

# Integrated AHP and fuzzy TOPSIS Approach for the Selection of a Rapid Prototyping Process under Multi-Criteria Perspective

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## Abstract

Rapid prototyping (RP) is a promising technology that has been implemented in many spheres of industry, particularly in the area of new product development due to its unique characteristics of fabricating functional prototypes timely and efficiently. Recent years have seen various rapid prototyping (RP) processes such as stereolithography (SLA), selective laser sintering (SLS), fused deposition modelling (FDM), and laminated object manufacturing (LOM) which can fabricate three dimensional (3D) solid models directly from the computer aided design (CAD) data without any tooling and human intervention. However, selection of an optimal RP system for the end use of a part is a tedious work due to involvement various criteria or objectives in the decision making process and it is often necessary to compromise among possibly conflicting factors. Thus, the multiple criteria decision making (MCDM) becomes a useful approach to solve this kind of problem. This study proposes an integrated Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method for the selection of rapid prototyping system that involves multiple, usually conflicting attributes. The proposed method enables decision analysts to better understand the complete evaluation process and provide more accurate, effective, and systematic decision support tool.

*Keywords: Rapid Prototype process selection, Multi criteria decision-making, AHP, Fuzzy TOPSIS*

## 1. Introduction

Rapid prototyping (RP) poses an emerging alternative to conventional manufacturing process during concept evaluation, design optimization, rapid tooling, and lately for direct production of customer driven products. It has emerged as a key enabling technology for the fabrication of highly customized, functionally gradient materials without the use of tooling and human intervention. RP relates to the rapidly growing number of automated machines or processes such as stereolithography (SLA), selective laser sintering (SLS), fused deposition modelling (FDM), laminated object manufacturing (LOM), and three dimensional printing (3D Printing) which enable fabrication of physical objects (3D) directly from CAD data sources. Simplicity of operation, durability of parts, flexible and fast way to create test parts prior to production have resulted in its widespread applications not only in prototyping but also for making functional parts. (Yan et al. 2009)

Due to the advent of capital intensive RP machines the need of selecting most appropriate RP process to

meet users' requirements from among a number of RP systems has become increasingly important. However, determining the best RP system from feasible ones is a critical issue because the improper selection may adversely affect profitability. Nevertheless, the best selection depends on many criteria which interact in a complex way making the judgment process difficult. Selection of an appropriate process requires a sound understanding of the interactions between the part quality, property, cost, build envelope, build time (speed) and other concerns. A tool that can identify the optimum process to meet specified requirements will therefore be immensely important to the designer as well as to the manufacturer of prototypes.

Masood and Soo (2002) have developed a rule based expert system known as IRIS intelligent RP system selector for the selection of RP system from all the commercial available RP systems. The system is designed to assist novice as well as experienced RP users in manufacturing and educational sectors to

quickly select the most appropriate RP system to suit their requirements. This selector program was not developed to select the best RP system that suits the end use of a given part rather it was design to select the right RP system that a purchaser would like to choose based on given rules. By using rule-based knowledge it is difficult to order the ranking of the most suitable RP systems according to weight factors of attributes. Rao and Padmanabhan (2007) have proposed a selection method based on graph theory and matrix approach for selection of a suitable RP process among a large number of available alternatives for prototyping a given product or part. This method considers RP process attributes and their interrelations to evaluate RP process and selection index are used for ranking of RP processes. Bibb (1999) has developed a computer based RP design advice system based on certain decision and calculation rules to help small manufacturing enterprises in their in product development process. The decision rules use the input data to select the most suitable RP system for a given solution whereas Calculation rules are used to compute the build time and build cost for each RP process. However, the decision rules take only several criteria into account while selecting the best RP process. Bauer et al. (1996) have developed the rapid prototyping system selector (a software tool) that helps in finding the best RP process to manufacture a physical prototype. This program tool is based on the relational database management system MS Access. It aimed to help RP users, designers to choose the best combination of materials and machines to fabricate a prototype rather than to select the most suitable RP process based on specific selection criteria. Though in this approach, a user is required to specify the details of both the RP machines and the materials to be used simultaneously many complex parameters should be specified and inputted. Phillipson (1997) has developed an RP advisor for choosing an appropriate RP process using multi criteria optimization theory. However, the system did not consider various criteria such as material property and had the limitation in calculation and ease of use. Benchmarking of major rapid prototyping technologies is made by Schmidt (1994). Byun and Lee (2004) have presented a methodology for selecting the RP process most appropriate for the end use of the part when multiple attributes includes either imprecise (or uncertain) and crisp data. A modified TOPSIS approach was used as a decision support system to rank the preference order of RP processes for a particular product in reducing cost and technical problems. Recently, Manguia et al. (2011) proposed an advice systems for selection of rapid prototyping (RP)/manufacturing (RM) systems as

alternative processes for low-volume production in the machinery and equipment design sector. assessment of knowledge sharing capabilities has been done. Mahapatra et al. (2013) jointly used grey relational analysis and fuzzy TOPSIS method for selection of RP process. The advantage of using grey theory over fuzzy theory is that grey theory considers the condition of the fuzziness, i.e., it can deal flexibly with the fuzziness situation. Differently from other studies, this study uses a methodology which combines AHP and fuzzy TOPSIS methods to select RP systems among five alternatives against five attributes.

The remainder of this paper is organized as follows: Section 2 and 3 briefly describes the proposed methods. In Section 4, proposed model for RP process selection is presented and the stages of the proposed approach are explained in detail. In Section 5, conclusions and suggestions are discussed.

## 2. Analytic Hierarchy Process (AHP)

Analytic hierarchy process (AHP) was developed in the 1970s by Thomas Saaty is a highly outstanding management tool for complex multi-criteria decision problems. The approach can be used to help decision-makers for prioritizing alternatives and determining the optimal alternative using pair-wise comparison judgments. Weighting the criteria by multiple experts avoids the bias decision making and provides impartiality (Dagdeviren, 2009). In this paper, we have used the following steps of AHP (Saaty, 1980) to help us to measure the relative importance or the weighted values of several criteria.

1. Define the problem and determine the criteria.
2. Structure the decision hierarchy taking into account the goal of the decision.
3. Develop a pair wise comparison matrix in which the set of elements is compared with itself (size  $n \times n$ ) by using the fundamental scale of pair-wise comparison shown in Table 1.
4. Assign the reciprocal value in the corresponding position in the matrix. Total  $n(n-1)/2$  number of comparison required to develop the set of matrices in step 3.
5. The hierarchy synthesis function is used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.
6. After all the pair wise comparisons are completed the consistency of the comparisons is assessed by using the Eigen value,  $\lambda$ , to calculate a consistency index,

$$CI : (\lambda_{\max} - n) / (n-1)$$

Where  $n$  is the matrix size.

7. The final consistency ratio (CR) is calculated as the ratio of the CI and the random index (RI), as indicated.

$$CR=CI/RI$$

Where R.I. Stands for Random Consistency Index.

Saaty(1980) suggests that the C.R. is acceptable if it does not exceed 0.10. If the CR is greater than 0.10, the judgment matrix should be considered inconsistent. To obtain a consistent matrix, the judgments should be reviewed and repeated.

**Table1 Fundamental scale of pair-wise comparison for AHP**

Definition	Intensity of importance
Equally important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9
Intermediate values	2,4,6, & 8

### 3. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was first presented by Hwang and Yoon (1981), for solving multiple criteria decision making (MCDM) problems. It is based upon the concept that the chosen alternative should have the shortest Euclidian distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS). The positive-ideal solution is a solution that maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria. In the classical TOPSIS method, the weights of the criteria and the ratings of alternatives are known precisely and crisp values are used in the evaluation process. However, under many conditions crisp data are inadequate to model real-life decision problems. Therefore, the fuzzy TOPSIS method is proposed where the weights of criteria and ratings of alternatives are evaluated by linguistic variables represented by fuzzy numbers to deal with the deficiency in the traditional TOPSIS. The algorithm of this method can be described as follows:

Step 1: Generating feasible alternatives, determining the evaluation criteria, and setting a group of decision

makers. Assume that there are m alternative, n evaluation criterion, and k decision maker.

Step 2: Choose the appropriate linguistic variables for the importance weight of the criteria and the linguistic ratings for alternatives with respect to criteria.

Step 3: Aggregate the weight of criteria to get the aggregated fuzzy weight  $\tilde{w}_j$  of criterion  $C_j$  and obtain the aggregated fuzzy rating  $\tilde{x}_{ij}$  of alternative  $A_i$  under criterion  $C_j$ .

$$\tilde{x}_{ij} = \frac{1}{K} [\tilde{x}_{ij}^1(+) \tilde{x}_{ij}^2(+) \dots (+) \tilde{x}_{ij}^K] \quad (1)$$

$$\tilde{w}_j = \frac{1}{K} [\tilde{w}_j^1(+) \tilde{w}_j^2(+) \dots (+) \tilde{w}_j^K] \quad (2)$$

Step 4: Construct the fuzzy decision matrix.

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \dots & \tilde{x}_{nn} \end{bmatrix} \quad (3)$$

$$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n] \quad (4)$$

Where  $\tilde{x}_{ij}, \forall_{i,j}$  and  $\tilde{w}_j, j=1,2,\dots,n$  are linguistic variables.

Step 5: Normalize fuzzy decision matrix denoted by  $\tilde{R}$ .

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad (5)$$

$$\text{Where } \tilde{r}_{ij} = \left( \frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right) \quad (6)$$

$$c_j^* = \max_i c_{ij}$$

Step 6: Construct the weighted normalized fuzzy decision matrix using the equation

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n}, i=1,2,\dots,m \quad j=1,2,\dots,n \quad (7)$$

$$\text{where } \tilde{v}_{ij} = \tilde{r}_{ij} (\cdot) \tilde{w}_j.$$

Step 7: Calculate fuzzy positive-ideal solution (FPIS,  $A^*$ ) and fuzzy negative-ideal solution (FNIS,  $A^-$ ) as:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*) \quad (8)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-) \quad (9)$$

Where  $\tilde{v}_j^* = (1,1,1)$  and  $\tilde{v}_j^- = (0,0,0), j=1,2,\dots,n$

Step 8: Calculate the distance of each alternative from  $A^*$  and  $A^-$  using the following equations:

$$d_i^* = \sum d(\tilde{v}_{ij}, \tilde{v}_j^*), i = 1, 2, \dots, m \quad (10)$$

$$d_i^- = \sum d(\tilde{v}_{ij}, \tilde{v}_j^-), i = 1, 2, \dots, m \quad (11)$$

Step 9: Calculate closeness coefficient.

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, i = 1, 2, \dots, m \quad (12)$$

Step 10: Based on the value of closeness coefficient of each alternative, rank the alternatives in descending order.

#### 4. Numerical application of Proposed Model

The proposed model is applied on a real world RP process selection problem, consist of three phases: (1) Identification of alternatives and criteria, (2) AHP computation, (3) evaluation of alternatives with fuzzy TOPSIS and determination of the final rank. Schematic diagram of the proposed model is provided in the Fig. 1

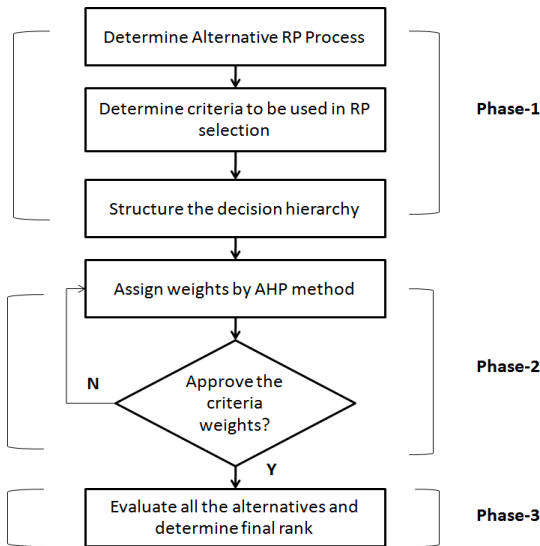


Figure 1 Schematic diagram of the proposed model for RP system selection

In the first phase, five RP systems such as laminated object manufacturing (LOM 1015), selective laser sintering (SLS2500), 3-D printing (Quadra), Stereolithography (SLA3500) and Fused Deposition Modeling (FDM8000) are chosen as alternative A1, A2, A3, A4, A5 and compared addressing to various criteria. Evaluation criteria includes only the

major attributes that significantly affect the performance of an RP system such as Dimensional accuracy (C1), surface quality (C2), part cost (C3), build time (C4) and material properties (C5). Here C1 and C4 are benefit attributes, the greater values being better where C3 and C2 are cost attributes, the smaller values are better. Criteria to be considered in the selection of RP process are determined by literature review and data obtained by different user group such as service bureau, governmental institutes and industry users. The hierarchical structure to select the best RP process is shown in Fig 2.

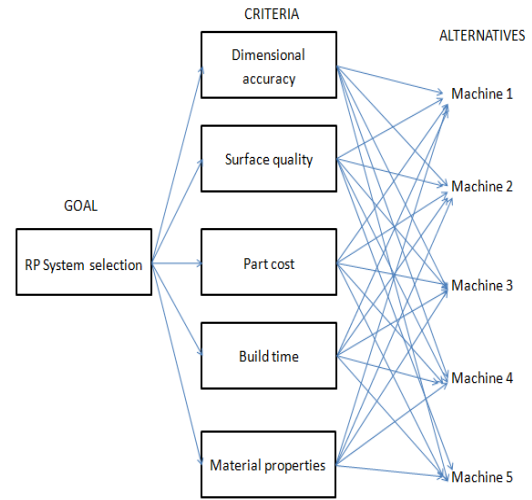


Figure 2 Hierarchical structure for RP system selection

After forming the decision hierarchy for the problem, the weights of the criteria to be used in evaluation process are calculated using AHP method in the second phase. In this phase, the experts are given the task of forming individual pairwise comparison matrix by using the scale given in Table 1. Geometric means of these values are found to obtain the pair-wise comparison matrix on which there is a consensus. The results obtained from the computations based on the pairwise comparison matrix provided in Table 2, are presented in Table 3.

Table 2 Pair wise comparison matrix for criteria

	C1	C2	C3	C4	C5
C1	1.0	0.3	0.4	0.5	0.4
C2	2.1	1.0	0.2	1.9	2.4
C3	1.0	0.2	1.0	0.3	3.0
C4	2.3	3.0	0.3	1.0	0.4
C5	1.7	3.2	2.3	3.0	1.0

**Table 3 Results obtained with AHP**

Criteria	Weights (w)	$\lambda_{max}$ , CI, RI	CR
C1	0.077	$\lambda_{max} = 5.1793$	0.04
C2	0.210	CI=0.044825	
C3	0.170	RI=1.12	
C4	0.191		
C5	0.351		

Consistency ratio of the pair wise comparison matrix is calculated as  $0.04 < 0.1$ . So the weights are shown to be consistent and they are used in the selection process. Using the criteria weights calculated by AHP (Table 5) in this step, the Weighted Evaluation Matrix is established with Eq. (7). The resulting fuzzy weighted decision matrix is shown in Table 4.

**Table 4 Weighted evaluation for the alternatives**

	C1	C2	C3	C4	C5
A1	(0.000, 0.015, 0.031)	(0.168, 0.210, 0.210)	(0.034, 0.068, 0.102)	(0.076, 0.115, 0.153)	(0.070, 0.140, 0.211)
A2	(0.015, 0.031, 0.046)	(0.084, 0.126, 0.168)	(0.102, 0.136, 0.170)	(0.115, 0.153, 0.191)	(0.140, 0.211, 0.281)
A3	(0.015, 0.031, 0.046)	(0.126, 0.168, 0.210)	(0.068, 0.102, 0.136)	(0.038, 0.076, 0.115)	(0.140, 0.211, 0.281)
A4	(0.046, 0.062, 0.077)	(0.000, 0.042, 0.084)	(0.136, 0.170, 0.170)	(0.076, 0.115, 0.153)	(0.070, 0.140, 0.211)
A5	(0.031, 0.046, 0.062)	(0.126, 0.168, 0.210)	(0.000, 0.034, 0.068)	(0.153, 0.191, 0.191)	(0.211, 0.281, 0.351)

After a weighted normalized fuzzy decision matrix is formed, fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) are determined as  $v_i^* = (1, 1, 1)$  and  $v_i^- = (0, 0, 0)$  for benefit criterion,  $v_i^* = (0, 0, 0)$  and  $v_i^- = (1, 1, 1)$  for cost criterion. Then the distance of each alternative from FPIS and FNIS with respect to each criterion are calculated by using Eq. (10) and Eq. (11). Finally calculation of closeness coefficient for the alternatives is done using Eq. (12) and the results of fuzzy TOPSIS analyses are summarized in Table 5.

**Table 5 Fuzzy TOPSIS results**

Alternative	$d_i^*$	$d_i^-$	$CC_i$
A1	2.92	2.70	0.480
A2	2.69	2.96	0.524
A3	2.84	2.80	0.496
A4	2.73	2.96	0.520
A5	2.75	2.93	0.516

Based on the closeness coefficient of five alternatives, the ranking order of three alternatives is determined as  $A2 > A5 > A4 > A3 > A1$ .

### 5. Conclusion

Selection of the most appropriate RP process to meet users' requirements has become increasingly important for firms to obtain competitive advantage. To achieve this goal, decision makers (DM) should apply an effective method and select suitable criteria for RP process selection. This paper proposed a novel method, which integrates AHP and fuzzy TOPSIS, for selecting the best RP processes. AHP is used to determine the weights of the criteria, while fuzzy TOPSIS is employed to determine the priorities of the alternatives. Similar calculations are done for the other alternatives and the results of fuzzy TOPSIS analyses are summarized in Table 5. Based on closeness co-efficient values, the ranking of the alternatives in descending order are A2, A5, A4, A3 and A1. Proposed model results indicate that A2 is the best alternative with CC value of 0.526. Although the model was developed and tested for use in RP process selection problem, it can also be used with slight modifications in other decision-making problems like supplier selection, weapon selection for different industry. Mathematical models can also be combined with the proposed model to improve its performance and is one of the directions in our future research.

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