerBot Replicator Plus
WANHAO Duplicator 4s	**1**	5	4
Flashforge Creator Pro	0.2	**1**	0.33
MakerBot Replicator Plus	0.25	3	**1**
Total sum value of column	1.45	9	5.33

Table 15: Pair-wise matrix with priority II values.

Based on criterion II	WANHAO Duplicator 4s	Flashforge Creator Pro	MakerBot Replicator Plus	Priority II
WANHAO Duplicator 4s	0.689	0.555	0.75	0.665
Flashforge Creator Pro	0.138	0.111	0.062	0.104
MakerBot Replicator Plus	0.172	0.333	0.188	0.231

Table 16: Pair-wise matrix with criterion III.

Based on criterion III	WANHAO Duplicator 4s	Flashforge Creator Pro	MakerBot Replicator Plus
WANHAO Duplicator 4s	1	7	3
Flashforge Creator Pro	1/7	1	1/5
MakerBot Replicator Plus	1/3	5	1

Table 17: Pair-wise matrix with total sum value based on criterion III.

Based on criterion III	WANHAO Duplicator 4s	Flashforge Creator Pro	MakerBot Replicator Plus
WANHAO Duplicator 4s	1	7	3
Flashforge Creator Pro	0.142	1	0.2
MakerBot Replicator Plus	0.33	5	1
Total sum value of column	1.472	13	4.2

Table 18: Pair-wise matrix with priority value.

Based on criterion III	WANHAO Duplicator 4s	Flashforge Creator Pro	MakerBot Replicator Plus	Priority III
WANHAO Duplicator 4s	0.679	0.538	0.714	0.644
Flashforge Creator Pro	0.096	0.077	0.0476	0.074
MakerBot Replicator Plus	0.224	0.385	0.238	0.282

calculated, similar to the above criteria weight finding procedure.

Table 10 shows pair-wise matrix formed by the standard Saaty scale values based on the respondents' data.

Table 19: Pair-wise matrix with criterion IV.

Based on criterion IV	WANHAO Duplicator 4s	Flashforge Creator Pro	MakerBot Replicator Plus
WANHAO Duplicator 4s	**1**	5	3
Flashforge Creator Pro	1/5	1	1/2
MakerBot Replicator Plus	1/3	2	1

Table 20: Pair-wise matrix with total sum value based on criterion IV.

Based on criterion IV	WANHAO Duplicator 4s	Flashforge Creator Pro	MakerBot Replicator Plus
WANHAO Duplicator 4s	**1**	5	3
Flashforge Creator Pro	0.25	**1**	0.5
MakerBot Replicator Plus	0.33	2	**1**
Total sum value of column	1.58	8	4.5

Table 21: Pair-wise matrix with priority value IV.

Based on criterion IV	WANHAO Duplicator 4s	Flashforge Creator Pro	MakerBot Replicator Plus	Priority IV
WANHAO Duplicator 4s	0.633	0.625	0.67	0.642
Flashforge Creator Pro	0.158	0.125	0.11	0.131
MakerBot Replicator Plus	0.209	0.25	0.22	0.226

Table 11 indicates the total sum value of each alternative, and the fraction numbers are converted into a decimal number.

The pair-wise matrix in Table 12 indicates the priority I value of each alternative based on criterion I. This matrix is solved by dividing each value by the individual total sum value and sum of row value to obtain the priority I value. Here, criterion I is the price of the FDM.

Table 13 shows pair-wise matrix formed by the respondents' (additive manufacturing machine user) data based on the size/volume criteria and alternative importance from the Saaty scale.

Table 14 indicates the total sum values of each alternative, and the fraction values are converted into decimal values.

Table 15 pair-wise matrix has been solved by the same procedure in Table 12 followed for obtaining the priority II values.

Table 22: Decision matrix formation with criteria weight.

Criteria weight	0.55 Priority I	0.17 Priority II	0.22 Priority III	0.07025 Priority IV
WANHAO Duplicator 4s	0.611	0.665	0.644	0.642
Flashforge Creator Pro	0.093	0.104	0.074	0.131
MakerBot Replicator Plus	0.294	0.231	0.282	0.226

Table 23: Decision matrix with calculation.

	Priority I × criteria weight	Priority II × criteria weight	Priority III × criteria weight	Priority IV × criteria weight
WANHAO Duplicator 4s	0.336	0.113	0.142	0.0451
Flashforge Creator Pro	0.051	0.018	0.016	0.009
MakerBot Replicator Plus	0.162	0.039	0.062	0.0159

Table 24: Final decision matrix.

	Sum of row	Priority value	Rank
WANHAO Duplicator 4s	0.336 + 0.113+0.142 + 0.0451	0.6361	I
Flashforge Creator Pro	0.051 + 0.018+0.016 + 0.009	0.094	III
MakerBot Replicator Plus	0.162 + 0.039+0.062 + 0.0159	0.2789	II

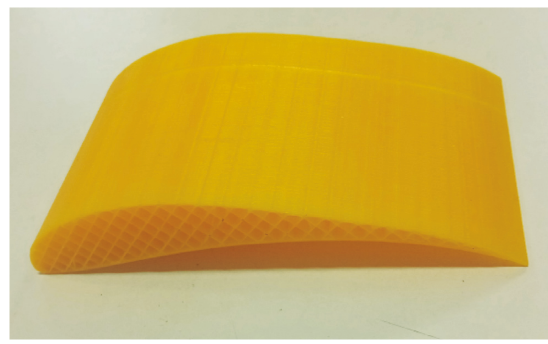

Figure 25: Construction prototype.

Figure 26: Prototype flower.

Table 16 indicates the pair-wise matrix formed by the respondents' (additive manufacturing machine user) data based on criterion III and table values from the standard Saaty scale.

Table 17 uses the similar step of Table 14 that sums each alternative value into a total sum, and Table 18 procedures are also similar to Table 15 formation procedures.

The pair-wise matrix in Table 19 is formed by the respondents' (additive manufacturing machine user) data based on criterion IV, and here, criterion IV is the weight of the machine.

Table 14 adopts a similar procedure to Table 20, and based on the criterion IV, all the machines had equal importance.

Table 21 shows the fourth priority values based on criterion IV for each different alternative.

4.3.7. Step-VII. Finally, form the decision matrix and give the rank based on the priority value by using the following procedure.

4.4. Decision Matrix. Table 22 shows the decision matrix steps using which the criteria weight and different priority values formed the final each individual value for different alternatives. These steps are executed in Table 23.

Finally, Table 24 shows the decision matrix with rank based on priority values of each alternative obtained. By the rank of different alternatives, the WANHAO Duplicator 4s is most preferable, MakerBot Replicator Plus is second preferable, and Flashforge Creator Pro is third preferable to purchase. This priority rank is only suitable for the mentioned MSME company based on the criteria such as price, size/volume, extruder type, and weight of machine.

5. Application and Case Study

The MSME company plays a very important role in this case study, and its main goal is to satisfy the customers. For this purpose, mass production is pretested by developing certain key sectors such as medical, construction, decorative, fancy, and religious doll. Therefore, the purpose of this case study is

Figure 27: Medical prototype.

Figure 28: Religious prototype.

to produce a multisectoral prototype using the selected FDM machine. Thus, we obtained the geometrical dimensions and the design required to make these products from WANHAO Duplicator 4s and started model production. In this FDM, a filament ingredient called PLA (polylactic acid) is used. Also, the products made in the sample production can be seen in the pictures shown in Figures 25–30. Through this process, it was possible to calculate the time and production cost required to produce a product. It takes about an hour to produce approximately 20 gm of material. The raw material (PLA) of this FDM contains at least 1 kg 869INR. It also sells final product that includes electricity, machine maintenance, labor, and other costs. This includes selecting remote villages and setting up production plants to receive government subsidies such as electricity bills and rent, and it minimizes the cost of the final product. Moreover, the cost of a product includes all expenses of production costs. This research has been used not only to help machine buyers choose the best machine but also to know the techniques in the manufacturing. In this case, different industrial prototypes can be possibly made in the selected WANHAO Duplicator

Figure 29: Decorative prototype.

Figure 30: Making photo.

4s. Moreover, the MSME company also acknowledges that the selected WANHAO Duplicator 4s FDM has satisfied their customers' expectation.

Figure 25 shows the construction prototype like bridge, and it has 40 gm weight. This prototype was made by using PLA material, and it take 2 hours 15 minutes as a manufacturing period. Figure 26 shows the flower prototype, and it has 50 gm weight. It was made in 2 hours 50 minutes.

Figure 27 shows the medical human skull prototype, and it has 120 gm weight and is made of PLA white filament material. The cost of white PLA filament material is 1500 INR per kilogram. This prototype was manufactured in approximately 7 hours. Figure 28 shows the religious doll prototype, and it was made in two hours only.

Table 25: Result of this research.

FDM machines	Rank
WANHAO Duplicator 4s	I
Flashforge Creator Pro	III
MakerBot Replicator Plus	II

Figure 29 shows the decorative flower pot, and it was made in 4 hours 13 min, and finally, Figure 30 shows a flower pot making photo of selected WANHAO Duplicator 4s FDM.

6. Result and Discussion

This research paper aims to help an MSME company choose the right AMM according to the AHP method. Another objective of this paper is to increase the use of 3D printing in many fields. Using AM can save factors such as minimize the production time, increase the quality, and protect the environment. The AHP method has been used to select the most suitable machine for the MSME company expectation and recommendation of WANHAO Duplicator 4s, Flashforge Creator Pro, and MakerBot replicator plus FDM machine enterprise. Also, the MSME company uses four criteria in AHP to compare all the special features of the machine of the three FDM companies mentioned. AHP is used here depending on price, size/volume, extruder type, and weight. Based on the respondents' answers, a pair-wise matrix is created and the criteria weight is determined. Moreover, the consistency index has a consistency ratio below 0.10 and it shows that the criteria are known to be correct.

Each criterion priority value is found based on the respondents' response. At this stage, the criteria importance and individual alternative importance are only obtained. The problem solver has to only form the pair-wise matrix based on the respondents' data. Priority values were found based on a number of criteria. In this paper, only four criteria were taken to select the FDM. However, "n" number of criteria and alternatives may be taken for AHP. After successfully finding the priority values for each criterion, further ranking is done by the priority value based on the decision matrix. Table 25 shows the rank of each different FDM; from this observation, WANHAO Duplicator 4s is the most suitable machine to the MSME company. Moreover, prototype models of various fields are prepared and tested by the selected machine through an application case study. This case study ensures the right machine has been selected by this research. The case study also shares the raw material, time, cost of production, and other techniques required to make a product. This proposed strategy is not only valuable but also helps future researchers choose the right machine from a variety of machines.

7. Conclusion

AM is capable of introducing new designs to the market, and this characteristic has the potential to transform AM into a long and sustainable manufacturing sector. The WANHAO Duplicator 4s was selected for purchase after several stages of research among the three machines recommended by the decision-maker MSME. The AHP method of MCDM is used here, and the WANHAO Duplicator 4s is selected from the three different FDM machines. This research site helps to choose new production methods and make decisions easier for decision-makers. In all fields, customers are the king of business and AM production is set to meet their expectations. Any geometrical complex materials can be produced very simply by AM. In the future, this study will solve the material and machinery used to produce by the fuzzy techniques. Moreover, different MCDM tools will be used to find the same data for validating this model.4232

Data Availability

The data that support the findings of this study are available from the corresponding author (Dr. Wubishet Degife Mammo) on request. The data are not publicly available due to privacy concerns.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Abbreviations

AM: Additive manufacturing
AMM: Additive manufacturing machine
AHP: Analytical hierarchy process
MCDM: Multicriteria decision-making
CM: Conventional manufacturing
FAHP: Fuzzy analytical hierarchy process
TOPSIS: Technique for order of preference by similarity to ideal solution
MSME: Micro, small, and medium enterprise
DEMATEL: Decision-making trial and evaluation laboratory
STL: Standard triangle language
OBJ: Object file
INR: Indian rupee.

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