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A hybrid method using experiment design and grey relational analysis for multiple criteria decision making problems

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ABSTRACT

To improve the market competitiveness of enterprises in the manufacturing industry, some of them involve picking the most appropriate strategies among multiple available alternatives. However, no single alternative works is suitable for all evaluation criteria which must be considered during the selection processes. This paper proposes a new hybrid MCDM method using design of experiment (DoE) and grey relational analysis (GRA), called DoE-GRA method, to solve this kind of problem. Three illustrative MCDM examples consisting of selection of (a) a rapid prototyping process, (b) a flexible manufacturing system, and (c) an automated inspection system, are analyzed to demonstrate the application capability of the DoE-GRA method. The results of comparisons show that the DoE-GRA method is featured by less sensitive to weight changing, simple and fast calculation, robust and practical. It is suitable for solving MCDM problems.

1. Introduction

There are many multiple criteria decision making (MCDM) problems in manufacturing industry. Different from single criterion decision making problems, in multiple criteria decision making problems, a decision maker (DM) has to choose the most appropriate alternative that satisfies the evaluation criteria among a set of candidate solutions. For that the evaluation criteria are frequently in conflict with each other, how to make a scientific decision becomes a difficult problem [1].

A number of methods have been proposed for solving MCDM problems such as scoring models [2], simple additive weighting [3], axiomatic design [4], analytic hierarchy process (AHP) [5], technique for order preference by similarity to ideal solution (TOPSIS) [6], preference ranking organization method for enrichment evaluation (PROMETHEE) [7], and multi-objective optimization on the basis of ratio analysis (MOORA) [8]. Almost all the methods above mentioned require the relative importance of each criterion which is supplied by weights. The result is sensitive to the change of weights [9], i.e., different weights will produce different results. When weight changes, the whole mathematical calculation process has to do all over again, which may be impracticable and ineffective for DMs, who may not have a strong mathematical ability.

As decision making requires multiple perspectives from different people, most organizational decisions are made in groups. To make the group decision making process as efficient and effective as possible, multi-criteria group decision making (MCGDM) method is proposed. In practice, subjective and objective information may need to be processed simultaneously in MCGDM problems that may contain uncertainties. Aiming at the uncertainties of subjective information and objective information, based on fuzzy sets [10] and fuzzy logic [11], several fuzzy MCGDM methods have been proposed and proved to be very effective technique to increase the level of overall satisfaction in MCDM problems [12–14]. However,the calculation of fuzzy MCGDM method is difficult. So a new method has been proposed in this work which is easy to use and adaptable.

Grey system theory provides a mathematical means to deal with poor, incomplete, and uncertain information. It is first developed by Deng [15,16],to study the uncertainties in system models, to help in prediction and decision making.In grey systems theory, according to the degree of information, if the system information is fully known, the system is called white systems, if the information is unknown, it is called black systems. A system with information known partially is called a grey system. The grey system theory includes five major parts: grey prediction, grey relational analysis, grey decision, grey programming and grey control [16,17]. Grey relational analysis (GRA) as an important part, reflects the trend relationship between an alternative and the ideal alternative, but it cannot reflect the situational relationship. In order to improve this situation, some steps of the GRA have been modified just as the normalized formula, the ideal and non-ideal alternative had been considered at the same time, etc. [18,19].

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In this paper, a new hybrid MCDM method using design of experiment and grey relational analysis, also called DoE-GRA method, is introduced. Three different MCDM problems in real-time manufacturing applications will be solved using the DoE-GRA method. According to the results, the DoE-GRA method is featured by less sensitive to weight changing, it is simple and fast calculation, robust and practical. It could help the DM get the most appropriate alternative in complex MCDM problems.

The remaining sections of the paper are organized as follows: Section 2 presents the methods;Section 3 describes the applying process of the DoE-GRA method in detail; Section 4 demonstrates the applicability and potentiality of the DoE-GRA method in solving different MCDM problems.Finally, conclusions and future works are discussed in Section 5.

2. Methods

2.1. Grey relational analysis

In this paper, among the most popular MCDM methods, the GRA method is selected because of its advantages compared with others. Table 1 depicts the comparative performance of some of the most widely used MCDM methods with respect to their computational time, simplicity, mathematical calculations involved and stability [1,8]. From Table 1, it is revealed that in all aspects, the GRA method clearly outperforms the other MCDM methods which proves its universal applicability and flexibility as an effective MCDM tool in solving complex decision-making problems.

Zavadskas and Brauers [20]identified the following seven conditions to justify the robustness of an MCDM method:

1. The MCDM method in which all the decision makers are included is more robust than that method in which only one decision maker is involved.
2. The MCDM method in which all the non-correlated objectives are considered is more robust than that on in which only a limited number of objectives is taken into consideration.
3. The MCDM method in which all the interrelations between objectives and alternatives are taken into account at the same time is more robust than that method in which the interrelations are only examined two by two.
4. The MCDM method which is non-subjective is more robust than that one which uses subjective approaches. The normalization procedure affords a subjective solution for comparing different units of various objectives. Consequently, the MCDM method which uses non-subjective dimensionless measures, like the DoE-GRA method, meaning that the determining results is more robust than that method which uses subjective weights.
5. The MCDM method based on cardinal numbers is more robust than that one based on ordinal numbers.

Table 1
Comparative performance of some popular MCDM methods.

MCDM method	Computational time	Simplicity	Mathematical calculations involved	Stability
GRA	Moderate	Moderately critical	Moderate	Medium
TOPSIS	Moderate	Moderately critical	Moderate	Medium
AHP	Very high	Very critical	Maximum	Poor
ELECTRE	High	Moderately critical	Moderate	Medium
PROMETHEE	High	Moderately critical	Moderate	Medium

6. The MCDM method which used the last recent available data as a base in the decision matrix is more robust than that one based on earlier data.
7. The GRA method satisfies the first six conditions if non-subjectivity in the choice of the objectives and non-subjectivity in the attribution of importance to an objective are solved.

The details of GRA method are presented as follows:

Step 1. Calculating the normalized decision matrix.

A decision matrix of n alternatives and m criteria is formulated just as $F = (f_{ij})_{n\times m}$. Then the normalized value r_{ij} is calculated as follows:

$$r_{ij} = f_{ij}/\sqrt{\sum_{k=1}^{n} f_{kj}^2} \tag{1}$$

where f_{ij} is the value of jth criterion function for alternative $A_i (i = 1, \ldots, n;\ j = 1, \ldots, m)$.

Step 2. Calculating the weighted normalized decision matrix.

The weighted normalized value u_{ij} is calculated as follows:

$$U = (u_{ij})_{n\times m} = (\omega_j r_{ij})_{n\times m} \tag{2}$$

The weights w_j indicates how many times more important or dominant one criterion is over another criterion which they are compared. Table 2 shows a standardized comparison scale numbers of nine levels.

Step 3. Determining the ideal and non-ideal solutions.

The optimal value of every criterion is selected from the weighted normalized decision matrix U which composes the ideal solution U^+,and the worst value of every criterion composes the non-ideal solution U^-, Then, the ideal solution U^+ and the non-ideal solution U^- will be:

$$U^+ = \{u_1^+, \ldots, u_m^+\} = \{(\max_j u_{ij} | j \in J^+), (\min_j u_{ij} | j \in J^-)\} \tag{3}$$

$$U^- = \{u_1^-, \ldots, u_m^-\} = \{(\max_j u_{ij} | j \in J^+), (\min_j u_{ij} | j \in J^-)\} \tag{4}$$

where J^+ is associated with beneficial criteria, and J^- is associated with non-beneficial criteria.

Step 4. Calculating the grey relational coefficient.

Based on the weighted normalized decision matrix, the grey relational coefficients of the ith alternative and the ideal solution about the jth criterion is calculated as follows:

$$r_{ij}^+ = \frac{m^+ + \xi M^+}{\Delta_{ij}^+ + \xi M^+}, \xi \in (0,1) \tag{5}$$

where $\Delta_{ij}^+ = |u_j^+ - u_{ij}|$, $m^+ = \min_i \min_j \Delta_{ij}^+$, $M^+ = \max_i \max_j \Delta_{ij}^+$; ξ is the distinguishing coefficient, generally ξ takes 0.5.

The grey relational coefficient matrix of the alternatives and ideal solution is as follows:

$$R^+ = \begin{vmatrix} r_{11}^+ & r_{12}^+ & \ldots & r_{1m}^+ \\ r_{21}^+ & r_{22}^+ & \ldots & r_{2m}^+ \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1}^+ & r_{n2}^+ & \ldots & r_{nm}^+ \end{vmatrix}$$

The grey relational grade about the ith alternative and the ideal solution can be obtained as follows:

$$R_i^+ = \frac{1}{m}\sum_{j=1}^{m} r_{ij}^+, \quad (i = 1, 2, \ldots, n) \tag{6}$$

The grey relational coefficient of the ith alternative and the non-ideal solution about the jth criterion is calculated as follows:

$$r_{ij}^- = \frac{m^- + \xi M^-}{\Delta_{ij}^- + \xi M^-}, \quad \xi \in (0,1) \tag{7}$$