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Modification of the Best–Worst and MABAC methods: A novel approach based on interval-valued fuzzy-rough numbers

Dragan Pamučar[a,*], Ivan Petrović[b], Goran Ćirović[c]

[a] University of defence in Belgrade, Department of Logistics, Pavla Jurisica Sturma 33, 11000 Belgrade, Serbia
[b] University of defence in Belgrade, Department of Tactics, Pavla Jurisica Sturma 33, 11000 Belgrade, Serbia
[c] The Belgrade University College of Civil Engineering and Geodesy, Hajduk Stankova 2, 11000 Belgrade, Serbia

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A B S T R A C T

This paper presents a new approach for the treatment of uncertainty which is based on interval-valued fuzzy-rough numbers (IVFRN). It is shown that by integrating the rough approach with the traditional fuzzy approach, the subjectivity that exists when defining the borders of fuzzy sets is eliminated. IVFRN make decision making possible using only the internal knowledge in the operative data available to the decision makers. In this way objective uncertainties are used and there is no need to rely on models of assumptions. Instead of different external parameters in the application of IVFRN, the structure of the given data is used. On this basis an original multi-criteria model was developed based on an IVFRN approach. In this multi-criteria model the traditional steps of the BWM (Best–Worst method) and MABAC (Multi-Attributive Border Approximation area Comparison) methods are modified. The model was tested and validated on a study of the optimal selection of fire fighting helicopters. Testing demonstrated that the model based on IVFRN enabled more objective expert evaluation of the criteria in comparison with traditional fuzzy and rough approaches. A sensitivity analysis of the IVFRN BWM-MABAC model was carried out by means of 57 scenarios, the results of which showed a high degree of stability. The results of the IVFRN model were validated by comparing them with the results of the fuzzy and rough extension of the MABAC, COPRAS and VIKOR models.

1. Introduction

The process of decision making and selection of the "best" alternative is usually based on more than one criterion and a series of constraints. In all problems of multi-criteria optimization the decision maker implicitly seeks to find a solution that to the greatest possible extent satisfies all of the given criteria, without violating the limitations that exist. Unfortunately, such problems do not have a unified and global solution, i.e., there is no optimal solution for all criteria at the same time (Wang, Yang, & Chen, 2016a). It very often happens that due to their natural differences some criteria are expressed in different units of measurement, from monetary units, through units of physical size, to probability or subjective evaluations which are determined on the basis of a scale formed for a specific problem.

Due to the complexity and ambiguity of numerous real indicators in the process of multi-criteria decision making, as well as the appearance of dilemmas in human thinking, there are difficulties in presenting information about the attributes of decisions in terms of accurate (precise) numerical values. These ambiguities and uncertainties are most commonly exploited using interval numbers (Shuping, 2009; Zeshui & Qingli, 2003), fuzzy sets (Pamučar & Ćirović, 2015; Zadeh, 1965), rough numbers (Ćirović & Pamučar, 2013; Ćirović, Pamučar, & Božanić, 2014; Đorović & Pamučar, 2012; Fan et al., 2016; Song, Ming, Wu, & Zhu, 2014; Zhu, Hu, Qi, Gu, & Peng, 2015), grey theory (Arce et al., 2015; Kuang, Kilgour, & Hipel, 2015) and the application of other approaches. The basic idea of applying algorithms based on the interval approach to making decisions involves the application of interval numbers for presenting the attribute values of the decisions. However, it is very difficult to determine the borders of the interval numbers, and they are based on experience, intuition and the subjective perceptions of the decision maker.

In order to exploit uncertainties in the process of multi-criteria decision making, many authors have used fuzzy sets in their basic methodology (Zadeh, 1965) or different extensions of fuzzy theory: interval-valued fuzzy sets (Sizong & Tao, 2016; Vahdani, Tavakkoli-Moghaddam, Meysam Mousavi, & Ghodratnama, 2013; Zywica, Stachowiak, & Wygralak, 2016), intuitionistic fuzzy sets (Atanassov, 1986; Ngan, 2017), interval intuitionistic fuzzy sets

* Corresponding author.
E-mail addresses: dpamucar@gmail.com (D. Pamučar), ivanpetrovic1977@gmail.com (I. Petrović), cirovic@sezampro.rs (G. Ćirović).

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(Nayagama, Jeevaraja, & Sivaraman, 2016; Nguyen, 2016; Yang, Sun, Deng, Zhang, & Liao, 2016), hesitate fuzzy sets (Ngan, 2017; Wang, Wang, Zhang, & Chen, 2015) and so on. From the widespread application of different forms of fuzzy sets (Ngan, 2017; Pamučar, Gigović, Ćirović, & Regodić, 2016a,b; Pamučar, Lukovac, & Pejčić Tarle, 2013; Sizong & Tao, 2016; Vahdani et al., 2013; Wang et al., 2015; Xu, Law, Chen, & Tang, 2016; Zywica, 2016), we can conclude that fuzzy sets are a very powerful and commonly used tool for the presentation of imprecision. One of the disadvantages of fuzzy sets is the subjectivism in defining their borders, which can significantly affect the final decision (Gong, Li, & Jiang, 2016).

Unlike fuzzy theory, rough set theory, first introduced by Pavlak (1982), is a very convenient tool for the treatment of uncertainty without the impact of subjectivism. In the current literature rough set theory has been successfully applied in many different fields of human activities. It can be said that its use is suitable for the analysis of imprecision, ambiguity and uncertainty (Gigović, Pamučar, Bajić, & Drobnjak, 2017; Zhai, Khoo, & Zhong, 2010; Zhang, Xie, & Wang, 2016; Zheng, Xu, & Xie, 2016). Knowing the advantages of rough set theory (Pavlak, 1991), the application of rough sets is fully justified in today's modern practice in the decision-making process when it includes vague and inaccessible data.

In the decision-making process the intention of the interval fuzzy technique is the transformation of crisp numbers into fuzzy numbers that with the help of the membership function show the uncertainties that exist in the real environment (Gigović, Pamučar, Bajić, & Milićević, 2016a; Gigović, Pamučar, Lukić, & Marković, 2016b; Liu et al., 2016). According to Zadeh (1975) and Zimmermann (1996) linguistic expressions (linguistic variables) can successfully be used to quantify uncertainty in complex and uncertain situations. Here, linguistic variables are variables whose values are linguistic terms that can be used in an intuitive simple way to express the subjectivity and/or qualitative imprecision in the estimates of the decision maker (Jovanović, Pamučar, & Pejčić-Tarle, 2014; Kacprzyk, 1986; Zadeh, 1975). In addition, Grattan-Ginis (1975) and Karnik and Mendel (2001) consider that these linguistic expressions with the help of classic fuzzy sets (fuzzy sets type-1) are not sufficiently clear and precise. Karnik and Mendel (2001) further consider that it is much more natural and accurate to represent linguistic expressions using interval-valued fuzzy sets. Interval-valued fuzzy sets can provide greater flexibility in presenting imprecise and vague information, especially in the process of group decision making, which is characterized by a high degree of uncertainty (Bigand & Colot, 2010; Gorzalczani, 1987; Han, Li, Wang, & Shi, 2016; Pamučar, Gigović, Bajić, & Janošević, 2017a,b; Pamučar, Vasin, Atanasković, & Miličić, 2016c). This is why the application of interval-valued fuzzy sets in multi-criteria decision making (MCDM) emerges as a logical step with the aim of ensuring a sufficiently clear presentation of the linguistic expressions of the decision makers (Abdullah & Norsyahida, 2015; Hosseini & Tarokh, 2013; Ji, Tang, Li, Yang, & Liao, 2016; Pamučar et al., 2013).

However, as with fuzzy sets type-1, interval-valued fuzzy sets are characterized by subjectivism when defining the borders of the sets and the footprint of uncertainty (Kang, Zhang, Tang, & Zhao, 2016; Qazi, Lam, Xiao, Ouyang, & Yin, 2016). In order to eliminate the above subjectivity, the authors of this paper suggest a novel approach which is a modification of fuzzy sets using a rough approach. Interval-valued fuzzy-rough numbers take advantage of both the theory of fuzzy sets and rough numbers. At the same time, using the advantages of both approaches (fuzzy and rough) IVFRN eliminate the disadvantages of fuzzy sets type-1 and interval-valued fuzzy sets. In the IVFRN approach, the borders are determined on the basis of border approximation areas and the uncertainty that governs them. While in traditional fuzzy theory and probability theory the degree of uncertainty is defined on the basis of assumptions, in the IVFRN approach uncertainty is determined on the basis of approximation, which is the basic concept of IVFRN. The IVFRN approach uses exclusively internal knowledge, i.e., operative data, and there is no need to rely on assumption models. In other words, in the application of IVFRN, instead of different additional/external parameters, only the structure of the given data is used. The approach based on IVFRN unites the fuzzy and rough approaches, taking into account the advantages of both concepts.

The IVFRN approach presented in this paper involves defining the initial reference fuzzy set, by means of which the uncertainty in MCDM is described. After defining the initial fuzzy set, the uncertainties contained in the evaluations of the decision makers (DM) are measured by means of rough sets. This leads to the objective indicators contained in the data. The basic logic of IVFRN is that the actual data should speak for themselves. IVFRN eliminate the shortcomings of the traditional fuzzy approach relating to the interval borders, since for every rating of the DM unique interval borders are formed. This means that the interval borders do not depend on subjective assessment, but rather are defined on the basis of uncertainty in the data. In the case of fewer uncertainties IVFRN are transformed into fuzzy sets type-1, while for a higher number of uncertainties there is an increase in the footprint of uncertainty and the IVFRN are transformed into interval-valued fuzzy sets with rough borders. If there is disagreement in the evaluations of the DM, the interval borders of the IVFRN are increased, since there is greater uncertainty in the decision making. On the other hand, greater consensus results in fewer changes in the borders and IVFRN are transformed into traditional fuzzy numbers. This reflects less uncertainty in the evaluations of the DM. In the case of consensus among the DM the borders of the initial fuzzy numbers are not changed and the evaluations are described with a unique linguistic expression from the defined fuzzy scale, i.e., the fuzzy set type-1.

In addition to showing the basic concept of IVFRN, the study also applies it to multi-criteria decision making. The IVFRN concept is applied in a case study that considers the optimal selection of fire fighting helicopters. In the multi-criteria model presented here, the BWM, MABAC, COPRAS and VIKOR methods are modified using the IVFRN approach. In addition to the contribution made by presenting a new approach for considering uncertainty using IVFRN, another contribution of this paper is an original IVFRN modification of the MABAC, COPRAS and VIKOR methods. The authors hope that the given modifications represent a significant contribution to MCDM literature. Fuzzy and rough modifications of the MABAC, COPRAS and VIKOR methods are used for the validation of IVFRN, which essentially represents the good side of the fuzzy and rough approach. Therefore a comparison between IVFRN and the fuzzy and rough approach emerges as a logical scenario for validation. The authors particularly emphasize the original rough modifications of the COPRAS and MABAC models developed for validating the MCDM model, which have so far not been considered in the literature. The authors also highlight the contribution of the paper in the field of evaluating fire fighting aircraft. The authors have not come across an MCDM model in the literature that considers the evaluation of fire fighting aircraft, and they hope that the IVFRN-BWM-MABAC model will make a significant contribution to DM when evaluating fire fighting aircraft.

The paper is organized into five sections. After the introductory section, the second section presents the basic concept of interval-valued fuzzy-rough numbers. The third section presents the algorithm of the hybrid IVFRN-BWM-MABAC model, which is later tested in the fourth section by means of a case study in which the optimal selection of fire fighting helicopters for the Republic of Serbia is considered. The fifth section presents a discussion of the results and validation of the IVFRN-BWM-MABAC model. The