Application of improved complex proportional assessment (COPRAS) method for rapid prototyping system selection

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Abstract
Purpose – The purpose of this paper is to demonstrate the methodology of a decision-making method for selection of rapid prototyping process and comparison of it with previously developed methods.
Design/methodology/approach – Here in this work, the methodology of improved complex proportional assessment (COPRAS) method is used which can handle even qualitative data for attributes.
Findings – The proposed methodology is useful and can be applied to any kind of decision-making situation.
Originality/value – The proposed method provides more effective results as compared to other methods and with a simple flow of analysis.

Keywords Optimization techniques, Rapid prototyping, Computer aided manufacturing

Paper type Research paper

Introduction

To satisfy the quality standards and challenges in the modern manufacturing processes, the industries has to select best available design, process planning, machine tool, materials, welding process, inspection system, etc. As the choice of suitable alternative is affected by various attributes, the process of decision making is not an easy task (Rao, 2007).

In the manufacturing process, the raw material of law value is transformed into high value products by number of processes. The suitable selection of alternatives in term of strategies, design, process, material, etc. from available alternatives is often economically essential. The manufacturing industries have to bring the change frequently to meet the demand of customers.

There have been lots of changes and innovations in the manufacturing area in recent years. Many latest technologies like robotics, flexible manufacturing systems, rapid prototyping (RP), etc. are developed by today's manufacturing. Research and development is also being carried out to develop new products with diverse attributes.

Decision-makers working in industry have to consider various characteristics of alternative like economical, esthetics, serviceability, technical details, etc., and based on this, selection of suitable alternative is possible.

The aim of any selection process is to identify best available choice by considering all the attributes of that choice. Rao (2007) discussed various decision-making situations and applications of some decision-making methods. Multiple attribute decision analysis has been studied for helping decision-makers to make their final decisions in multiple attribute decision-making (MADM) problems. This paper aims to describe a simple, systematic and logical method for decision making known as complex proportional assessment (COPRAS) method to make decision in manufacturing field.

COPRAS is in the category of MADM methods. Zavadskas (1987), Zavadskas and Kaklauskas (1996) used the COPRAS method for selecting alternatives based on its terms of significance and utility degree. The success of the methodology is basically due to its simplicity and to its particular friendliness of use. However, only a few successful applications of COPRAS method have been reported in literature in various fields for decision making such as construction (Zavadskas *et al.*, 2008), sustainability evaluation (Viteikiene and Zavadskas, 2007), buildings construction, road design (Zavadskas and Antucheviciene, 2007) and education (Datta *et al.*, 2009). Most of the people have not considered the qualitative criteria of the alternatives. The improved COPRAS method is described here.

Improved COPRAS method

To achieve the ranking of alternatives, it requires to have the value of each attributes and their values and to use a decision-making method for evaluating the alternative to meet the functional needs. The attribute data available may be quantitative or qualitative. When the method was developed, it has considered only qualitative criteria. In practice, it may not possible to obtain quantitative data for some attributes, and the data may be available in qualitative or linguistic terms, i.e.

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corrosion resistance, welder skill required, etc. In such cases, a judgment from fuzzy conversion scale can be used to convert the data into quantitative data. The value of the attributes can be converted into some linguistic terms, and then, it can be concerted into suitable crisp score. A logical approach, based on the work of Chen and Hwang (1992), had been presented for these conversions. This presented approach converts the qualitative term in fuzzy number and then into crisp score.

The various steps of improved COPRAS method are as given below:

Step 1: Find out the alternatives available for the choice and also list down the various criteria considered based on the requirements.

Step 2:

1 Prepare a table and put the values of each attribute with respect all the alternatives considered.
2 The weights of relative importance of the attributes can be find out by using analytic hierarchy process (AHP) method (Saaty, 2000), or the decision maker can assign the weights by own preference.
COPRAS calculations for final ranking

Step 3: The various steps for COPRAS method are as given below:

1 The first step is to prepare the table or matrix:

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \vdots & \vdots & \dots & \vdots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix} \tag{1}$$

where n is the total number of alternatives and m number of attributes considered.

2 Now normalize the data available. Normalization of matrix can be done by using the following formula:

$$\overline{Xij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \qquad (i = 1, 2 \dots n \text{ and } j = 1, 2 \dots m) \tag{2}$$

In equation (2), j refers the attribute and i the alternative. After this step, the normalized decision-making matrix can be presented as:

$$\overline{X} = \begin{bmatrix} \overline{x_{11}} & \overline{x_{12}} & \dots & \overline{x_{1m}} \\ \overline{x_{21}} & \overline{x_{22}} & \dots & \overline{x_{2m}} \\ \vdots & \vdots & \dots & \vdots \\ \overline{x_{n1}} & \overline{x_{n2}} & \dots & \overline{x_{nm}} \end{bmatrix} \tag{3}$$

3 In this step, the weighted normalized matrix is prepared by multiplying the value of weights of each alternative with respect to relative normalize value. The following formula can be used for it.

$$\hat{X}_{ij} = \overline{X_{ij}} * W_j \qquad (i = 1, 2 \dots n \text{ and } j = 1, 2 \dots m.) \tag{4}$$

After this step, the weighted normalized matrix can be given by:

$$\hat{X} = \begin{bmatrix} \hat{x}_{11} & \hat{x}_{12} & \cdots & \hat{x}_{1m} \\ \hat{x}_{21} & \hat{x}_{22} & \cdots & \hat{x}_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ \hat{x}_{n1} & \hat{x}_{n2} & \cdots & \hat{x}_{nm} \end{bmatrix} \tag{5}$$

4 Calculate sums Pj of beneficial attributes, means higher value is desirable for all alternatives:

$$P_j = \sum_{i=1}^{k} \hat{X}_{ij} \tag{6}$$

In equation (6), k shows the total number of beneficial attributes.

5 Calculate sums Rj of non-beneficial attributes for all the alternatives:

$$R_j = \sum_{i=k+1}^{m} \hat{X}_{ij} \tag{7}$$

Here $(m - k)$ is number of attributes non-beneficial attributes for which minimum value is desired.

6 Determining the minimal value of Rj :

$$R_{min} = min_j R_j; \qquad j = 1, 2, 3 \dots m. \tag{8}$$

7 Calculation of the relative weight of each alternative Q_j:

$$Q_j = P_j + \frac{R_{\min} \sum_j^n R_j}{R_j \sum_{j=1}^{n} \frac{R_{\min}}{R_j}} \tag{9}$$

Equation (9) can be written as follows:

$$Q_j = P_j + \frac{\sum_{j=1}^{n} R_j}{R_j \sum_{j=1}^{n} \frac{1}{R_j}} \tag{10}$$

8 Determination of the optimality criterion K:

$$K = max_j Q_j; \qquad j = 1, 2 \dots n. \tag{11}$$

9 Calculation of the utility degree of each alternative:

$$N_j = \frac{Q_j}{Q_{max}} 100\% \tag{12}$$

where Qj and $Qmax$ are the significance of projects obtained from equation (10):

The ranking is determined by examining utility degree calculated from equation (12). Complete ranking can be obtained by arranging the alternatives in the descending order of their utility degrees, as higher values of utility degree are proffered over the lower ones.

Application example using COPRAS

Here an example of RP system selection is demonstrated to apply the proposed method. RP systems are used to prepare the prototypes of any machine or component to check and assess its design and other functions for service. Generally, RP processes starts with a stereo lithography (STL) file showing a model created by any CAD modeling software. The application of RP is mainly in aerospace, automobile industry or in some home appliances sector (Rao (2007)).

Nowadays, because of the very wide range of RP systems available in the market, it is required to pay more attention to select the suitable alternative for our application. In addition, for this reason, it requires a good knowledge and information about the quality and properties of parts, cost, performance, flexibility and speed.

Byun and Lee (2004) proposed the modified Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method for RP system selection. They had collected the data from various industries, organizations and stack holders, and considered the attributes, such as dimensional accuracy, surface roughness, part cost, build time and material properties (tensile strength and elongation) to assess the best option available among different processes of RP. The details of RP systems considered are as given below (Rao and Padmanabhan, 2007)

- *SLA3500*: This RP system uses stereo lithographic process using liquid layer curing as the layer creation technique. A laser beam solidifies the photo-sensitive liquid resin, and the phase change type is photo polymerization.
- *SLS2500*: This RP system uses selective laser sintering process and uses a laser beam to sinter the layers of powder into an individual object. The materials commonly used are polyamides.
- *FDM8000*: This RP system uses fused-deposition modeling process using extrusion of melted polymers. The phase change type is solidification by cooling, and the materials used are polymers, such as ABS, poly carbonate (PC), PC-ABS, etc.
- *LOM1015*: This RP system uses laminated object manufacturing process. A laser beam cuts sheets of adhesive coated paper, and these sheets are laminated into a single model. No phase change is involved and the materials used are paper, polyester, etc.
- *Quadra*: This RP system creates rapid prototypes with an inkjet process. Instead of ink, however, the print head deposits photopolymer that is immediately cured with a UV lamp.
- *Z402*: This RP system uses three-dimensional printing process. The machine applies a precisely controlled thin layer of material in powder form to the building platform, then the head traverses over the layer like a print head, squirting binding liquid (like thin glue) onto the powder layer. When one layer has been traversed and solidified, the bed drops by one layer thickness, another layer of powder is applied, and the process is repeated for all layers, bottom to top. No phase change is involved and the materials used are paper, polyester, etc.

Byun and Lee (2004) had considered six attributes and these were:

1. accuracy (A);
2. surface roughness (R);
3. tensile strength (S);
4. elongation (E);
5. cost of the part (C) and
6. build time (B) including pre-processing and post-processing time.

To apply and validate the proposed technique for selection of RP process by COPRAS method, various steps as given below:

Step 1

In the present work, the attributes considered are same as of Byun and Lee (2004). The attributes cost and build time which is expressed in fuzzy term can be converted into suitable crisp value by using Table I. The objective data of the considered attributes is given in Table II.

Step 2

The quantitative values of the attributes, which are given in Table II, are to be normalized. For this problem, tensile strength and elongation are considered as beneficial attributes, and higher value of it is desirable, and accuracy required, surface roughness value, cost of the part and build time are considered non-beneficial attributes, and lower value is desirable.

The weights for each attributes was determined by using AHP method, and these are WA = 0.3185, WR = 0.3185, WS = 0.1291, WE = 0.1291, WC = 0.0524 and WB = 0.0524 (Rao and Patel, 2009).

Step 3

After applying the COPRAS method, the result Table III is as given below.

According to COPRAS method, the ranking of RP system is 6-4-5-3-1-2. It means Quadra is the best suitable system by

Table I 11-point scale to convert linguistic terms into crisp scores

Linguistic term	Fuzzy no.	Crisp score
Exceptionally low	M1	0.045
Extremely low	M2	0.135
Very low	M3	0.255
Low	M4	0.335
Below average	M5	0.410
Average	M6	0.500
Above average	M7	0.590
High	M8	0.665
Very high	M9	0.745
Extremely high	M10	0.865
Exceptionally high	M11	0.955

Source: Chen and Hwang (1992)

Table II Attribute value of RP system

RP system	A	R	S	E	C	B
SLA3500	120	6.5	6.5	5.0	VH (0.745)	M (0.500)
SLS2500	150	12.5	40.0	8.5	VH (0.745)	M (0.500)
FDM8000	125	21.0	30.0	10.0	H (0.665)	VH (0.745)
LOM1015	185	20.0	25.0	10.0	SH (0.590)	SL (0.410)
Quadra	95	3.5	30.0	6.0	VH (0.745)	SL (0.410)
Z402	600	15.5	5.0	1.0	VVL (0.135)	VL (0.255)

Notes: A = accuracy required; R = surface roughness value; S = tensile strength; E = elongation; C = cost of the part; B = build time
Source: Byun and Lee (2004)

Table III Result table and ranking of alternatives

RP system	P_j	R_j	Q_j	N_j	Rank
SLA3500	0.02214	0.07609	0.02215	2.4211	6
SLS2500	0.06480	0.10778	0.18140	19.820	4
FDM8000	0.06010	0.13921	0.15033	16.432	5
LOM1015	0.05540	0.14290	0.20200	22.080	3
Quadra	0.04740	0.05611	0.91484	100	1
Z402	0.00789	0.21887	0.35110	38.378	2

considering all other available alternatives, and SLA3500 is the last choice among all. Byun and Lee (2004) tried relative importance weights of the attributes and proposed Z402 as the best choice and FDM8000 process as the last choice. Rao and Padmanabhan (2007) proposed Quadra, best available alternative among all. The next choice is SLA3500 and the last choice is Z402. Rao (2007) proposed the Quadra system as first choice by considering various methods like SAW, WPM, AHP and VIKOR. Here the ranking of the alternatives depends upon the judgment of decision-maker regarding the relative importance of alternative with others. If the decision-maker changes the value of weights or relative importance, then the ranking will be different than the proposed ranking. The same is true with the approach proposed by Byun and Lee (2004), and they have got different ranking. However, the proposed method may be comparatively better than the method used by Byun and Lee (2004) in that it enables a more critical analysis, as any number of quantitative and qualitative attributes can be considered. Further, the proposed method can effectively handle the quantitative attribute data by converting it into a suitable value.

Conclusion

Followings are the conclusions:

- In such situations where the decision making is affected by conflicting criteria, MADM method COPRAS can be useful to solve the decision-making problem. Here, the situation of RP system selection is explained and ranking is obtained by improved COPRAS method. It is found that the ranking obtained using proposed method is more reliable.
- The method can effectively handle any number of alternatives and attribute data, and can be used for qualitative as well as quantitative data in a logical way. It can be also noted that the proposed method is much simple and logical in its category.
- The proposed technique can be applied to any type of selection and decision-making problems.

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Further reading

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