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Expert Systems with Applications 36 (2009) 1362–1370

Expert Systems with Applications

www.elsevier.com/locate/eswa

A methodological concept for material selection of highly sensitive components based on multiple criteria decision analysis

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Abstract

Material selection of highly sensitive components is one of the most challenging issues in the design and development of structural elements in aerospace and nuclear industry. This work compares some of the most widely potential multi-criteria decision making models for addressing all the stages in solving a material selection problem of highly sensitive components involving conflicting as well as multiple design objectives. For the first step, the compensatory models are discussed and employed to solve a multi-criteria material selection for a thermal loaded conductor in the presence of its required multi-functional characteristics. For the next step, using different versions of the non-compensatory methods examine the outranking approach to solve the same problem. The results are compared to each other to verify the effect of compensations and non-compensations in the methods and their sensitivity to ranking stability. It is of particular interest to see how different approaches of the Multiple Attribute Decision Making (MADM) models differ from each other when criterion of cost is a critical factor in the problem. The effect of individual attributes of cost criterion has been studied to ensure the reliability of the chosen candidate material by MADM models.

Keywords: Modeling; Multiple Attribute Decision Making; Material selection; Ranking; Outranking relation; Ideal solution; Entropy

1. Introduction

Reliability and safety in material selection of sensitive parts in aerospace and nuclear engineering industry is a critical task and using multi-criteria analysis concept has been of major interest to material designers in recent years. Appropriate material choice for a given technology is the key aspect, in order sustain relationship between high performance and reliability of observed manufacturability process. For selecting the most suitable material in the sensitive structural elements, the making of decisions from complex hierarchical comparisons among candidate materials and for each material selection criterion, a wide range of material properties and performance indices should be taken in account involving conflicting multiple objectives of several design concepts. Moreover, in order to explore better design alternatives, it is always vital to gain a rapid knowledge of new materials under development. When choosing a new material or replacing an existing one with another that contains better performing components, the experts usually apply trial and error methods or base themselves on previous experimentation leading to a loss of time and a considerable increase in cost.

Ashby (2005) has introduced material selection charts for a wide range of materials. The material selection procedure is performed based on two performance indices per chart. It should be noted that the constructed material property chart introduced by Ashby for a wide range of mechanical and thermal properties is empirical correlation between some physical properties of materials (i.e. electronic conductivity, elastic modules, etc.) and the interstice parameters (i.e. density, heat capacity, etc.). Due to the fact that the number of materials available to the engineering designer is very large in empirical approach, graphical methods have been applied to the problem of the optimized

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doi:10.1016/j.eswa.2007.11.052

Nomenclature

X_j	*j*th attribute in decision matrix
M_i	*i*th candidate material in decision matrix
r_{ij}	an element of decision matrix
r_j^*	the best value of *j*th attribute
r_j^-	the worst value r_j^- of *j*th attribute
α	the weight of strategy of the maximum group utility
M_i	*i*th candidate material
q_j	indifference threshold of *j*th criterion
p_j	preference threshold of *j*th criterion
$c_j(M_i, M_k)$	the concordance index of the *j*th criterion for M_i and M_K
C_{ik}	the global concordance index for M_i and M_K
M	bending required moment
t	thickness of the sheet
w	width of the thermal loaded conductor
σ_θ	the stress in θ direction
Y	yield stress
r'	the new radius of curvature of the mid plane after unloading
r_0	the radius of curvature of the mid plane before unloading
v	Poisson ratio
E	elastic modulus

selection of materials, but have been limited to, at most, two objectives. For overcoming to these challenges, simulation and decision supports systems are needed to become a central diagnostic in order to predict material performances and achieve optimal design of components. Our developed mathematical model may help to explore ways in which it can be extended to more than two objectives. The addressing of these needs could be supported by the adoption of a Multiple Attribute Decision Making (MADM) (Pratyyush & Jian-Bo, 1998), which provides solutions to the material selection problems involving conflicting and multiple objectives. The MADM models are capable of performing the compromised solution regardless of the functional relationship for the objectives and constraints and, secondly, the number of criteria and alternatives applicable to the model is computationally limitless (Collette, 2003). The MADM problem under consideration is depicted by a decision matrix which is given in Table 1.

There are essentially two different approaches for solving MADM problems: compensatory and non-compensatory. The main difference between the two is that in compensatory models, explicit trade-offs among attributes are permitted. Compensatory MADM models have been based mainly on the multi-attribute utility theory (MAUT) where a single overall criterion is postulated and optimized, and therefore explicit tradeoffs between attributes are allowed. The non-compensatory MADM models are mainly based on pair wise comparisons of alternatives, which are made with respect to individual criteria (Collette, 2003; Pratyyush & Jian-Bo, 1998).

Table 1
Decision matrix in MADM models

Alternative	Attribute			
	X_1	X_2	...	X_j
M_1	r_{11}	r_{12}	...	r_{1j}
M_2	r_{21}	r_{22}	...	r_{2j}
$\vdots$				
M_i	r_{i1}	r_{i2}	...	r_{ij}

In the earlier work of authors Shanian and Savadogo (2006), the original and ELCTRE II non-compensatory approach is introduced for the multi-criteria material selection. Inversely, with the Elimination and Choice Expressing the Reality (ELECTRE) model that gathers a set of preferences, ranking them according to how much each satisfies a given concordance, this work is also dedicated to the Compromise ranking method models in which a single index is usually assigned to each multi-dimensional characterization representing an alternative. This category of compensatory models selected the alternative with the highest score; the problem, then, consists of how to assess the appropriate multi-attributes utility function for the relevant decision situation. For the next step, using ELECTRE IS and ELECTRE IV (Rogers, Bruen, & Maystre, 2000; Roy et al., 1993) examine the outranking approach to solve the same problem. The results of two are compared in order to verify the effect of compensations and non-compensations in the methods and their sensitivity to ranking stability.

2. Ideal solution compensatory analysis

VIKOR (Opricovic, 1998; Tzeng, Lin, & Opricovic, 2005) and Technique of ranking Preferences by Similarity to the Ideal Solution (TOPSIS) (Pohekar & Ramachandran, 2004; Yoon & Hwang, 1980; Zanakis, Solomon, Wishart, & Dublish, 1998) methods are considered as the ideal solution compensatory models; but they have some differences and similarities in the basic definitions. The methods suppose that there is straight access to the values of the decision matrix. In the decision matrix all the elements are normalized to the same units in order to consider all the possible criteria in the decision problem. Both methods work based on an aggregating function which measures the closeness to the reference point(s). The VIKOR method presents an aggregating function, representing the distance from the ideal solution.The ranking score of each candidate material is derived from an aggregation of all material selection attributes, the weights of the attributes and a