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Multi-criteria group decision making under uncertainty with application to air traffic safety

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ABSTRACT

There are many methods for solving problems of multi-criteria group decision making under uncertainty conditions. It is quite often that decision makers cannot formulate unequivocally their individual preference relations between variants. Analysing the causes of a serious aircraft incident is an example where a group of experts is required to have a very detailed yet interdisciplinary knowledge. Obviously, each expert has only a fraction of such knowledge. Hence, experts can make fuzzy evaluations when they are not sure about them or it is not possible to gain full knowledge. There is a need for a method that in such a case takes into account the strength of preference expressed in the significance of each criterion. Both the significance of criteria and the scores assigned to variants can be represented using fuzzy expressions.

The proposed method reflects the problems of decision making when both objective (represented using non-fuzzy expressions) and subjective (represented using linguistic expressions) criteria, are involved. The proposed method enables to obtain a solution without having to conduct negotiations between decision makers. This is of advantage when there is a risk that some experts will be dominated by others. The method not only helps define a single preferred solution but also create the preference relation within a group. By applying this method, it is possible to reproduce the actual preference relations of individual decision makers. Presenting them to decision makers may induce them to change their evaluation of the weights of criteria or how they score variants.

1. Introduction

In the contemporary world many decision problems pose a major challenge for decision makers. On the one hand, the systemic approach prevails, in which as many effects of decisions made have to be taken into consideration as possible. This, in turn, causes that a large array of evaluation criteria have to be used to find the optimal decision. On the other hand, applying a great number of evaluation aspects requires a very extensive knowledge. At the same time, for the assessment of individual permissible decisions to be accurate, it has to be an in-depth knowledge. Under such conditions it may be impossible for a single decision maker to make responsible decisions. Then a group decision to be made by a number of decision makers or, as the case may be, a single-person's decision based on the opinions of many experts is sought (Kocher, Strauß, & Sutter, 2006).

However, as far as expert evaluations are concerned, it is generally known that they are very often descriptive and unclear. This is due to many factors, for example, unavailability of full knowledge of a phenomenon or difficulty in a precise and formal definition of relations or relationships. Therefore, the decision problem has to be addressed in the context of decision making under uncertainty (Dubois & Prade, 1992). In addition, evaluation criteria may be fuzzy, as may also be their significance to the selection of the optimal variant. All this may place a decision problem among considerations described using e.g. fuzzy or rough set theory (Greco, Matarazzo, & Slowinski, 2001).

This paper proposes a method for solving problems of multi-criteria group decision making under uncertainty conditions. The method represents a new approach based on the assumption that decision makers cannot formulate unequivocally their individual preference relations between variants, but at the same time takes into account the strength of preference (Hamouda, Kilgour, & Hipel, 2006). In addition, it presumes that negotiations between decision makers (experts) are impracticable or inadvisable and the decision has to be based on their one-off evaluations. The third important aspect of the approach is to include in the evaluation criteria of variants both objective criteria (represented using non-fuzzy expressions) and those that are subjective (represented

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using linguistic expressions) (Merigó, Casanovas, & Yang, 2014; Rao & Patel, 2010). The weight of individual criteria is derived from the aggregated weights assigned to them by each decision maker using linguistic variables.

The presented method can be the basis for building a decision support system, which can draw conclusions and make decisions which consist in indicating a solution preferred by the group. This system uses knowledge base that comes from experts who express it in the form of multi-criteria ratings of variants and criteria weights. Such expert systems are very necessary in practice, especially when each expert has only partial competence in the problem studied. An example from the field of aviation safety, presented in Section 4, belongs to a class of problems for which there is no formal mathematical model of problem solving algorithm. Part of the knowledge, necessary to build the knowledge base for the expert system, is available and expressed precisely, but some knowledge is uncertain and subjective. Hence, within the proposed model for inference engine, both objective and subjective criteria for evaluating the alternatives appear.

The paper is organised as follows: Section 2 briefly discusses the problem of multi-criteria group decision making under uncertainty. This section also provides a short overview of the literature. Section 3 provides a description of the new proposed approach to solving the problem of multi-criteria group decision making under uncertainty conditions. Section 4 presents an example of applying the developed approach. It has been used to illustrate the problem of attempting to rank in significance the causes of the serious aircraft incident that actually occurred at the F Chopin Airport in Warsaw. This ranking is the final step in the work of the aircraft accident investigation team, which is composed of experts in various fields. This issue is extremely important to improving air traffic safety because for major causes of aircraft incidents recommendations are issued that specify what actions are to be taken in the future. The paper is closed with the summary and conclusions contained in Section 5.

2. Multi-criteria group decision making under uncertainty

2.1. Group decision making

Group decision making has been discussed in the world's literature for many years. Obtaining a mutual decision agreed on between all decision makers is a major difficulty here. Decision makers are often individuals of strong personality, who are able to persuade others to accept their argumentation and judgement even if in reality such argumentation and judgement are not correct. Similarly, persons of weaker personality will not be successful with their standpoint despite it being sound (de Wit, Jehn, & Scheepers, 2013). The problem becomes more complicated when it is a multiple-criteria evaluation and each decision maker has a different hierarchy of criteria significance. The literature often refers to the need to reach a consensus (Wibowo & Deng, 2013; Zhang, Zhang, Lai, & Lu, 2009). This may be a long-lasting process, however, which does not necessarily have to lead to finding the best solution. The main reasons are stated above. Another one may be the need to keep the assessments of individual experts anonymous. An example of such an example is the evaluation of personnel, where it is necessary to exclude psychic pressure when making judgements. This issue is discussed in (Yu, Zhang, & Xu, 2013). Xiong, Tan, Yang, and Chen (2013), in turn, proposes a model of supporting group decisions in which a group decision is evaluated using two measures. One measure is the acceptance of a reached decision among group members. The other one is the vulnerability of a solution to changes in the preferences of individual decision makers. An interesting method of developing a shared standpoint while minimising necessary concessions is presented in (Zhang & Dong, 2013).

This paper focuses more on making decisions through the evaluation of variants by a group of experts, whose primary objective is rather delivering a reliable opinion, which e.g. enables to create a rank list of various solutions, than working out a common decision. There are many examples of such problem-solving strategies, e.g. a review of research grant applications based on a number of reviewer's views (Cook, Golany, Penn, & Raviv, 2007). Group decision-making is also used for transport-related purposes. For instance, (Rosmuller & Beroggi, 2004) discusses how group decision making methods can be used in the design of railway infrastructure, with particular attention paid to safety criteria. (Tavana, Khalili-Damghani, & Abtahi, 2013) presents a method of prioritising advanced technological projects at NASA, whereas (Chuu, 2011) discusses a model of group decision making for flexible supply chain management using a fuzzy linguistic approach. And (Yousefi & Hadi-Vencheh, 2010) presents how group decision making methods can be used to chart development directions for the automotive industry.

Section 4 presents an example solution to such a problem with regard to air transport, and more precisely in analysing the causes of a serious aircraft incident.

2.2. Multi-criteria analysis

The approaches to group decision making discussed in Section 2.1, whether they address the issue in terms of fuzziness or not, are based on the assumption that decision makers know how to describe the preference relations for a set of alternatives. For the ith decision maker such a relation can be defined as non-fuzzy preference order

$$O_i \subset A \times A \tag{1}$$

which means that if the ith decision maker prefers variant a_1 to a_2, then $(a_1,a_2) \in O_i$. It can also be written as

$$O_i = (\cdots \succ a_1 \succ a_2 \succ \cdots) \tag{2}$$

A reasonable preference relation should be transitive, reflexive and asymmetric. There are many solutions leading to accepting a reasonable order of variants for a whole group of experts based on individual preference relations. Among the most interesting papers are those by Zhang, Dong, and Xu (2012) and Kacprzyk (1986). The first proposes a model for incomplete additive preference relation that aims to calculate a complete fuzzy preference relation. The latter presents a method leading to a solution in terms of fuzzy values, although it does not include decision making uncertainty. These two methods share one major drawback, however. They do not take into account the strength of the decision maker's preferences. It is identical for them whether the decision maker prefers variant a_1 to a_2 to a minimal degree (the decision makers finds them almost indifferent) or does so very strongly. The approach presented in this paper eliminates that drawback by enabling decision makers to define and including the strength of preferences expressed using evaluation criteria and weights. A somewhat similar approach is mentioned in Chin and Fu (2014) and Wu and Chiclana (2012).

In multi-criteria evaluation of variants, the assumed existence of a transitive, reflexive and asymmetric preference relation does not have to be true. Decision makers often formulate preference relations that are e.g. non-transitive. It is true that they change their mind and modify the preference order of alternatives when they realise it but then doubts may arise whether the finally formulated preference relation reflects the decision maker's actual opinion (Tsai & Böckenholt, 2006).

There are numerous non-fuzzy methods of evaluating variants under multi-criteria conditions. An overview of them can be found