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# Heterogeneous multigranulation fuzzy rough set-based multiple attribute group decision making with heterogeneous preference information

Bingzhen Sun[a], Weimin Ma[b,*], Xiangtang Chen[b,c], Xiaonan Li[d]

[a] School of Economics and Management, Xidian University, Xi'an, Shaanxi 710071 China
[b] School of Economics and Management, Tongji University, Shanghai 200092, China
[c] Business Administration Department, Wenzhou Vocational and Technical College, Wenzhou 325035, China
[d] School of Mathematics and Statistics, Xidian University, Xi'an, Shaanxi 710071, China

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ABSTRACT

This study proposes a heterogeneous attribute multigranulation fuzzy rough set approach to the problem of multiple attribute group decision-making (MAGDM) under uncertainty. We first present the definition of heterogeneous attribute multi-source information systems and then construct the heterogeneous multigranulation approximation space using the arbitrary binary relation classes generated by different categories attribute. We then give the rough approximation of a fuzzy decision-making object with respect to heterogeneous multigranulation approximation space, i.e., the heterogeneous attribute multigranulation fuzzy rough set model over multi-source information system. Meanwhile, we investigate some interesting properties and conclusions for the proposed new model and also discuss the interrelationship between the proposed heterogeneous attribute multigranulation fuzzy rough set model and the existing generalized rough set models. After that, we construct a new approach to MAGDM problems based on heterogeneous attribute multigranulation fuzzy rough set theory. The decision-making procedure and the methodology as well as the algorithm of the proposed method are given and a detailed comparison of the traditional methods to MAGDM problems illustrates the advantages and limitations. Finally, an example of handling MAGDM problem of evaluation of emergency plans for unconventional emergency events illustrates this approach.

## 1. Introduction

We constantly make decisions in our private and professional life. The basic problem of decision-making for any individual is how to reach a final result from a given set of finite number of alternatives by handling the objection, various criteria and evaluation information in practice. There will be a group decision-making (GDM) problem when more than one individual takes part in a considered decision-making problem. For a GDM problem, experts in the group express their preference opinions (attitudes) on alternatives and interact to derive a common solution. As a matter of fact, a MAGDM problem is described as the selection of the best alternative among $m$ alternatives while trading-off between $n$ attributes with the preference evaluation given by all experts in the group. Then the complexity of the analysis increases dramatically when moving from a single decision maker to a multiple decision maker setting (Hwang & Lin, 1987; Ma, Zhan, Ali, & Mehmood, 2018; Zhan & Alcantud, 2018). The problem no longer depends on the preferences of a single decision maker; nor does it simply involve the summing up of preferences of multiple decision makers (Dong, Zhang, & Herrera-Viedma, 2016; Özgür & Bilal, 2017; Xu, Li, & Wang, 2013; Xu, Cabrerizo, & Herrera-Viedma 2017). So, dealing with the preferences given by experts in group and then reach a consensus solution is the key issue of a MAGDM problem.

As an effective and powerful approach to the complexity decision-making problems under uncertainty, the MAGDM methods are used to deal with complexity decision-making problems with multiple decision makers increases dramatically of reality. For a considered MAGDM problem, the first step is all decision makers (or experts, stakeholders, participants, etc.), which may have different backgrounds and knowledge on the problem on hand, provide evaluations regarding to performances of the alternatives under multiple criteria, and then obtain the comprehensive result for all alternatives by fusion the evaluations given by all decision makers. Since many multiple dimensional decision problems of different fields requires multiple experts and/or decision makers, MAGDM methods are receiving considerable interest in many different research fields (Shen, Xu, & Xu, 2016) such as energy (Onar, Oztaysi, Otay, & Kahraman, 2015), logistics (Kucukaltan, Irani, & Aktas, 2016), safety management (Inan, Gul, & lmaz, 2017), facility

* Corresponding author.
*E-mail addresses:* bzsun@xidian.edu.cn (B. Sun), mawm@tongji.edu.cn (W. Ma).

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location (Chauhan & Singh, 2016), business process management (Maio, Fenza, & Loia, 2016), and supplier selection and sustainable development (Ünlüç, Ç Ervural, Ervural, & Kabak, 2017). Detailed review for the studies of MAGDM which are refer to Özgür and Bilal (2017). At the same time, many different mathematical theories such as fuzzy set theory (Zadeh, 1997), interval mathematic (Zhou & Wu, 2008), probability theory and mathematical programming (Savage, 1954) are used to construct the model and method for all existing approaches to MAGDM problems.

Recently, a new mathematical theory of handling uncertainty named as rough set (Pawlak, 1982) is used to MAGDM problems (Sun, Ma & Qian, 2017; Sun, Ma & Xiao, 2017). The basic philosophical ideas of Pawlak rough set comes from the perception that objects characterized by the same description are indiscernible in light of the available information about them. The equivalence classes or elementary building blocks which are induced from an indiscernibility relation form a partition of the universe of discourse, and constitute the basic granules of knowledge (Sun, Ma & Qian, 2017; Sun, Ma & Xiao, 2017). By using the concept of lower and upper approximations in rough set theory, knowledge hidden in information systems may be unraveled and expressed in the form of decision rules. Though the equivalence or indiscernibility relation provides a powerful tool to deal with the approximate the inaccurate and uncertain target in decision information systems, the partition or indiscernibility relation also is restrictive for many applications. To overcome such unreasonableness, several extension forms of Pawlak rough set models have established. In general, the relation-oriented extensions (i.e., *relaxing the restriction of the equivalence relation of the universe of discourse*) (Slowinski & Vanderpooten, 1990; Wang, Shao, He, Qian, & Qi, 2016; Wang, Hu, Wang, Chen, & Qian, 2017; Wang, He, Shao, & Hu, 2017; Yao, Wong, & Wang, 1995) and decision-making object-oriented extensions (i.e., *combing the other mathematical theories such as fuzzy set theory, Dempster-Shafer theory of evidence, and intuitionistic fuzzy set theory*) (Chakhar, Ishizaka, Labib, & Saad, 2016; Sun, Ma, & Zhao, 2016; Sun, Ma, & Chen, 2014) and other related problems (Kong, Zhang, & Ye, 2016; Ma et al., 2018) are two mainly directions of improving the classical Pawlak rough set model. Nowadays, the classical Pawlak rough set and its extensions have become important and efficiently theory and tool to deal with various decision-making problems under uncertainty. Meanwhile, several models and methodologies for decision-making under uncertainty are proposed based on Pawlak rough set and its extensions (Abastante, Bottero, Greco, & Lami, 2014; Chakhar et al., 2016; Ishizaka & Nemery, 2013, 2013).

Granular computing, established by Zadeh (1997), has attracted many researchers and practitioners as a new and rapidly growing paradigm of information processing. Granular computing is referred an umbrella term to cover several theories, methodologies, techniques, and tools that make use of information granules in complex problem solving (Yao, Vasilakos, & Pedrycz, 2013). From the perspective of granular computing (Zadeh, 1997), an indiscernibility relation on the universe of discourse can be regarded as a granularity, and the corresponding partition can be regarded as a granular structure (Yao et al., 2013). Then, the Pawlak rough set theory is based on a single granularity (only one indiscernibility or equivalence relation). However, there may be several granular structures when the rough set theory is using to handle decision-making problems under uncertainty. So, extending the single granularity to multiple granularity structures for the classical Pawlak rough set theory is necessity. Inspired by the concept of granulation computing, Qian, Liang, Yao, and Dang (2010) defined the multigranulation rough set model, where the set approximations were defined using multiple equivalence relations on the universe of discourse, by replacing the single granulation with multiple granulation on the universe of discourse. Then, under the framework of multiple granularity structures, several generalized multigranulation rough set models have established with various backgrounds of decision-making under uncertainty. Detailed review for multigranulation rough set theory is suggested refer to Sun, Ma, Li, and Li (2018).

It is easy to know that the attribute values in the existing multigranulation rough set models are usually the same type such as fuzzy attribute values, symbol values, intuitionistic fuzzy set, or interval-valued attribute values (Sun et al., 2018). In many applications, especially management decision-making in practice, however, there may not only be different combination of the selected evaluation attributes but also different categories for the attribute values which describe the objects or alternatives of a universe of discourse (Ma et al., 2018). We consider a MAGDM problem of reality, all invited experts may come from different areas with different background and knowledge and then present the evaluation for all candidate alternatives. On the one hand, the experts usually select different evaluation indices from all criterion which are familiarized with themselves background and knowledge or their personal preference. That is, different experts may select different evaluation indices as the optimal combination to express their preference evaluation for all candidate alternatives. So, the preference evaluations related to the optimal combination of the selected evaluation indices given by different experts are made of a multiple granularity structure of all candidate alternatives. On the other hand, because the experts come from different areas and then the evaluation results given by different experts will be natural numbers between 0 and 100, and it can also be graded as *Excellent, Good, Moderate, Bad,* and *Unacceptable.* Sometimes, if needed, it might be graded into two values, *Accept,* and *Reject.* Furthermore, there are other values could be given such as interval-value, and vague-values or fuzzy-values. So, the evaluation results given by the experts for all candidate alternatives are heterogeneous values with respect to different indices. Therefore, the MAGDM problem is a multiple granularity and heterogeneous attribute values structure with many different decision-makers (experts). Then, how can obtain the final optimal alternative from all candidates under the conditions of different decision-makers that select differently evaluation indices to express their preference evaluation with heterogeneous attribute values? For this reason, the existing rough set models with one single granularity and multiple granularity with the same type of available information for all indices (attributes) are incapable of handling this type of decision-making problem. Therefore, a new generalization model of the existing multigranulation rough set (Qian et al., 2010; Wu & Leung, 2011) should be defined and then establishes a new perspective and theoretical tool to deal with the above problems of decision-making under uncertainty. That is, the multigranulation rough set model based on heterogeneous attribute values and the corresponded approach to decision-making problem under uncertainty.

Based on the above description for the decision-making problem of selecting supplier and the philosophical ideas of existing multigranulation rough set theory with same type of attribute values (Ishizaka & Nemery, 2013, 2013; Qian et al., 2010), the objective of this paper is to propose an approach to MAGDM problems with heterogeneous values by defining a new multigranulation fuzzy rough set model over heterogeneous attribute information systems. We first present the basic definition of the multigranulation fuzzy rough set model over heterogeneous attribute information systems, i.e., heterogeneous attribute multigranulation rough set model. We then investigate the properties and the relationship between the established new multigranulation model with the existing generalized rough set models (Ishizaka & Nemery, 2013, 2013; Qian et al., 2010; Sun et al., 2018; Wu & Leung, 2011) in detail. Also, some interesting conclusions are given for the proposed heterogeneous attribute multigranulation fuzzy rough set model. Finally, we present the methodology for MAGDM problems with heterogeneous values based on heterogeneous attribute multigranulation fuzzy rough set model. Meanwhile, the detailed procedure of decision-making for the proposed model is given. Meanwhile, the approach is illustrated in detail through an example of the optimal selecting supplier in the decision-making of supply chain.

The rest of this paper is organized as follows. Section 2 briefly reviews the fuzzy set theory, Pawlak rough set and multigranulation

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