# Additive Manufacturing Process Selection Using MCDM

**Vishwas Dohale, Milind Akarte, Shivangni Gupta, and Virendra Verma**

**Abstract** Additive manufacturing (AM) has huge benefits over traditional manufacturing, viz. cost saving, lesser product development time and lead time. AM easily produces complex geometry. However, selecting the right AM process/machine compatible for part as per customers' specification and manage manufacturability and functionality is a critical issue. This study uses a multi-criteria decision-making (MCDM) methodology for deciding the most suitable AM process that is presented. For this, 17 criteria under five group criteria are used.

**Keywords** Additive manufacturing · Process selection · AHP · 3D printing

## 1 Introduction

Additive manufacturing (AM) has been introduced in the 1980s for producing prototypes and models [1]. It was invented to manufacture a three-dimensional object through computer-aided design (CAD). Using data of 3D model, AM joins materials layer by layer to produce objects [1]. AM has been defined as, "the use of a computer-aided design (CAD)-based automated additive process to construct parts that are used directly as finished products or components" [2]. AM produces complex customized parts at rapid pace and significantly provides the benefits like low inventory turnover, minimum time to market, low wastage of material and higher flexibility [1]. Selecting a right process/machine for producing such a complex part through

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AM always remains a tedious task. To address this issue, the focus of the current study is to develop a framework for evaluating most suitable AM process/machine for producing parts.

## 2 Literature Review

The problem of determining the most suitable AM process has received a huge attention and addressed by researchers in different ways using different methodologies [3]. Some of them includes question table and comparison chart [4], rule-based expert system [5], modified TOPSIS [6], fuzzy synthetic evaluation with experts system [7], graph theoretical approach [8], AHP [9], fuzzy logic and artificial neural network [10]. Despite having huge literature on AM process determination, as far as authors knowledge, there is a lack of literature which has discussed and used the fuzzy representation for objective criteria. In this article, a rating approach of AHP is used to evaluate subjective criteria while the fuzzy representation is used for objective criteria [11] to solve the problem under study.

## 3 Research Methodology

Identification of AM process, most compatible for a part as per customer requirement and optimizing manufacturability and functionality simultaneously is a crucial task. So, the study is focused, "to select additive manufacturing process/machine for manufacturing a particular customer required part." A MCDM approach is used, and the overall methodology is adopted from [11] for solving the problem. 17 criteria consisting of seven subjective, and 10 objective are identified through the literature [8, 9] which are shown in Table 1. Subjective criteria are evaluated using rating approach of AHP, while fuzzy representation method is used for evaluating objective criteria. The relative importance of all criteria is evaluated through AHP.

**Table 1** Categorization of criteria

| | |
|---|---|
| Subjective (7) | Color, size, maximum dimension, part complexity, shape complexity, resistance to heat, electrical conductivity |
| Objective (10) | Dimensional accuracy, surface roughness, running cost, equipment cost, material cost, post-processing cost, scan speed, overhead time, post-processing time, mechanical strength |

## 3.1 AHP

Analytical hierarchy process (AHP) is the MCDM approach of decision making comprising perception, feelings, judgment and memories by creating a hierarchy involving multiple levels to divide a complex problem into sub-problems [12, 13]. AHP helps to carry a pairwise comparison of the criteria on the scale of 1–9 at each level [12, 13]. The problem considered in this study is divided into five levels as shown in Fig. 1. The study followed [12, 13] guidelines for conducting AHP as: (a) developing hierarchy of criteria, sub-criteria and alternatives; (b) conducting pairwise comparison at each level of hierarchy; (c) determining the relative weights for criteria and alternatives and consistency ratio; (d) performance evaluation of each alternative against each criterion. The relative/local and global weights of each criterion are evaluated from AHP and shown in Fig. 1. The sample calculation of AHP for a sub-criteria under technology criterion is given in Table 2. The global weight of the criterion is calculated by multiplying local weight of criterion and the local weight of group criterion it belongs. Further, the criteria are rated on five-point Likert scale. The importance of the individual components on the sub-criteria is identified through experts by rating it on five-point Likert scale (very high, high, medium, low, very low) as given in [14]. The normalized weights of rating scale are

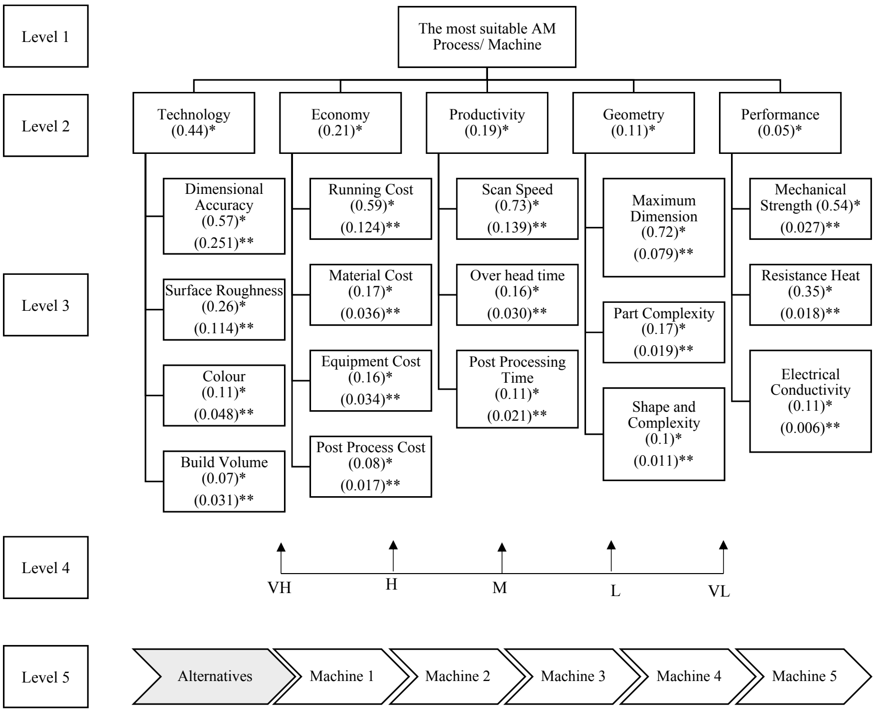


**Fig. 1** Hierarchy of criteria for AHP (*: local weights of criteria, **: global weight of criteria)

**Table 2** Evaluation of sub-criteria under technology criterion using AHP

| Sub-criteria | Dimensional accuracy | Surface roughness | Color | Size | Local weight |
|---|---|---|---|---|---|
| Dimensional | 1.00 | 5.00 | 4.00 | 7.00 | 0.57 |
| Surface roughness | 0.20 | 1.00 | 6.00 | 3.00 | 0.26 |
| Color | 0.25 | 0.17 | 1.00 | 2.00 | 0.11 |
| Size | 0.14 | 0.33 | 0.50 | 1.00 | 0.07 |
| C.R. | | | | | 0.04 |

**Table 3** Rating values [14]

| Rating scale | VH | H | M | L | VL | Weight |
|---|---|---|---|---|---|---|
| Very high (VH) | 1 | 3 | 5 | 7 | 9 | 0.51 |
| High (H) | 1/3 | 1 | 3 | 5 | 7 | 0.26 |
| Moderate (M) | 1/5 | 1/3 | 1 | 3 | 5 | 0.13 |
| Low (L) | 1/7 | 1/5 | 1/3 | 1 | 3 | 0.06 |
| Very low (VL) | 1/9 | 1/7 | 1/5 | 1/3 | 1/5 | 0.04 |
| C.R. | | | | | | 0.03 |

measured using AHP shown in Table 3. The objective criteria are evaluated using fuzzy approach, explained in Sect. 3.2. Finally, the overall score obtained by each alternative is calculated as:

$$S_a = \sum_{i=1}^{I} \sum_{j=1}^{J} W_i w_{ij} P_{ija} \tag{1}$$

$S_a$ overall score of the $a$th alternative;
$W_i$ weight of the ith group criteria;
$w_{ij}$ local weight of $j$th criterion from $i$th group;
$P_{ija}$ is the performance of the $a$th supplier for the $j$th criterion of the $i$th group;
$J$ is the total number of criteria in $I$ groups.

The performance of the alternatives is evaluated using AHP. For doing this, the values for subjective and objective (qualitative and quantitative) criteria are taken from the literature [8, 9, 15, 16]. However, due to space constraint, a sample data and calculations of subjective and objective criteria are provided in Tables 4 and 5.

The alternatives considered in this study are:

| | | | | |
|---|---|---|---|---|
| Machine 1 (M1) | Machine 2 (M2) | Machine 3 (M3) | Machine 4 (M4) | Machine 5 (M5) |

**Table 4** Sample data and performance evaluation of alternatives—objective criteria

| Sub-criteria (objective) | Local weight ($w_i$) | Global weight ($GW_i$) | Sample data | | | | | Performance evaluation (fuzzy method) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | M1 | M2 | M3 | M4 | M5 | M1 | M2 | M3 | M4 | M5 |
| Dimensional accuracy (μmm) | 0.57 | 0.251 | 120 | 150 | 125 | 185 | 95 | 1 | 0 | 0.49 | 0 | 1 |
| Surface roughness (μm) | 0.26 | 0.114 | 6.5 | 12.5 | 21 | 20 | 3.5 | 0 | 0.78 | 0 | 0 | 0 |

**Table 5** Sample data and performance evaluation of alternatives—subjective criteria

| Sub-criteria (subjective) | Local weight ($w_i$) | Global weight ($GW_i$) | Sample data | | | | | Performance evaluation (rating method) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | M1 | M2 | M3 | M4 | M5 | M1 | M2 | M3 | M4 | M5 |
| Color | 0.11 | 0.048 | L | VL | L | L | L | 0.003 | 0.002 | 0.003 | 0.003 | 0.003 |
| Shape complexity | 0.1 | 0.011 | H | VH | H | M | VH | 0.003 | 0.006 | 0.003 | 0.001 | 0.006 |

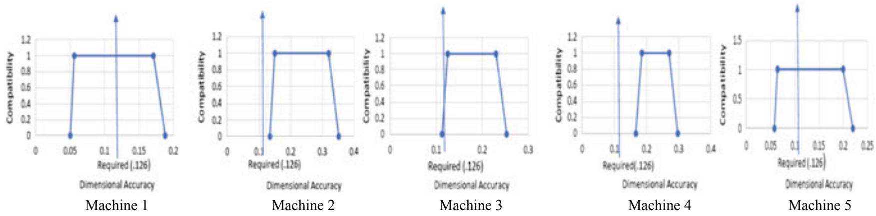


**Fig. 2** Fuzzy representation of alternatives for dimension accuracy criterion

## *3.2 Fuzzy Representation*

In this approach, a graph plotted in which *Y*-axis represents the capabilities with values ranging from 0 to 1, and the *X*-axis represents evaluation criterion with its value. A tolerance of 10% is considered for getting the result [11, 17, 18]. In this article, the fuzzy representation helps to measure the level of compatibility between the customers' requirement for a specific part. Here, in this case, component A with the following specification is given. Further, based on the values, the graphs of fuzzy representation for all criteria are plotted. A sample graph of dimension accuracy criteria for all alternatives is shown in Fig. 2.

| Part | Volume (cubic inch) | Surface area (sq. inch) | Dimension mm ($X * Y * Z$) | Dimension accuracy (μm) | Surface finish (μm) | Tensile strength (MPa) |
|---|---|---|---|---|---|---|
| Component A | 0.47 | 11.2 | 33.4 * 16.8 * 46 | 0.126 | 11.93 | 40.75 |

# 4 Result and Discussion

As per the AHP results shown in Table 6, the machine 3, has obtained the highest overall performance value, i.e., 0.268, whereas machine 1 received the least value, i.e., 0.168.

**Table 6** Overall performance score

| Machines | Overall performance score |
|---|---|
| M1 | 0.162 |
| M2 | 0.206 |
| M3 | 0.268 |
| M4 | 0.156 |
| M5 | 0.173 |

## 5 Conclusion

The study helps to identify the most compatible AM machine for a given part. Five different machines are considered in this study. In this study, a robust methodology is developed to accommodate dynamics in the criteria. At first, the relative weights of both subjective and objective criteria are calculated through AHP. Then, further the performance rating of alternatives is determined using AHP to find compatible AM machine regardless of part criteria. Further, the part specifications, i.e., objective criteria, are matched with the machine's criteria value using fuzzy representation for providing the compatibility score to specific machine concerning particular criteria to address the purpose of study.

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