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A novel hybrid multiple criteria decision making model for material selection with target-based criteria

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ABSTRACT

In engineering design, the decision to select an optimal material for a particular product is a problem requiring multi-criteria decision analysis that involves both qualitative and quantitative factors. The evaluation of alternative materials may be based on imprecise information or uncertain data. Furthermore, there can be significant dependence and feedbacks between the different criteria for material selection. However, most existing decision approaches cannot capture these complex interrelationships. In response, this paper proposes a general framework for evaluating and selecting the best material for a given application. A novel hybrid multiple criteria decision making (MCDM) model combining DEMATEL-based ANP (DANP) and modified VIKOR is used to solve the material selection problems of multiple dimensions and criteria that are interdependent. Moreover, target-based criteria as well as cost and benefit criteria can be addressed simultaneously in the proposed model. Finally, an empirical case concerning the bush material selection for a split journal bearing is presented to illustrate the potential of the new model. The results show that the proposed method for material selection is effective and provides meaningful implications for designers and engineers to refer.

1. Introduction

In engineering designs, the selection of the best suitable material for a given application is a major challenge for engineering designers due to the immense number of available materials in the marketplace and trade-offs between properties of alternatives in complex applications. Materials are responsible for function, structure and interaction with the customer/user or with other chunks of the product, which play a more and more important role in the entire product design and manufacturing process. To satisfy the requirements of lower cost, better performance and weight reduction, many traditional used materials in industry have being substituted by newly developed materials in recent times [1,2]. But, selecting the most appropriate material, or combination of materials, is a demanding intellectual process that takes a vast amount of time and expert expertise [3]. Incorrect choice of a material often results in an overall increase in production cost and/or early failure of the product in the field of application, which adversely affect the productivity, profitability and reputation of the manufacturing organization concerned [4,5]. Therefore, design engineers must have to identify and select the optimum material for a product for achieving the preferred output with minimum cost involvement and specific performance considerations [6,7].

When choosing the right materials for engineering designs, designers have to take into account various important criteria or attributes simultaneously for successful outcomes and optimal decisions. During the material selection, a large number of factors such as material cost, mechanical properties, physical properties, environmental performance, manufacturing properties, market trends, cultural aspects, and safety are often included in the process [1,8]. They contradict and even conflict each other [9]. Each material has different performance for each property. There is no material which satisfies all the relevant properties. Thus, the material selection with multiple non-commensurable and conflicting criteria for an engineering design can be viewed as a complex multi-criteria decision making (MCDM) problem. To ease out the material selection procedure and make right decision, a systematic and efficient approach is required.

Up to now, a lot of mathematical techniques have been developed and applied for solving material selection problems arising from various engineering domains. The main problem associated with the existing decision analysis approaches is that

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most of them cannot handle the analysis of complicated and interrelated relationships among different hierarchical levels of criteria. However, the decision to select an optimal material for a particular product requires a decision model that performs just that analysis. As a result, the analytic network process (ANP) and the correlation effects weighting were used by different researchers to solve this problem [3,5,10,11]. But, the method of normalizing the unweighted supermatrix in the traditional ANP is not reasonable (refer, e.g., to [12]), and the relationship structure among features cannot be considered by the application of correlation test to criteria. Thus, this study aims to develop a hybrid MCDM model that combines DEMATEL-based ANP (DANP) with modified VIKOR to overcome the limitations of conventional decision methods, which can be used to help engineering designers analyze the interrelated relationships in material selection. Specifically, an empirical case concerning the bush material selection for a split journal bearing is utilized to study the interdependence of the factors that influence the selection of materials, as well as to evaluate alternatives to achieve the desired level of performance.

The remainder of this paper is organized as follows: the relevant literature on the selection of materials is reviewed in Section 2. A hybrid MCDM model combining DANP and VIKOR for material selection is developed in Section 3. In Section 4, a case study of the bush material selection for a split journal bearing is presented to demonstrate the proposed model, and in Section 5, discussions of the results and comparisons with other existing approaches are conducted. Finally, some conclusions are drawn in Section 6.

2. Literature review

Material selection has a very important role in the product design and manufacturing process. Various approaches regarding material selection have been suggested in the literature for diverse engineering applications and so great progress has been made in this field. For example, Rao and Patel [8] proposed a decision making method to deal with the material selection problems for a given engineering design considering both qualitative and quantitative attributes. In particular, the method uses fuzzy logic to convert the qualitative attributes into the quantitative attributes. Jahan and Edwards [13] introduced a new VIKOR method based on interval data to address material selection problems with target-based criteria as well as cost and benefit criteria. The proposed method is able to address effectively mixed data, with precise and imprecise values, and with interval data. Karande et al. [14] applied utility concept and desirability function for solving the material selection problems. These two methods are based on the quality characteristic values of the considered material alternatives for arriving at the satisfactory results. Peças et al. [15] presented a material selection procedure (material selection engine – MSE) intending to contribute to a more informed decision-making process in material selection. Maniya and Bhatt [16] implemented a tool named preference selection index (PSI) to help the decision maker for selection of a proper material that will meet all the requirements of the design engineers. Zhou et al. [17] presented an integrated approach based on artificial neural networks (ANNs) and genetic algorithms (GAs) to optimize the multi-objectives of material selection, which can help designers to select suitable materials to develop sustainable products. Lin et al. [18] developed a hybrid fuzzy decision making model combining fuzzy weight average (FWA) with fuzzy inference system (FIS) for material substitution selection in the electronics industry. İpek et al. [6] proposed an expert system approach for material selection in manufacturing and implemented it for a real world past case in automotive industry as well as body implants.

In [19], the analytical hierarchy process (AHP) method was used in the selection of the most suitable natural fiber to be hybridized with glass fiber reinforced polymer composites for the design of a passenger vehicle center lever parking brake component. Yousefpour and Rahimi [20] improved the wear and corrosion resistance, microhardness, coefficient of friction and selected the best coating condition to satisfy these parameters using combined AHP-TOPSIS method. Çalışkan et al. [21] proposed a systematic evaluation model including the EXPROM2, TOPSIS and VIKOR methods for the selection of the best material for the tool holder used in hard milling. The weighting of the material properties was performed using the compromised weighting method which composes of the AHP and entropy methods. As opposed to the AHP decision making, Milani et al. [10] used the analytic network process (ANP) for multiple criteria material selection by means of allowing feedback and interactions within and between the decision criteria and alternatives. In [5], the method of preference ranking organization method for enrichment evaluations (PROMETHEE) was combined with ANP to select the best material for a given application, where ANP is used to identify weights, and PROMETHEE to rank alternatives. In addition, other mathematical techniques (including MCDM methods) have been proposed by the researchers for arriving at the best material selection decisions, which include Ashby approach [22], graph theory and matrix approach [23], TOPSIS [24,25], VIKOR [1,26–28], ELECTRE (elimination and choice expressing the reality) [29], grey relational analysis (GRA) [30], MOORA (multi-objective optimization using ratio analysis) [31], COPRAS (complex proportional assessment) [32,33] and quality function deployment (QFD) [4,34]. A broad overview of materials screening and choosing methods can also be found in [35].

The review of the literature indicates that although the existing methods provide many useful tools for material selection, most of them still lack of capability to explore the relationships among selection criteria for more in-depth analysis. In order to help fill the gap, this study proposes a hybrid MCDM model combining DANP and VIKOR to deal with the material selection problem, aiming at exploring the plausible interrelationships among the considered criteria for making better decision. The DANP is used to determine the degrees of influence among the criteria and the VIKOR method is utilized for calculating the compromise ranking and performance gaps of the alternatives for improvement. The proposed model applied in this study may preserve the interrelationships among criteria, which could be used to adjust the influential weights based on the basic concept of the ANP.

3. Proposed hybrid MCDM model for material selection

Material selection for an engineering design is a MCDM problem which requires consideration of a number of available materials and conflicting evaluation criteria. This research uses the DANP technique and combines with the VIKOR method to establish a new hybrid MCDM model to address the problems of material selection with interdependence and feedback among certain criteria. The DEMATEL technique is first adopted to uncover the relationship between the criteria and their network structure in the presence of interdependence and feedback among them. Then, the ANP approach is used to find the influential weights for each dimension and criterion in the evaluation structure. To rank the alternative materials, the VIKOR method is employed for calculating the compromise ranking and performance gaps of the alternatives. Based the results obtained, it is possible to determine how to improve material performance and reduce the gaps to achieve the aspiration level and satisfy the products' needs. In short, the proposed model for material selection consists of three main phases: (1) constructing the influential relation map (IRM) among