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A novel hybrid MCDM model combining the SAW, TOPSIS and GRA methods based on experimental design

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ABSTRACT

Multiple criteria decision-making (MCDM) is a difficult task because the existing alternatives are frequently in conflict with each other. This study presents a hybrid MCDM method combining simple additive weighting (SAW), techniques for order preference by similarity to an ideal solution (TOPSIS) and grey relational analysis (GRA) techniques. A feature of this method is that it employs an experimental design technique to assign attribute weights and then combines different MCDM evaluation methods to construct the hybrid decision-making model. This model can guide a decision maker in making a reasonable judgment without requiring professional skills or extensive experience. The ranking results agreed upon by multiple MCDM methods are more trustworthy than those generated by a single MCDM method. The proposed method is illustrated in a practical application scenario involving an IC packaging company. Four additional numerical examples are provided to demonstrate the applicability of the proposed method. In all of the cases, the results obtained using the proposed method were highly similar to those derived by previous studies, thus proving the validity and capability of this method to solve real-life MCDM problems.

1. Introduction

Multiple criteria decision-making (MCDM) refers to making decisions in the presence of multiple conflicting criteria [50]. MCDM occurs in a variety of actual situations, such as risk assessment [48], supply chain management [13], manufacturing environments [37], material selection [12], and weapons system evaluation [16]. For example, when a family wants to buy a car, they must consider its price, comfort, safety, fuel consumption, maintenance and so on. These criteria are frequently in conflict with each other. It is a difficult task to choose the most comfortable and safest car with the lowest price. There are many MCDM problems that are more complicated than purchasing a car. The world's increasing complexity and uncertainty make the decision-making process even more challenging.

In MCDM problems, a decision maker (DM) must choose the most appropriate alternative that satisfies the evaluation criteria among a set of candidate solutions. How to make trade-off between these conflicting attributes and make a scientific decision largely depends on the DM's experience. Currently, there are many MCDM methods that have been developed to solve this type of problem. The most commonly used methodologies are the analytical hierarchy process (AHP) [39], simple additive weighting (SAW) [26], techniques for order preference by similarity to an ideal solution (TOPSIS) [20], data

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envelopment analysis (DEA) [10], grey relational analysis (GRA) [17], the compromise ranking method (VIKOR) [30], the preference ranking organization method for enrichment evaluation (PROMETHEE) [47] and multi-objective optimization on the basis of ratio analysis (MOORA) [7]. These developed MCDM methods use different analysis models and have different decision rules. AHP relies on the judgments of DMs to decompose a complex problem into a hierarchy with the goal at the top level of the hierarchy, the criteria at the sub-level of the hierarchy, and decision alternatives at the bottom level of the hierarchy. In the SAW method, the score of an alternative is equal to the weighted sum of its evaluation ratings. The TOPSIS method is based on the notion that the best decision should be the closest to the ideal solution and farthest from the non-ideal solution. The DEA method determines a solution by measuring the relative performance of a set of decision-making units. Based on the grey system theory, GRA is suitable for solving problems with complicated interrelationships between multiple factors and variables. The main procedure is to calculate the grey relational grade between the reference sequence and every other comparability sequence. The VIKOR method introduces a multi-criteria ranking index based on the particular measure of "closeness" to the ideal solution. PROMETHEE carries out a pairwise comparison of the alternatives and computes the magnitudes of leaving or entering flows for the alternatives. MOORA is a multi-objective optimization technique developed to solve problems with discrete alternatives. This method consists of two components: the ratio system and the reference point approach.

Although many methods have been developed to address MCDM problems, in all these methods there are three main disadvantages that need to be discussed. First, different users will obtain different results when using the same method. Different DMs often have different backgrounds, expertise and experience. The preferred information associated with DMs on the evaluation criteria varies from person to person. Meanwhile, different relative criteria weights have a significant effect on the selection of the most appropriate alternatives. The ranking results are very sensitive to the changes in attribute weights. The presence of different attribute weights may result in different ranking orders [53]. The decision made by a single expert may not be conclusive. In most of these cases, different groups of DMs are involved in the selection process. Each group has different criteria and perspectives to make the decision more reliable [32]. Second, different techniques may yield different results when applied to the same problem [54]. Different approaches are proposed from various schools of thinking. There are no better or worse techniques, only techniques that fit better to a certain situation. It is not easy to say which MCDM approach is more reasonable and reliable for a given decision-making problem, as the selection of MCDM methods itself is a complicated MCDM process [45]. Many DMs apply several MCDM approaches to the same problem, compare their results, and then make the final decision. This approach is difficult to comprehend and complex to implement because it requires extensive technical knowledge in MCDM fields. A combination of different MCDM evaluation techniques to construct a hybrid model may be the correct choice in solving this problem. Third, the evaluation process of the existing MCDM approaches is complicated. For a proper and effective evaluation, DMs require a large amount of data for analysis and many factors for consideration. The DM should be an expert or, at least, very familiar with the selection problem. It is difficult for a general DM who does not have a strong background in mathematics to effectively complete the evaluation process. On the other hand, when the selected alternatives have changed, e.g., a new alternative is added to the MCDM problem, the entire mathematical calculation process must be repeated. This is impracticable and ineffective for DMs. Thus, a simple, logical and systematic approach to solving MCDM problems is required. An MCDM model constructed by experienced experts may be useful and effective for decision-making.

In this study, a novel hybrid MCDM model combining the SAW, TOPSIS and GRA methods is presented. Constructing a regression model typically involves two steps: (1) employing an experimental design to sample computer simulations, and (2) selecting an approximation model to represent the data and fit the model with sample data. In this study, an optimal Latin hypercube design and orthogonal array technique are performed for the weight experiment and criterion experiment, respectively. The average ranking scores of the SAW, TOPSIS and GRA methods are calculated to create an approximation dataset. Experimental data are approximated using the response surface method (RSM). The generated model can guide a decision maker in making a reasonable judgment. Compared with other MCDM methods, the proposed method has three main advantages. First, weight assignment is conducted using an experimental design technique. This technique helps a DM to quantify the relative importance of each criterion statistically. In classical MCDM methods, the weights of experts' opinions play an important role in the decision-making process. The DM's evaluations of multiple criteria are subjective, thus, imprecise. Ranking results are very sensitive to changes in attribute weights. If the weighting procedure of an MCDM method is not performed correctly, then the weights will be generated incorrectly, thus directly affecting the outcome of the MCDM approach. In our method, there is no need for an expert to assign exact numerical values to the comparison judgments. This avoids the subjectivity of human preference in making a decision and decreases sensitivity to changes in the attribute weights. Thus, the ranking results become more reasonable and reliable. Second, a regression model is generated to help DMs make the decision. In our study, an MCDM model is obtained using an integrated experimental design and an RSM regression approach. When the regression equation is obtained, the alternative evaluation process can be easily facilitated. The MCDM model ranks the alternatives and the highest ranked one is recommended as the best alternative. DMs do not need to have technical knowledge in MCDM fields or a strong background in mathematics; rather, they can use the obtained regression model to choose and analyze factors and attributes easily. Moreover, if a new alternative is added to or removed from the MCDM problem, all the DMs need to do is to use the regression model and the final results would be got. It is quite convenient and practicable. Third, different MCDM evaluation methods are combined to solve the same MCDM problem with the aim of taking the best features of each method. A ranking agreed upon by multiple MCDM